Characterizing the Digital Planetarium as a Teaching and Learning Space

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Abstract

The modern planetarium exists today as a digital immersive facility with a multitude of capabilities and applications while also being tied to its analog roots among instructional media in astronomy education. I characterized the use of the digital planetarium as a teaching and learning space by following two lines of inquiry: a) how students engage with a digital planetarium and b) what shapes the teaching and learning space in the planetarium. For these two questions, two sources of data respectively formed the basis of the investigation: student responses and observational data. The data were analyzed using the Grounded Theory Method.

Student responses were gathered from a cohort of university students during two separate planetarium visits which constituted part of their introductory astronomy course. An instrument was designed to probe both how the students responded to the overall planetarium experience and how they engaged with the educational content. In the second student visit, the show content was specifically designed by me, and the instrument had been modified based on the results of the first visit. Individual student responses were analyzed for key ideas which were grouped into several categories that emerged from the data. These categories allowed me to develop a localized mid-level model of student engagement. This led to the notion of a "spectrum of attentiveness" that strongly influenced how students engaged. The data also suggested an optimal level for relevant engagement that was influenced by the nature of coincident distractions.

Detailed observations were documented throughout the investigation that included multiple additional visits to the planetarium. These visits familiarized me with the planetarium and its use as an educational space. Categories were constructed from the observational data, allowing the development of a second localized mid-level model that described the key contextual factors that influenced the planetarium teaching and learning space.

In addition to addressing the initial lines of inquiry, the localized models were then supplemented with broader cognitive models, in particular Working Memory (WM) and Cognitive Load Theory (CLT). By combining both models with the explanatory power from WM and CLT, a Model for Curriculum Design in the Planetarium (MCDiP) was developed to systematically shape the digital planetarium as an effective teaching and learning space.

Declaration

I, Alexander Sivitilli, hereby declare that the work on which this thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university. I authorize the University to reproduce for the purpose of research either the whole or any portion of the contents in any manner whatsoever.

Signed by candidate

“The cosmos is also within us; we're made of star-stuff.

We are a way for the cosmos to know itself.”

– Carl Sagan

Dedication

This thesis is dedicated…

to

Hilde Seidel

who encouraged my love of the stars from an early age,

&

to the memory of

Gerhard Seidel

who taught me to always appreciate how things work at the fundamental level.

My academic journey would not have been possible without the continued support from both of them.

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List of Acronyms & Abbreviations

AER	–	Astronomy Education Research
CLT	–	Cognitive Load Theory
GQs	–	Guiding Questions
GTM	–	Grounded Theory Method
DSDM	–	DigitalSky-Dark Matter
EB	–	episodic buffer
IDIA	–	Inter-University Institute for Data Intensive Astronomy
IPDD	–	Iziko Planetarium & Digital Dome
LTM	–	Long-term memory
MCDiP	–	Model for Curriculum Design in the Planetarium
PhAsER	–	Physics & Astronomy Education Research
PL	–	phenomenological loop
SKA	–	Square Kilometer Array
SPV	–	Student Planetarium Visit
UCT	–	University of Cape Town
VisLab	–	IDIA/UCT Visualisation Laboratory
VS	–	visual-spatial sketchpad
WM	–	Working Memory

List of Terms

Affective – In the context of the mind, things relating to feelings or emotions as opposed to “cognitive” which refers more to understanding and acquiring knowledge.

Category – Overlapping common themes identified in lower-level codes that introduce the early levels of abstraction in GTM. These correspond to emergent categories, key-ideas, and sources in my investigation.

Coding – Breaking down the data in GTM via organizing into discrete “incidents” or “codes”. This can be “open” in early stages in which recognized patterns on the part of the researcher are initially identified in the low-level data. This then gives way to “focused” coding where abstraction is introduced through identifying overlapping common themes as higher-level “categories”.

Cognitive load – A construct representing the resultant combined mental effort and mental load due to the limited resources of working memory. This can be modeled as one of three types in the context of learning. Intrinsic load is the inherent load that learning material has for a student based on its complexity. Extraneous load is the total added load that results from the method of teaching this learning material. Germane load is the productive component of the extraneous load that results in schema construction.

Concepts – High levels of abstraction in GTM with which the researcher goes “beyond the data” and accounts for the various categories as well as the relationships between them. This sets the basis for a substantive grounded theory.

Constant comparison – Iterative process of identifying codes and categories in the data, revisiting and reidentifying them as more data is added, and over time developing higher abstraction that narrows in on individual concepts. This can sometimes be considered another term for the methodology of GTM.

Grounded theory – A model that emerges from the data surrounding an issue based in social processes via the Grounded Theory Methodology. This can be “substantive”, which serves as a theoretical explanation or model that addresses a limited scoped problem of a particular area. It can also be “formal” and take on more generalized concepts and apply to broader social situations.

Memos – Field notes of the researcher(s) using GTM that “conceptualize” the collected data into a narrative form. In this investigation memos form the critical observational data that I refer to as the descriptive temporal narrative of events.

Pragmatism – A school of philosophical thought that determines the quality of theory based on its utility rather than its ability to mirror reality.

Preconceptions – In the context of GTM, what the researcher takes into the investigation. These include ideas and knowledge about the subject under study. In this thesis regarding the digital planetarium, these included my preliminary research of what a planetarium is, how the facility fits into astronomy and its teaching, a limited literature review, and the colorful marketing discourse that exists.

Rigor – A measurement for the quality of the investigation. In the context of my investigation, I chose an assessment of identified opportunities of theoretical sampling and the theoretical saturation of the final model.

Schema – Knowledge structures in long-term memory that store and organize common features from our different experiences. These determine how we perceive, interpret and remember events. Learning essentially amounts to constructing and manipulating these schema.

Theoretical coding – A later stage in GTM in which a substantive grounded theory is taken “back to the literature” to be supplemented by external theory in order to draw relations between high level concepts.

Theoretical sampling – A concept critical to the coding process of GTM in which data added to the investigation is directed by outcomes of the initial coding. High quality implementations of GTM should have instances where this takes place.

Theoretical saturation – An assessment to judge the quality of resultant abstraction when using GTM. When introducing low-level data to the grounded theory, if no significant ideas emerge which are not already accounted for in high-level categories, then saturation is high.

Working memory – The system that holds things temporarily in the mind to allow complex tasks to be performed. This includes the things currently being attended to through perception, but also how they can be condensed into workable chunks with the help of schema in long-term memory. Working memory has the ability to construct new schema or manipulate old schema.

1 Introduction

The origins of this investigation were based in an apparently simple scenario: the astronomy department at the University of Cape Town obtained access to a newly refurbished digital planetarium, the Iziko Planetarium & Digital Dome (IPDD). As I considered the situation, this simple scenario revealed more and more complexity. The facility's existence itself seemed a contradiction: On the one hand, the digital planetarium was a relatively new technology with unbounded possibilities in its use and capabilities. On the other hand, it carried with it a century of history rooted in a narrow range of use in astronomy education and outreach.

As I initially explored the space, with assistance of the UCT Physics & Astronomy Education Research (PhAsER) group, our discussions took the form of an inquiry. I desired to investigate how the digital planetarium was being used in a formal educational setting and how the users were responding to that use. For this I posed a broad open goal:

Characterize the digital planetarium as a teaching and learning space.

The broadness of the goal reflected the broadness of the perceived issue. The technology of the digital planetarium seemed to offer many possibilities that users could both develop and experience. This should rightfully be met with asking questions that encapsulate these new possibilities and how users interact with them. However, such evidence seemed to be rather sparse. Educational studies that accompanied the planetarium were either too old to incorporate the new digital form of the facility or were simply framed as verifications of the facility's benefit over other forms of media. There were gaps in theorizing how the space could be effectively shaped as a formal teaching and learning space. This was understandable given the complexity surrounding the planetarium. The situation was both novel and complex, something that the Grounded Theory Method (GTM) was well suited for. The goal was thus to produce a theory grounded in data elicited from documented social processes taking place in the digital planetarium. The resultant theory would ideally address the broad guiding research goal above.

I open here with a look at the methodology of the GTM because it provides a necessary justification for why the thesis is written in the way it is. Without it, the substance and structure may seem confusing, and the reader may struggle to grasp the points I express. I therefore use this space to explain GTM, including how it guided my own study and how it may produce unorthodox moments for the reader. It is necessary to quickly point out what I mean by *method* versus *methodology*. Whereas method signifies the procedure on which the investigation is conducted, the methodology, according to Bryant (2017), "includes explicit justification for the approach or method being used: the underlying philosophy serving to justify the basis of the method in general as well as its use". This is important because while I invoked the method in the investigation, in the thesis I use the methodology to justify certain decisions that I had made in the implementation of the study and its write-up.

1.1 Grounded Theory *Methodology*

The GTM provides a flexible, yet systematic, method of taking an open issue and seeking to make sense of it by developing "theory" that is "grounded" in the data surrounding the issue. It seeks to establish this theory as models that "emerge" from the data. Broadly speaking, there tend to be three distinct flavors to GTM (Mills et al., 2006). The first two are associated with the "original" of Glaser and Strauss (1967) from which two parallel strands formed based in Glaser (1992) alongside Corbin and Strauss

(1990) (see Figure 1-1). This is recognized as a split between Glaser and Strauss, which formed the "Classical" GTM and "Straussian"[1] GTM flavors respectively (Rakhmawati, 2019; Sebastian, 2019). The former developed a very strong stance against the initial preconceptions and role of the GTM researcher throughout an investigation in addition to an absence of pre-set research questions or goals. The latter of the two, although taking on a more explicit and acknowledged role of the researcher, simultaneously established a more rigid and prescriptive approach to how both data gathering and analysis are conducted.

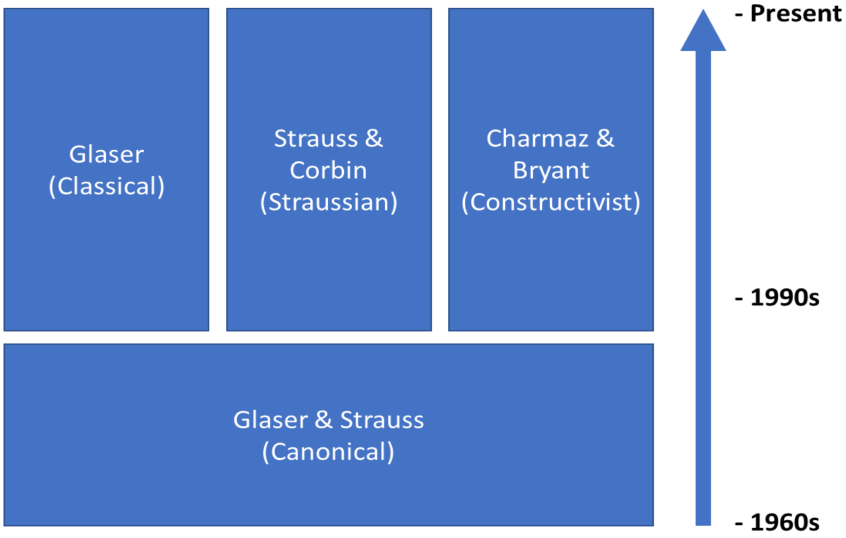

Figure 1-1 Visual diagram demonstrating the different flavors of GTM that have taken form since the original formulation of the methodology from Glaser and Strauss (1967). My investigation adopted the Constructivist tradition of GTM. Diagram is adapted from Bryant (2017).

The third flavor of GTM emerged as a modern alternative that involved a more pragmatic philosophy within the methodology. This is the "Constructivist" GTM (CGTM) from Charmaz, a former student of Glaser and Strauss. This flavor was detailed in Charmaz (2014), Charmaz and Thornberg (2021), and Bryant (2017) specifically in that, how Charmaz described, the data in CGTM "form[s] the foundation of our theory and our analysis of these data generates the concepts we construct." This approach "leads us to attend to what we hear, see, and sense while gathering data" and this data is constructed "through our observations, interactions, and materials that we gather about the topic or setting." There were notable advantages of CGTM over the other flavors for the context of my study. For example, CGTM acknowledges the active role of the researcher in the investigation. This includes not only during the study but also prior to it in the form of documented preconceptions that are brought into the investigation. This I found essential as I intended to play an acknowledged active role as I explored the digital planetarium space throughout the study. I also identified the importance of conducting an initial review of education research literature and marketing discourse around the planetarium to inspire initial broad research goals, something that Classical GTM would disagree with. Meanwhile, I preferred the flexibility of the Constructivist approach over the Straussian. As will be seen in Table 1-2, this flexibility led to adapting certain elements of GTM to fit the situation at hand. This would have been far

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[1] Sometimes Straussian GT is also referred to as "interpretivist".

more prohibitive with Straussian GTM. Overall, CGTM provided a flexible implementation of GTM that allowed me to bring in my initial background findings on the digital planetarium into the investigation.

Data in GTM are predominantly qualitative and can come from a variety of sources in a variety of modes or formats. It is also important to emphasize that the results from GTM typically do not take the form of verification of existing theory or frameworks. Rather the results take the form of new theory as models with utility grounded directly in the data, e.g., grounded theories. As there are many interpretations and implementations of GTM, even in the constructivist camp, I generally followed that of Bryant (2017) for guidance.

To provide as much transparency to the method as possible, I review here my own interpretation and understanding of the GTM process. I also include many of the relevant terminology with my own generated definitions in the List of Terms preceding the thesis. Data collection itself in GTM starts out broad and reasonably unstructured as the researcher does not initially have a concrete idea of what they are looking for. However, this can take on a more structured form as data collection and analysis takes place. From this collected data, an iterative process of hierarchal coding is undergone by the researcher. The process, referred to as “constant comparison”, breaks down the data via organizing into discrete “incidents” (Glaser & Strauss, 1967) or “codes”. This essentially starts with the low-level data and, through a process of open coding, establishes “open” codes through recognized patterns on the part of the researcher. As the process continues, these initial open codes are further categorized through “focused” coding where overlapping central common themes are identified. This refines the collection of codes into higher-level categories that add abstraction to the analysis. This is also accompanied by further data introduction. This predominantly acts to refine previously identified categories, a process referred to as “theoretical sampling”. However, new data can indeed still produce new categories depending on the achieved “theoretical saturation” of the investigation. This saturation is the degree to which further data sampling and analysis provide examples of previously acknowledged categories. Meanwhile, further abstraction takes place as relationships between categories are identified as high-level “concepts”. At this point, the researcher has gone “beyond the data” and the basis for a “substantive grounded theory” is identified. This theory serves as a theoretical explanation or model that addresses the limited scoped problem of a particular area.

Throughout the process, culling of codes and categories can take place in which codes and categories are set aside for other studies. This puts the focus onto core concepts that bring together the lower-level codes and mid-level categories and make up the grounded theory. This emergent theory may then undergo “theoretical coding” by the researcher to reinforce the model though a “return to the literature”. In this process the conceptual findings of the substantive grounded theory are interwoven with concepts from relevant extant literature identified as applicable to, and reinforcing of, the emergent theory (Thornberg & Charmaz, 2014). This then sets the basis for a “formal grounded theory” that can take on more generalized concepts and be applied to broader social situations.

Bryant illustrates this process as a spiral (recreated in Figure 1-2) that moves inward towards the middle where large numbers of codes are consolidated to a small number or set of core concepts. Meanwhile the method moves upward towards higher levels of abstraction that integrates the significant aspects of the investigation based on their explanatory power. The spiral signifies the iterative nature from which low-level codes become higher-level categories and eventually high-level concepts. From the concept phase, relations are identified between components of the lower levels to produce models or “grounded theories”.

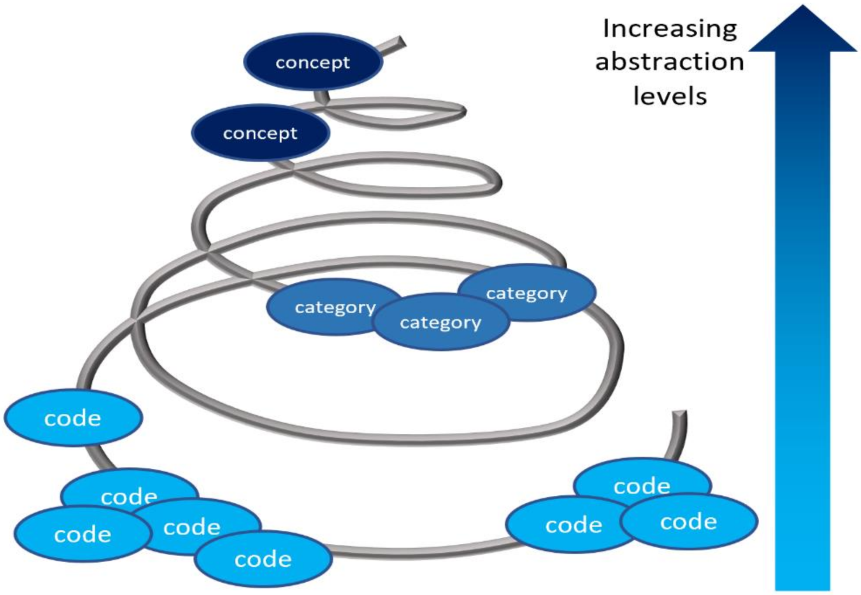

Figure 1-2 A spiral representation of the GTM adapted from Bryant. As the investigation proceeds, the researcher identifies codes in the data. Overlapping qualities of the codes are identified as more abstract categories. Eventually relationships between categories lead to high-level concepts. The upward spiral reveals not only increasing levels of abstraction, but the necessary iterative nature of GTM where data, codes, categories, and concepts are consistently revisited in a process of constant comparison. This process is not indefinitely cyclic however as the spiral contracts towards the foundations for a substantive grounded theory. Image is adapted from Bryant (2017).

The iterative nature of constant comparison is emphasized because the coding process is not a simple step-wise procedure where codes become categories become concepts (LaRossa, 2005). Analysis happens from the moment data is initially collected. This means data gathering is initialized with very broad inquiries that attempt to not limit the scope of what is being assessed. Limitations and constraints essentially risk asking the wrong questions. If questions are asked, they themselves should be broad and encourage participants to speak their mind. This allows the researcher to probe the social processes and analyze them as they take place. The researcher then consistently revisits these codes and their relationships, sometimes creating new ones or culling old ones. As abstraction is achieved in the form of higher-level categories and concepts, data collection itself can be refined to contribute to theoretical sampling, confirming the previously constructed abstraction. Or the continued stream of data can lead to revisiting and refining the coding hierarchy. This key aspect of GTM creates visibility of features that may have gone unnoticed in a traditional investigation. Such features may emerge as data comes in, or much later long after the intended collection process has concluded.

1.2 Research Strategy

An end point of the GTM is a pragmatic localized theoretical description. In the terminology of the Grounded Theory Methodology more broadly, this is termed a substantive grounded theory. The term *model* in my thesis is to be understood as being this emergent description. This methodology lent itself appropriately to the aims of my investigation in which I wanted to characterize how the digital planetarium was being used in an educational setting and how the users were responding to that use. With the GTM, I adopted a methodology that would allow for the key issues to emerge from the data rather than to identify potential categories beforehand.

The final study design included the following components that contributed to the final discussion:

- My own preconceptions of the digital planetarium
- Documenting observed social processes around the digital planetarium
- Eliciting responses from students experiencing the digital planetarium
- Analysis through the iterative coding of constant comparison
- Returning to the literature for theoretical supplements

The final discussion then makes the case for developing what I call “pragmatic localized models” that emerged from the compiled high-level concepts of the analysis. These serve the same purpose as the substantive grounded theories of the GTM. I then proceed to make the case to formulate the basis for a formal grounded theory with broader application that can directly address the investigation’s broad guiding research goal. This emerges a synthesis of the localized models, along with theoretical coding, which I highlight below.

1.3 Thesis Structure

The open and flexible nature of the Constructivist flavor of GTM means an investigation outcome can be unpredictable. In fact, Bryant stresses that researchers should be “prepared to be surprised by what they find”. The rest of this chapter is therefore devoted to explaining the frame of the final thesis structure. This includes key explanations on how I handle the background and literature review, which I include in a chapter on preconceptions; how I report the results of data collection through a temporal narrative through two chapters anchored to the two main visits of the students to the planetarium; and finally, how the quality of the investigation is assessed through examining theoretical saturation and sampling. A more detailed overlook of the study design itself is done later in chapter 3.

I open the thesis with a background exploration in chapter 2. This chapter is labeled “What I bring into the Investigation” because it is a critical practice given the open-ended GTM to identify what the researcher is entering the investigation with. This practice is sometimes mistakenly interpreted as the researcher needing to shed their preconceptions, as is practiced in Glaser’s Classical GTM. However, the pragmatic flavor of GTM from Charmaz and Bryant identifies this as realistically impossible. A researcher simply cannot enter an investigation as a blank slate. I therefore use this particular chapter to recount my initial background research on what the digital planetarium actually is. Included is how astronomy and technology have a history of co-evolution, inherent to both the research and teaching within the field. This is necessary to establish the position of the digital planetarium facility in the scope of astronomy education. I also take note of the marketing discourse surrounding the planetarium to highlight the complex relationship it has with society. This is followed by a summary of planetarium education studies in the past century. The goal of this background chapter is to establish, from terminology Strauss initially adopted from (Blumer, 1954), the “sensitizing concepts” for the study. These concepts, according to Blumer “merely suggest directions along which to look” as opposed to “definitive concepts” which “provide prescriptions of what to see”. In fact, Bryant explains the importance of these sensitizing concepts down to the level of the initial literature review itself. This resulted in my own limited initial review of the literature in this chapter. It functioned merely for me to see where the digital planetarium currently sits in the context of astronomy education. Interestingly enough, whereas grounded theorists would make a conscious effort to limit their initial engagement with the literature, this became practically unnecessary as there seemed to be limited literature available with planetarium education research itself.

The word "initial" above is key, because I revisit the literature later in the thesis to inform the synthesis of my localized pragmatic models into a unified model. Whereas the initial literature review should take on a lighter influence on the direction of the study, the literature can and should be later revisited with what Charmaz calls "theoretical coding". I emphasize this nature of GTM by not including a thorough theoretical framework at the beginning of the thesis as would normally be expected. I do indeed give the relevant theory its own dedicated chapter (see chapter 7) but relegate it to the more proper position as a prelude to the final discussion. Indeed, I hesitate to refer to this as a theoretical "framework" as it is not something around which the investigation or data collection was framed. The chapter instead reveals the theoretical "supplement" that was emergent from skimming for sources of theoretical coding to bolster the localized pragmatic models grounded in the data.

This delayed return to the literature is also a key justification for the application of GTM. If this step is needed, then the data revealed a level of complexity that was not clearly documented in research elsewhere. In other words, if a valid justification is given to return to the literature, that reveals the shortcomings of an extensive initial literature review. The conceptual and theoretical framing thus does not appear until the end because it was in no way present in the study until gaps in the emergent localized models suggested its need.

Chapter 3 on the study design begins with the broad research goal mentioned above that emerged from the initial background exploration. From this, two manageable guiding questions are derived to anchor the investigation:

Guiding Question #1 (GQ1):
How do students engage with a digital planetarium?

Guiding Question #2 (GQ2):
What shapes the teaching and learning space in the planetarium?

I then continue the study design with information on the Iziko Planetarium and Digital Dome (IPDD) as well as the introductory astronomy course that both form the core of the investigation. My study involved multiple visits to the IPDD. Several of these were exploratory assessments in which the Physics & Astronomy Education Research (PhAsER) group and I observed the space and interacted with it to gain familiarity. Two of these visits accompanied a cohort of university introductory astronomy students that their lecturer brought to the IPDD. I refer to these particular visits as Student Planetarium Visits 1 & 2 (SPV1 & SPV2). This is followed by a look at the ethical considerations that went into planning the investigation. This included consent and impact on the subjects of the study. An essential reference diagram of the planned study is then presented that shows the initially planned investigation under guidance of GTM.

I organize SPV1 and SPV2 under their own chapters (chapters 4 & 5) in the thesis. They were identified as two prominent “phases” in this implementation of GTM. Throughout these phases, I took note of the various interactions that the research team observed regarding the planetarium being used and then put it together in a descriptive narrative of what took place. Through the GTM process described above, I could over the course of our initial observations witness the emergence of a form of analysis that then had influence on how I conducted my data acquisition and reflections going forward as an iterative process of constant comparison. This formed the “observational” data that included detailed narratives of events, an unstructured interview and even bits from the background chapter itself. Bryant and other GTM researchers refer to this type of data as forming a core component of the “memos” in GTM that serve to “conceptualize the data in narrative form”. Parallel to this, these observations also formed the basis for designing two questionnaires for each SPV to elicit responses from students regarding their experience in the facility. These responses formed the “questionnaire” data.

From both sets of data, coding was undergone from which categories emerged through early iterations. I then looked at and discussed these codes and their categories with members of the PhAsER group. This led to combining them into higher-level categories that formed more conclusive findings. In the case of the questionnaire data, this was primarily done with the *NVivo* software (QSR International Pty Ltd, 2020) to code patterns and emerging categories through the iterative process mentioned. In the case of the observational data, this was also done iteratively, but with sticky notes. Early findings from SPV1 were then used to influence a new cycle of the study in SPV2 which then repeated the process until eventually it revealed a “big picture” view of how the digital planetarium can effectively be used for education. Such a big picture was to be explained through the emergent GTM descriptions, models, or substantive grounded theories as I defined earlier.

This process used the iterative “constant comparison” of GTM in which analysis took place as data collection occurred. This analysis also informed further data collection. Examples included how observing the planetarium instructor and operator later influenced the questionnaire for SPV1, how observing the show of SPV1 later influenced the show design of SPV2, and how initial results of the SPV1 questionnaire influenced later construction of the SPV2 questionnaire. I give the final analysis its own dedicated chapter 6 that provides sections to the analysis of the questionnaire and observational data respectively. Chapters 4 and 5 thus serve to provide narratives as events unfolded along with the ongoing, low-level analysis that accompanied them. This format serves to both document summaries of the crucial observational data, while also providing rationale for decisions made along the way.

This also brings up an important point regarding instrument design and data collection. I started from a broad position being faced with the situation I wanted to investigate using GTM. This meant not only being open in how I explored the space for my observational data, but also in how I interacted with users such as conducting my interview with the instructor or structuring the student questionnaire. The initial stages of a GTM investigation should, in the words of Bryant, “be one of gaining familiarity, based on adopting a position of open- minded and flexible questioning.” This meant that when it came to directly interacting with users of the planetarium, the questions needed to be as broad as possible. According to Charmaz’s advice, I needed “to phrase… questions to allow respondents to express their views without constraints.” To put it more bluntly, when it came to initially designing my interview or questionnaire questions, I was looking at simply probing “what is going on?”. In the tradition of working closely with the data through the constant comparison of GTM, these questions were mildly guided over time. This included the ongoing analysis through discussion with the PhAsER group as will be explained in the SPV chapters. However, the point remains, that instrument design was not a product of rigorous construction looking to directly validate previous theories but rather unstructured inquiry to elicit extended responses with wide remit.

In chapter 6 I present the final results. I compare the questionnaire analysis from SPV1 and SPV2 to show how student engagement not only revealed a division of attention to the learning and novelty aspects of the shows, but how over time these divisions would change. This was accompanied by a diversity of student recollection of content apparently reflecting the diversity in instructional intents. I capture these observed phenomena as a diverging “spectrum of attentiveness” that suggests an ideal level of student attentiveness for maximum relevant engagement. I label this my “localized model of student engagement”, which addresses GQ1 as my first substantive grounded theory. From the observational data analysis, I present the combined diagrams of sources that create the planetarium experience. This combined diagram reveals the diverse cluster of inputs that go into the student experience when they are brought into the learning environment of the digital planetarium. I label this my “localized model of contextual influence”, which addresses GQ2 as a second substantive grounded theory. With both guiding questions addressed, I turn my sights back to the broad guiding research goal I initially posed. I introduce an early synthesis of the localized models to directly address this goal. However, in order to convincingly combine these separate models into a unified model, I propose the theoretical supplement of Working Memory (WM) and Cognitive Load Theory (CLT). This required a “return to the literature,” an essential component of GTM.

Chapter 7 introduces what is to become the theoretical supplement to the proposed unified model from the results chapter. A brief background in the historic development of Working Memory theory is summarized. This progresses with the development of the concepts of chunking and schema construction. I then reveal how this l leads into Cognitive Load Theory, a practical application of WM for the purposes of teaching and learning.

Chapter 8 as the final discussion chapter applies WM and CLT to the proposed unified model through theoretical coding. I first make the argument that student engagement in the digital planetarium can be modeled as a situation of limited WM. I then directly apply CLT to the scenario by arguing that effective teaching in the digital planetarium is a question of effectively managing cognitive load. From here I expand the initial proposed unified model into the Model for Curriculum Design in the Planetarium (MCDiP). This is my resulting attempt at laying the basis for a formal grounded theory. Its purpose is to characterize the digital planetarium as an effective teaching and learning space, satisfying the broad research goal.

Chapter 9 considers implications of the MCDiP and its usage in curriculum design. I suggest how an instructor could use the model to systematically assess incorporating the digital planetarium into their teaching curriculum. I also give suggestions on how documented empirical effects from CLT in the literature can be applied to different situations of teaching in the digital planetarium.

Chapter 10 takes a look at the rigor of the investigation. The uniqueness of GTM extends to its handling of experimental trustworthiness. In the camp of the constructivist flavor of GTM, I consider the pragmatic stance concerning results. Specifically, as Bryant states, “the outcome of all coding activities has to be judged in terms of the usefulness of the abstractions that result, rather than any criteria of ‘correctness.’” In other words, it is highly beneficial to assess the quality of the investigation’s results through utility rather than its reflection of reality. This is not to say that I did not take a critical look at the validity of my investigation. I do make efforts throughout the thesis to explain levels of agreements of codes between myself and the research group. Rather, based on the philosophy underpinning this investigation, validity is discussed with a wider focus than what traditional studies may offer. Specifically, validity is not confined to the details of the processes that produced the data but extends to the usefulness of the resulting model. The quality of the data collection and analysis process can certainly be directly judged through the amount of theoretical sampling that took place throughout the investigation. A final assessment of the theoretical saturation achieved should also be considered. A quality implementation of GTM should include some acknowledgement of both. This chapter therefore includes a qualitative assessment of how instances of theoretical sampling manifested throughout the thesis where previous findings guided how new data was sampled and analyzed. I also consider the theoretical saturation achieved with the final model. In other words, I assess how extra data sampling agrees with the concepts embedded in the final grounded theory, MCDiP. This includes categorizing results and instances from revisiting low-level data of SPV1 and SPV2. I also consider experimental results from specific external studies taken from my initial literature review.

The overall utility of the resultant model is also considered in chapter 11. This includes how this investigation resulted in a limited final model and how it could be improved in future studies. This utility could only be strengthened and refined through extensive empirical tests to improve theoretical saturation through further theoretical sampling in future research. Further generalizing of the model through broader theoretical coding from external models would also add to its robustness. Given the limited scope of this investigation, I actually refrain from labeling my final model as a “formal” grounded theory, but rather merely as the basis for one.

1.4 Reading this Thesis

This thesis introduced many non-aligned cases of duality. For example, the broad research goal is split into two separate manageable guiding questions that rely on two types of data, observational and questionnaire. Meanwhile, the data gathering is split into two phases of SPV1 and SPV2. On top of this, chapters tend to offer dual roles of documenting the processes of the investigation and the narrative data simultaneously. The literature review and discussion are also divided within the structure. To aid the reader, I finish here with tables that serve to demystify some of the duality. Much of the substance of these tables will not make sense to the reader initially. However, as progress is made through the thesis, relevant terms will appear that can be found here for guidance on how they fit into the big picture. Table 1-1 breaks down different components of the study based on the separation of the two manageable guiding questions. This is where data was split between questionnaire and observational. I include the various sources of data that fall under these as well as the abstractions that emerged in their analysis.

As Bryant would no doubt agree, a powerful method is one that evolves to be useful in a given situation. Such evolution needs flexibility and for this reason, I tailored the methodology to the investigation. Divergence was necessary when terminology was not directly fitting to the task at hand. For example, I did not follow the strict definition of codes, categories, and concepts, which Bryant provided. He himself admitted that these terms can vary in definition and implementation between different GTM researchers. I was therefore flexible as the need presented itself. I used terms like codes, categories and theories, but also invented terms like key-ideas, aspects, and localized models. This, however, can cause confusion for the reader as I do not directly use the terms described in this methodology throughout the thesis. In Table 1-2 I provide a translation table of sorts that captures the notable divergences.

Goal	Characterize the digital planetarium as a teaching and learning space.	
GQs	How do students engage with a digital planetarium?	What shapes the teaching and learning space in the planetarium?
Data	Questionnaire/Student Data SPV1 Questionnaire Likert-scale tik-a-box Written Responses Best Part What was learned Content reflection SPV2 Questionnaire Forced choice response Written Responses Enjoyment of Segments Content reflection	Observational Data Researcher's Preconceptions What is a planetarium Sensitizing concepts in literature Marketing discourse Unstructured Interview w/ instructor Narrative of events SPV1 Planning SPV1 Implementation SPV2 Development SPV2 Implementation
Analysis	- Iterative coding from low-level codes to categories to key ideas - Key ideas quantified and compared to identify concepts of how students engage with planetarium experience - Rating content reflection responses on relevance to intent	- Iterative coding from low-level to higher level aspects to high-level sources - Visual diagrams connecting aspect layers to identify concepts of what shapes the planetarium space
Products	Localized model of student engagement	Localized model of contextual influence
	Model for Curriculum Design in the Planetarium	

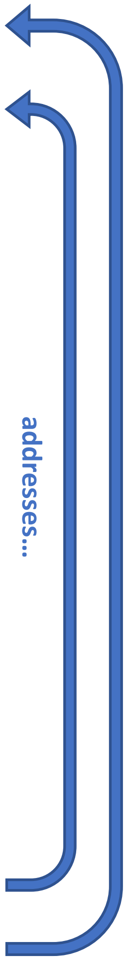

Table 1-1. Referenceable details of how the investigation unfolded using GTM. The inception took place through a broad guiding research goal that was deconstructed into two manageable guiding questions. These GQs each relied on their own base of data extracted from the SPV1 and SPV2 phases of the investigation. Analysis both involved the iterative nature of coding to achieve high levels of abstraction culminating in the development of two localized models with each answering an individual GQ. The initial broad guiding research goal was then addressed by combining the localized models with a theoretical supplement through a "return to the literature" into the Model for Curriculum Design in the Planetarium (MCDiP).

GTM Terminology	Descriptive Implementation in investigation
Preconceptions	Background research on what is a planetarium Marketing discourse around digital planetarium Past planetarium education research studies
Memos	Descriptive temporal narratives of events & group discussions Observational data (see Appendix A for example coding) Early findings of SPV1
Codes and categories	Codes key ideas, key themes (student response data) Aspects and sources (observational data)
Theoretical sampling	Observational & questionnaire data from SPV2 Finding low-level aspects based on previously identified higher-level (observational data) Correlating student content reflection with instructor's intentions
High-level Concepts	Spectrum of attentiveness MCDiP Components, including: Instructional Intent Instructional Outcome Primary/secondary/tertiary digital planetarium aspects
Substantive grounded theories	Localized model of student engagement Localized model of contextual influence Proposed unified model of curriculum design as synthesis of localized models
Return to Literature	Theoretical supplement of Working Memory (WM) and Cognitive Load Theory (CLT)
Theoretical coding	Applying WM and CLT to the proposed unified model of curriculum design
Formal grounded theory	Model for Curriculum Design in the Planetarium (MCDiP) as a basis
Assessing utility & theoretical saturation	Applying MCDiP to low-level SPV1 & SPV2 data Applying MCDiP to external study results
Culling of concepts	Seating position's effect on planetarium experience (see appendix B) Student segment preference from SPV2 (see appendix C)

Table 1-2. This look-up table shows GTM terminology in the left-hand column with the corresponding implementation in the right-hand column. As the investigation unfolded, there was not always strict adherence to how components of GTM presented themselves. For example, the PhAsER group referred to the emergent models from the data as localized pragmatic models throughout our discussions rather than identifying them strictly as concepts giving way to substantive grounded theories. Although the Constructivist flavor of GTM allows for this flexibility in its implementation, this can cause confusion for readers, so this table intends to provide a guide.

2 What I Brought into the Investigation

In this chapter I cover the various preconceptions that I entered the investigation with. This included my look into the background of astronomy and its relationship with technology, particularly in how it has impacted education in the field. This establishes where the planetarium and its modern digital variant fits in with astronomy education, of which I summarize my findings. This is followed by my look at the marketing discourse surrounding the planetarium, and the initial literature review I undertook of previous educational studies in the planetarium.

2.1 Technology in Astronomy: An Intertwined Fate

Astronomy as a discipline is particularly responsive to human technological progress. Whereas many historical factors go into the development of novel reproduceable tools and techniques that can aid in our refinement of science, production, commerce, art, etc., it is noticeably in astronomy where we can see clear shifts in the field as they are introduced. These are shifts that have influenced both the progress of the field through data acquisition and analysis as well as its own accessibility through teaching and learning. With added capability brought on by new technology came added volumes and types of data, and the inevitable development of new techniques to process this data. Astronomers could then find the necessary patterns to further constrain theory and explanations while also communicating meaning and significance to the rest of the population and future generations.

Technological advancement historically not only meant shifts in the frontiers of the field, but also added accessibility through pedagogical means. As introduced technology has become scaled to more common and widespread usage, it could be more easily adapted to new techniques in the teaching and learning of astronomy. With instructional material more representative of the field's state-of-the-art, instructional scaffolding has become more achievable between novice and expert.

The establishment of written communication, whether on cave walls (Sweatman & Coombs, 2018) or eventually on clay tablets (Walker, 1984), and paper (Brahe, 1603), allowed early astronomers to take static visual records over time of celestial structure and movements. The advent of modern optics led to an essential shift in observational techniques by allowing us to better control light and image the night sky at finer detail of ever dimmer and further objects. Photography a few hundred years later enabled the recording of this light on plates that could then be saved and transported for systematic and comparative study. Formerly a science primarily constrained by our night-time, naked-eye observations, astronomy was essentially opened up across time, resolutions and wavelengths. This could be further refined by optical filters to select out particular emissions. Meanwhile, spectrographs allowed us to deduce the material composition of entities physically unreachable. Writing also eventually enabled the formulation of mathematical laws and models that could not only make accurate predictions but could also be introduced to the peer review process for collaboration and universal acceptance. Likewise, such concrete media enabled the transfer of knowledge to new generations to learn and build upon where previous astronomers would leave off. The possibility of recording and representing ideas through written and graphical media has had a direct impact on the ability to represent astronomy as an aid for teaching about the universe and our place within it. For experts giving instruction of their knowledge, this enabled better control of visual and verbal aids that were independent of time and space, factors that heavily influence instances of experience in the field of astronomy.

Digital electronics and imaging in the information age could be argued as one of the greatest paradigm-shifts in the history of the field. Charge-coupled devices (CCDs) and computers introduced the use of scripted pipelines to process pixel array stacks that could reduce noise, incorporate easily adjustable visuals like color, and run automated analysis in bulk. In the last decade we have even made use of lasers and piezo electronics to cancel out atmospheric distortion of light for ground-based telescopes in real-time through adaptive optics (Rabien et al., 2019). Related techniques are also used to detect distortions in space-time with instruments like the Laser Interferometer Gravitational-Wave Observatory (LIGO; Aasi et al., 2015) to give rise to the emerging gravitational-wave branch of observational astronomy.

Advances in material science and manufacturing processes has allowed the construction of telescopes larger and with more light-gathering power than ever, such as the 39.3-meter Extremely Large Telescope (ELT; Gilmozzi & Spyromilio, 2007). Powerful modern rocketry has even enabled the placement of telescopes, such as the Hubble Space Telescope (HST; Williams, 1996) and the James Webb Space Telescope (JWST; Gardner et al., 2006), far away from earth’s light-distorting atmosphere and, in the case of JWST, in a considerably more stable thermal environment at the second Lagrange point to access a new range of infrared sources.

Meanwhile, powerful supercomputers have also unlocked virtual universes as tunable laboratories that can model and refine our laws so we could better make sense of the evolution of our cosmos and the complex subsystems within it (Katz et al., 1995; Springel et al., 2005).

Teaching telescopes have also been introduced at centers of learning for students to recreate the observing processes undertaken by professional astronomers, but now directly under their guidance. Eventually, personal computers and image processing have found a regular place in the classroom, allowing further emulation of the data reduction process undertaken within the discipline. Faster and more accessible high-speed internet has also allowed the booking of time at remote teaching telescopes or data-intensive research clouds. Students can make observations in optimal nighttime conditions on the other side of the planet or even request server time on supercomputers to conduct their own theoretical simulations. Even mobile apps can now be incorporated into teaching by making use of miniaturized internal sensors to identify celestial objects and take measurements of the sky. Scalability and accessibility of technology, in addition to its general advancement, sees astronomy education programs implement more and more practical components to accompany curricula at all levels of disciplinary knowledge.

Today this evolutionary trend continues as we find ourselves on the frontier of two new promising technological additions to the field of astronomy for both research and education- Big Data and immersion.

2.1.1 Big Data

Today with the power and speed of modern computing coupled with powerful new data gathering techniques, we are entering a new generation of digital information processing known as the era of Big Data. This is a time where scientists must process and analyze extremely large data sets in both volume and complexity that are orders of magnitude larger than what has been previously worked with. Familiar examples include DNA sequencing, social media mining, and analyzing particle collisions of the Large Hadron Collider.

In astronomy, we see Big Data being introduced to both the observational and theoretical ends of the field. For example, the Vera C. Rubin Observatory, known also as the Large Synoptic Survey Telescope (LSST), will take optical surveys of the entire sky every few days (Tyson, 2002). Radio interferometry projects, such as the Square Kilometer Array (SKA), will have celestial light sources being detected across thousands of antennae simultaneously (Dewdney et al., 2009). This will require mass communication infrastructure as well as daily sorting through observational data on the order of exabytes[2], both through automated, machine-learning means and direct systematic quality control by astronomers. Meanwhile, modern supercomputer clusters have given rise to large-scale simulations to model celestial phenomena, with N-body simulations keeping track of billions of data points across many dimensions.

Astronomy students are already being introduced to this technology in their courses. Radio interferometry for example is finding its way as a necessary practical component in the teaching of observational techniques. At the time of writing, the University of Cape Town (UCT) is constructing a pair of radio telescopes at the South African Astronomical Observatory (SAAO) which will be integrated into the UCT Astronomy degree program to teach hands-on radio interferometry techniques. Similarly, students are also being introduced to the same computing techniques in their astronomy degree programs, including pipeline data reduction, machine learning, and N-body simulations.

2.1.2 Immersion

Coinciding with this, the further development of modern optics and computing has given rise to a new class of tools that promise a qualitative change in how we interface with the digital world. These new tools not only stimulate our senses in ways unafforded by previous means, but also enable brand new methods of interaction. This is the era of immersive technologies.

Immersive technology is a very broad categorization which cannot easily be defined. Yu (2019) used the definition of immersion in the context of technology as the “degree to which the senses are dominated by a computer-mediated environment”. Although not necessarily new, what defines the current scope of this technology’s adoption is its accessibility. Virtual reality (VR) for example has been around in different forms for decades, but only in the last few years have cheap, mass-produced iterations of it been available at the widespread consumer level, such as with the Meta Quest headset[3] (Heaney, 2022; Meta, 2022).

The logical continuation of incorporating new technology into the field means immersive technology is now finding its way into astronomy. This is occurring both in the realm of furthering the frontiers of the field through research as well as the teaching of the various topics within it. For example, analyzing of three-dimensional data sets, such as voxel data cubes in radio astronomy, was once only possible through tomographic slicing the data so it could be displayed on two-dimensional displays. Immersive technology is being explored to enable alternative viewing techniques so the entire data set can be viewed at once instead of slicing (Jarrett et al., 2021).

Another prominent form of immersive technology is the re-emergence of a familiar tool from the realm of astronomy education: the planetarium. Many planetariums are being either built or upgraded to

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[2] 1 million gigabytes

[3] The Quest 2, developed by Meta (formerly Facebook) is, at the time of writing, the most widely distributed consumer VR headset with about 15 million units sold.

digital capability with the included justification of the potential benefits that the immersive environments have on data analysis through visualization and interaction with scientific data. These digital planetariums are becoming increasingly available as museums and universities move to upgrade their old analog planetariums. What was once a tool constrained in use by its own specialized analog limitations, the modern digital planetarium has today opened a whole new world of potential. This includes added capabilities for research in addition to its initial intended uses in outreach, entertainment, and education.

2.2 The Planetarium

The advancement of digital computing and optics also meant the renewed relevancy of the familiar planetarium facility. Since its invention at the beginning of the 20th century, planetariums could be built to provide a configurable simulation of the night sky that could be presented to theatres of students akin to the real-life experience. With the introduction of the digital planetarium, such a classic example of immersive technology has found new potential for use as a teaching tool with added capabilities. It is in this thesis that we investigate the use of the modern digital planetarium and its role as a teaching tool in astronomy.

Tools such as maps, globes, and mechanical orreries that visualize the night sky have existed for millennia. The often-cited origin of the modern projection planetarium dates back to 1923 with the installation of the Zeiss star projection system at the Deutsches Museum in Munich, Germany (Chartrand III, 1973). For the next 50 years in what some refer to as the “Golden Age” of the planetarium, thousands were built around the world (Slater & Tatge, 2017). An especially big boost came at the dawning of the Space Age when the USA put funding towards the training of teachers in astronomy for the new generation of scientists. Today there exist more than 3000 planetariums worldwide (Audeon, 2021).

Towards the end of the last century, advances in optics and computing introduced the digital planetarium with construction of the first by Evans & Sutherland at the Hansen Planetarium in Salt Lake City in 1983 (Lantz & Route, 2002). Since then, more digital planetariums continue to be built or emerge from renovation of old ones.

2.2.1 Digital Planetariums

To understand what I mean when I refer to the digital planetarium, also known as the ‘fulldome’ planetarium, it is essential to explore how it differs from its analog predecessor, also known as the optomechanical planetarium (Lantz, 2011). The primary technology that has run the analog planetarium (see Figure 2-1) is the star-ball, a variation of the ZEISS star projection system mentioned above. This starball projects pinpoints of light on the screen of an overhead dome to simulate the starfield of the night sky. The star-ball could be rotated and pivoted to display portions of the night sky from different times of year, from different geographic locations, or even demonstrate historical planetary precession. Over time more and more complex mechanics were incorporated into the star-ball to emulate movements of the celestial bodies more closely, such as epicycle-like contraptions to mimic wandering planetary movements (Todd, 1925). Additionally, labels and other graphical aids such as the celestial sphere could often be overlayed as separate projections to the stars. Slide projectors could also be added to project images or series of images to simulate rudimentary videos or display extended visuals such as the Milky Way (Vorenkamp, 2019).

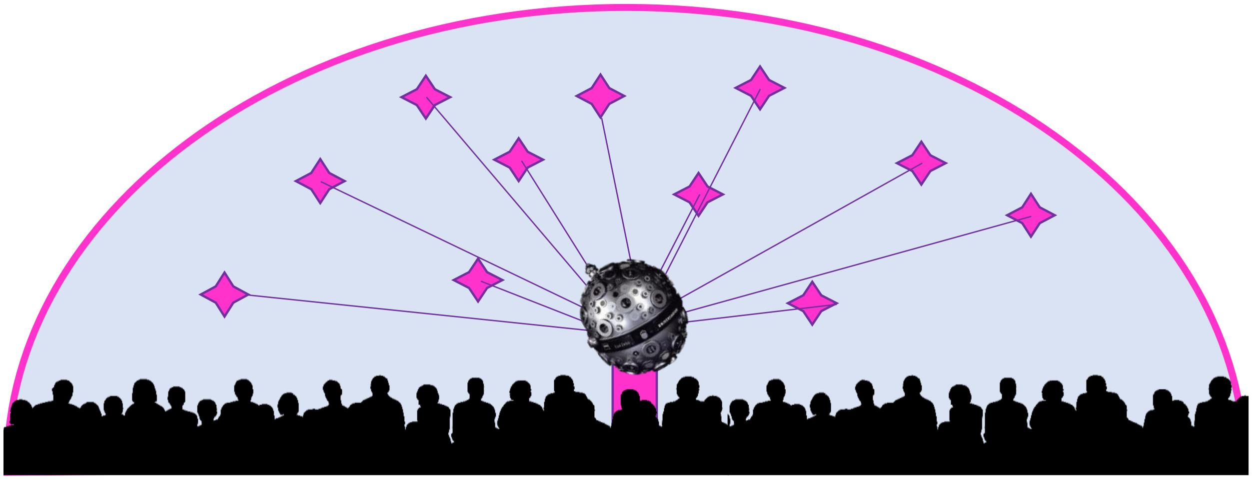

Figure 2-1. Analog planetarium example diagram with a ZEISS star-ball projection system.

The digital planetarium (see Figure 2-2) has replaced this star-ball with one or more video projectors, sometimes along with spherical mirrors, that display content fed to them by a computer. Part of this projection often involves "warping" and "blending" software to convert the multiple rectangle images of most projectors to a uniform image displayed on the dome. This change has not only promised reduced maintenance and equipment costs compared to the analog (Lantz & Route, 2002) but has also opened up the potential use of the planetarium. The facility has gone from the strict constraint of a night sky simulation to virtually anything that a computer is able to graphically render, including videos and vector graphics renderings of 3D spaces.

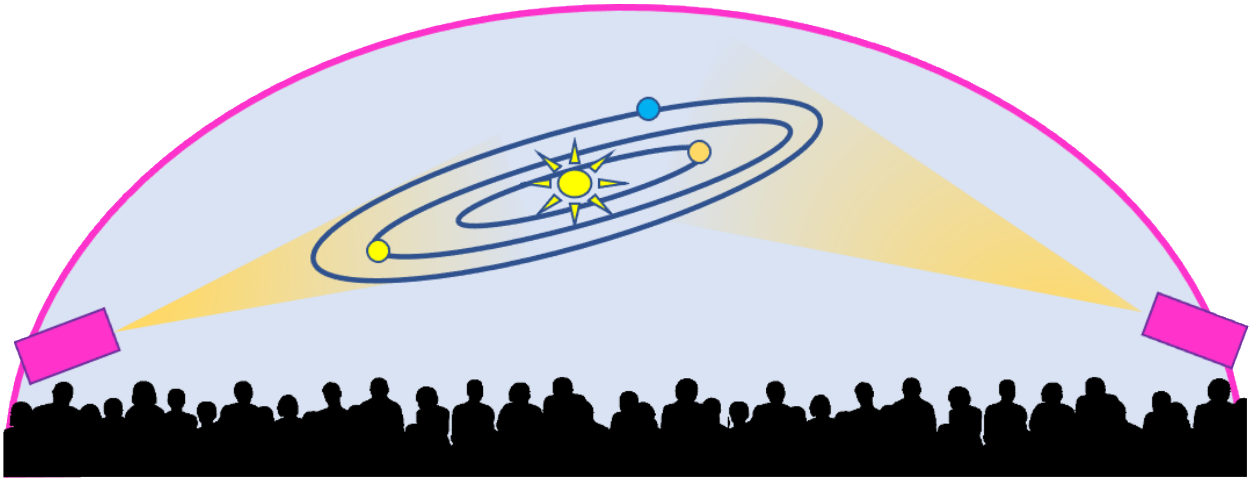

Figure 2-2. Digital planetarium example diagram with a fulldome projection system.

The digital planetarium generally includes the capabilities of the analog planetarium in that a simulation of the night sky can be displayed through the process of projecting a digital fisheye representation of that night sky through the projectors. This means the capabilities of digital planetariums essentially supersede those of their analog predecessors. There are, however, still selected advantages of the analog systems when it comes to the quality of star appearance. The narrow beams of light projected on darker, matte-grey surfaces would provide added contrast for analog systems compared to digital systems that require a light surface (Vorenkamp, 2019).

During my early investigations, I received comments from planetarium users regarding issues with the new digital projection systems. This included that they “don’t do the stars justice” compared to the star-ball projection in that the individual simulated stars do not appear as “bright” or “sharp”. Vorenkamp (2019) explained a cause for this issue: analog planetariums vary star brightness through variation in light allowance through pinholes and lenses while digital planetariums vary star brightness through projecting them larger or smaller in cross-sectional size. Despite this, it is still important to emphasize that digital planetariums offer more capabilities in general than the specialized analog planetariums.[4]

For the purposes of this thesis, I wanted concrete terms to refer to visuals either strictly “from the earth” or “from elsewhere”. I adapted terminology from Chastenay (2016) by categorizing them based on their apparent and intended perspectives. This included **geocentric[5]**, the perspective from an earth-based location looking out to the cosmos, and **allocentric[6]**, the perspective from somewhere else, which could be a non-physical entity. The latter term properly encapsulated the ability of the digital planetarium to display images from a wider range of sources. This includes fisheye video camera footage for a film, a virtual camera that can be placed anywhere in a rendered digital universe away from earth, or a range of digital data sets. I therefore assert that the analog planetarium possesses *geocentric* experience capabilities, which the digital planetarium retains along with adding *allocentric* experience capabilities.

It is also important to note here that there are important differences that distinguish one planetarium from another that can influence the experience of users. For example, planetariums can vastly range in size. The smallest facilities only allow a single person with the use of an inflatable dome or cardboard hemisphere of a few meters made of triangular panels in a geodesic pattern (Figure 2-3A). This is in sharp contrast to theatres holding an audience of hundreds, such as the 35-meter diameter Nagoya City Science Museum planetarium that seats 350 people. Seating can be flat, with or without chairs or arranged as a theatre-style incline (See Figure 2-3C). This may include a tilted dome as well. Sometimes the seating is arranged concentrically facing the middle of the dome (See Figure 2-3B), a relic from a planetarium’s current or former analog state. In other instances, it is unidirectional with seats generally facing the same point on the dome known as the “sweet spot”. Planetariums also range in a variety of materials used for construction. The first permanent planetarium in East Africa, for example, is made out of bamboo, intended as an affordable and environmentally-friendly alternative (Carlson, 2020).

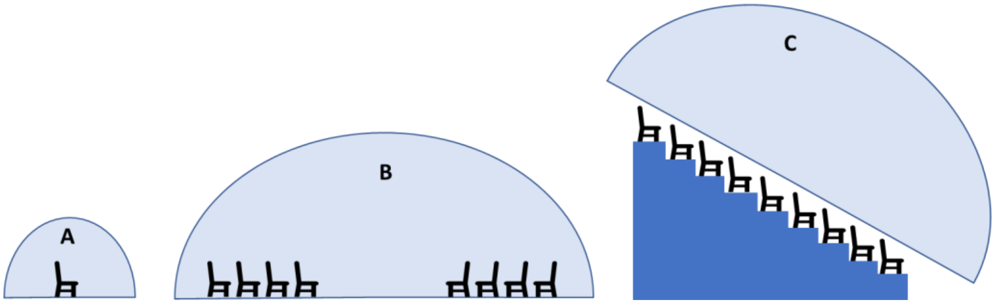

Figure 2-3. Diagrams representing the range of different planetarium types, adapted graphic from (Lantz, 2011).

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[4] Some planetariums even contain hybrid systems that combine the analog starballs with digital projection. The Deutsches Museum in Munich, site of the world’s first projection planetarium, contains such a system from ZEISS.

[5] geo- prefix from Greek word for Earth

[6] allo- prefix from Greek word for different

Another differing aspect is that the hosted locations of planetariums can vary widely. Portable inflatable and constructable domes mentioned above can make their rounds at schools for rent or in garages as hobby projects. Larger planetarium theatres can feature at museums, universities, observatories, or even as standalone facilities (Audeon, 2021). Digital and optical technology is always evolving, and digital planetariums are consequently always implementing new methods of display. 3D planetariums, for example, make use of glasses and multiple overlapping polarized projection images to create a stereoscopic effect for the audience, effectively allowing imagery to “pop out” from the dome. At the time of writing, LED dome technology is also being developed that could potentially allow brighter, higher contrast domes that don’t require projectors or dark theatres (Allred, 2019). This would also close the gap of the starfield quality mentioned above that still exists between analog and digital systems.

Although the digital planetarium makes use of imagery present on a full 360-degree screen, humans have a limited 120 x 150 degrees with their peripheral vision and only a few degrees of acute foveal vision (Mazuryk & Gervautz, 1996). This means that most of the dome is not in view for users in a given instant and much of what is in view is actually present mostly in the peripheral area. The visuals surrounding the users with stimulation extending to peripherals is a key component to what puts the planetarium into the “immersive” category. This is also often supported by a multi-channel surround sound system that can incorporate directional audio in a show using the separate channels.

With such a variety of planetarium shapes, sizes, software, capabilities, and styles, it is important to acknowledge that findings confined to a single planetarium are simply a piece of a much greater puzzle. Generalizing results would therefore need to consider how different variations in the planetarium environment can potentially contribute to a variation in experience for all users involved.

Although the digital planetarium has been around since its introduction in 1983, adoption has not been as quick as the original analog planetarium. By 2010, of the more than 3000 planetariums worldwide, only about 600 to 800 of them were fully digital systems (Bruno, 2008; Lantz, 2011). While it is already a costly process if building a planetarium from scratch, there are immense costs associated with upgrading older facilities as well. Upgrading a planetarium is not a straightforward affair and often involves shutting down the facility for extended periods and potentially losing the generated income on top of the upgrade costs.

2.3 The Digital Planetarium as a Potential Educational Tool

2.3.1 Marketing Discourse

As generally commercial products, planetariums tend to be directly tied to the marketing discourse that accompanies their development. This is especially the case with their building, upgrading and use along with their operational software. For example, ZEISS, the company that developed the original star-ball a century ago, states very prominently on its website:

"The star projector is still, 100 years after its invention, the best tool for teaching and learning astronomy." (ZEISS)

Evans and Sutherland, producer of digital projection environments including planetariums, introduces its software as:

"New physically-based rendering and 3D sound generation help Digistar 7 deliver impact where it counts – in the eyes and ears of your visitors." (Evans & Sutherland, 2020)

Meanwhile, Sky-Skan, the company responsible for Iziko's upgrade, refers to their digital planetarium systems with the following:

"The result is magic: A seamless hemispheric image that engulfs the audience, extending beyond the periphery of their vision." (Sky-Skan, 2019)

RSA Cosmos tells potential customers:

"Live the best immersive experience. Dive into SkyExplorer & explore the Universe. Step into the shows & live it for real. Amaze the audience." (RSACosmos, 2018)

The Planetarian, the professional journal of the IPS, is itself peppered with similar claims and imagery of these and other companies through advertising space. (International Planetarium Society, 2022)

In addition, there is also general hype around the idea of a planetarium that can be seen, for example, in a local Cape Town blog referring to the IPDD:

"Thankfully, we have a wonderful planetarium that reproduces the night sky with breathtaking visuals and intriguing information. As soon as you enter the round celestial theatre, you immediately know you are going to experience something special. The high dome is the perfect canvas to recreate the skies…" (Cape Town Etc, 2016)

There can also be the promotion of fondness from memories about past visits to planetariums. The director of the Hayden Planetarium, Neil deGrasse Tyson, does so on recounting his first visit:

"I was nine years old when I first visited the Hayden Planetarium and I felt as though I could see forever. In the Planetarium's starry dome I saw thousands of stars, essentially an uncountable number… Which was the real sky, the thousand-star-studded sky of the dome, or the sky I recognized? That conflict got me started." (American Museum of Natural History, 2018)

It is important to take all this into consideration when undertaking a study involving planetariums. The facility is potentially more than simply an alternative form of media with capabilities outside what an audience is normally exposed to. Digital planetariums are relatively new, with many coming out of the upgrade of former analog facilities in the past couple decades. It was therefore important in my study to acknowledge that what a planetarium is in somebody’s mind may not be exactly what planetariums are now. The planetarium potentially bears with it emotion or even expectations based on the general ideas that surround what it is. Sometimes planetariums are even prominent landmarks and tourist-attractions of the cities they reside in with the Iziko Planetarium in Cape Town and the Hayden Planetarium at the American Museum of Natural History in New York being great examples. In general, we find a number of top-down influences of the planetarium that potentially affect expectations and experience of users when they are under the dome. This I acknowledged as I explored the space.

2.3.2 Previous Educational Studies in the Planetarium

As my study involved the digital planetarium, a facility rooted in the teaching of astronomy, I decided to constrain the scope of my investigation to that particular use. This was not a straightforward or trivial case to make with the digital planetarium. Although the initial intended use of the facility was based in astronomy education, the added capability from the new systems meant it no longer held that constraint. In fact, one could even make the argument that the name itself, planetarium, is outdated for the digital variant as capabilities go above and beyond astronomy content. Nevertheless, I learned through studies such as Small and Plummer (2010) that astronomy remains the dominant common topic covered by planetarium professionals. It was therefore appropriate to consider the planetarium as a formal teaching and learning space for astronomy for the purposes of my study.

Taking this sort of “meta” view of astronomy itself regarding techniques of research and teaching within, my study fit into the broader scope of Astronomy Education Research (AER). This is a subject under the umbrella of the UCT Physics and Astronomy Education Research (PhAsER) group. AER, a form of discipline-based education research (National Research Council, 2012), is the study of the teaching and learning of astronomy from the position of the discipline. It can include identifying aspects that are challenging or gatekeeping in the discipline and exploring ways to address them. For example, the celestial sphere, the mapping system used by astronomers, is a key concept when learning astronomy. It links the two-dimensional sky above our heads, something that most if not all humans consistently experience in one way or another, to the systematic, multidimensional study of celestial objects and events that we observe and model. This is often granted a few weeks at the beginning of an introductory astronomy course (UCT, 2019b). If the concept is not solidified, that key component is potentially lost for the remainder. This can be detrimental in recruiting new minds to the field of astronomy. It could also deny temporary, curious participants the ability to end a course with an understanding of basic astronomy principles.

Of course, discipline-based education researchers may focus on specific topics within the discipline, but it is also essential to look at methods and techniques as well. In the case of this study, I investigated the use of a digital planetarium in the service of education in astronomy. This was in line with an AER review by Bailey and Slater (2003) which included studies on the “Efficacy of Planetarium Instruction” as a subcomponent of research on “instructional methods” within the field. Here the authors very briefly highlighted the “considerable debate” around using the planetarium as a teaching tool.

Explicit research on the planetarium for educational use dated as far back as the introduction of the Zeiss planetarium. A later, in-depth review from Slater and Tatge (2017) gave a much more thorough overview of this research along with the various shifts that took place in response to changing circumstances around the concept of the planetarium. This review was a great place to start when approaching the planetarium in an open study regarding its usage in education. It was split into looking at an overview of methods in planetarium education research and then broke down a chronological review notably split between pre-1990s and post 1990s. The review then finished off with a focus on the emerging interest in the planetarium's effect in the affective domain, or the emotional consequences of the planetarium experience. Of note are the general findings from the pre-1990s systematic and comparative education research that the analog planetarium was not any more successful as a teaching facility than the classroom. There were many of these studies that accompanied the 20th century planetarium building trend mentioned in section 2.2. One such study is from Reed (1970) that found no statistical difference in teaching students about the celestial sphere via classroom-based interactive methods and demonstrations in the planetarium.

Slater and Tatge (2017) then contrasted the pre-1990s with the more recent decades where newer education studies being conducted in the digital planetarium have shown greater learning gains, especially regarding complex astrophysical topics. Of note are the studies of Yu et al. (2016; 2017; 2015). These found that when teaching students about seasons, the solar system, and celestial distances respectively, the groups that visited the digital planetarium had better long-term retention of content compared to groups that were shown the same show on a flat screen monitor in the classroom.

The review authors referred to the pre- and post- 1990s split in planetarium education research as a "paradigm shift". This included the rise of the digital planetarium (summarized in section 2.2) in addition to a transition to pre-recorded planetarium multimedia productions involving the latest news in scientific research instead of live night-sky shows. This shift also included the acknowledgement of changes in education research itself from quantitative to qualitative methods. Whereas most research conducted in the past would be quantitative-based by answering questions through the analysis of numerical data, qualitative-based is more subjective with analysis revolving around the researcher's own systematic observations and interpretations (Plummer et al., 2015). These trends were especially interesting for my study because a major backdrop to my research study was that of a planetarium, the IPDD, that had itself recently undergone both a digital upgrade and reassessment of its role. We also relied on more qualitative than quantitative methodology as we invoked the Grounded Theory Method (GTM) for analysis.

Another area of relevance to the present work was the classification of the planetarium as a learning environment in terms of it being a formal or informal setting. The Slater review looked to Plummer et al. (2015) in which the authors, as experienced educational researchers and planetarium users, presented a guide to researchers seeking to conduct planetarium-based education research. A key takeaway from this is the acknowledgement of the blurred nature of this classification. Slater and Tatge (2017) used the example of school students taking a field trip to a museum planetarium to learn about the lunar phases. The museum would normally be considered an informal learning environment; however, the context of the instruction being done within a class of students means the study itself could be considered within a formal environment. This was important for my study as the IPDD is used by local university lecturers as part of their course curriculum. Its position as part of a more informal museum and outreach environment means it could follow a similar route of blurred classification. This was important to consider during my project.

Another critical piece of information within the review is that of standardized instruments in the field of planetarium education research, specifically the absence thereof. According to the review, one of the potential reasons for the lack of conclusive evidence in finding dramatic learning gains for students in the planetarium is the need for researchers to often recreate their own knowledge survey instruments for their studies. This is due to the generally difficult task of constructing such instruments to be widely accepted and reliable across contexts of research within the field (Slater et al., 2015). This was followed up with the point that planetarium education research does not have anything resembling a universal knowledge survey instrument. This was fascinating as it showed not just the “Wild West” nature of this niche of education research, but also the opportunity that exists in potentially contributing to such an instrument.

The final section of the Slater review looked at the increasing presence of research on the planetarium’s impact on the affective domain outside the cognitive. What this essentially means is research is starting to look more at what students feel (affective domain) instead of just what they understand (cognitive domain). This provided potentially useful insight to carry into my study at how students engage with the planetarium space.

I also looked more into the work of Ridky (1975) that critically considered the planetarium environment itself. From his study was coined the term “mystique effect” to refer to the unique elements of the planetarium as a classroom that could distract students’ cognitive abilities depending on their familiarity with them. This seemed to agree with later controlled psychology laboratory work of Mayer (2002) who found that “nearly everything not directly related to the information at hand was cognitively distracting and resulted in lower levels of learning measured.”. This appeared to be mildly contradicted by Croft (2008b). Croft interviewed planetarium professionals with the resulting advocation that for planetarium shows to be effective, they should at a minimum include a select group of planetarium features. These features included the immersive quality of the dome, music, taking the audience on an apparent ‘journey’, live presentation or instruction, and making the environment peaceful and relaxing. Whereas the former ideas suggested a cautious introduction of elements for an effective learning experience, the latter explicitly lists a set of elements as essential. However, Croft (2008a) did acknowledge the importance of orientation planetarium sessions, as also suggested by Sunal (1976), in familiarizing students with the planetarium environment before teaching, which agrees with Ridky. It is also important to note that Ridky’s and Croft’s studies occurred on opposing ends of the planetarium “paradigm shift” labeled in Slater and Tatge’s review. The sources of data also came from different subjects, with Ridky analyzing student knowledge and Croft interviewing planetarium professionals who drew from their own observations. A planetarium professional may identify certain signs of engagement from an audience to be positive, yet mistakenly associate these signs as effective learning.

The planetarium has also been shown to influence students’ own view of astronomy as a field. Reed (1975) found this when surveying college students. When these students considered whether to take an optional astronomy course during their studies, the majority of them (70%) indicated that knowing the course was taught in the planetarium had an influence on their decision. This seemed to suggest that the presence of the planetarium had a positive effect on how students felt about astronomy, resulting in them desiring to learn more about it through a course that utilizes the facility.

Also useful was a later study by Small and Plummer (2010). Through interviewing a cohort of planetarium educators concerning their goals with using the planetarium, they found two common prominent themes in the planetarium’s purpose of use. These were the desire to increase knowledge about specific concepts in astronomy and to increase interest in and awareness of astronomy. This was interesting because when considering the planetarium as an educational space, we must also take note of the historic use of the planetarium as a medium of astronomy education. With its new digital capabilities, the facility is no longer limited to showing only the night sky but can display anything a computer is capable of visually rendering. Jacobson (2011) investigated how students respond to game-based instruction about ancient Egyptian architecture within a visually immersive display. The students in the study are found to obtain better information recall than those who use a standard flat-screen desktop. Although not using a planetarium specifically for the study, Jacobson showed how educational studies in the realm of immersive displays can be conducted outside of astronomy. A similar study could very well be conducted in the digital planetarium. However, the digital planetarium facility in such a case would still be known as a "planetarium" which, along with the marketing discord discussed above, are signs of how the facility is potentially perceived. This may introduce a number of expectations not only for students in what they expect to be shown at a planetarium, but what instructors think is possible to teach.

In summary, the background exploration revealed apparent contradictory issues that arose without a clear consensus on the role of the planetarium as an educational space. This is what I wanted to explore in the present work by broadly observing how the users of the instructor and students interact with the space, probing experience of these interactions through questionnaires and interviews, and finally analyzing the collected data through the GTM.

3 Study Design

Here I overview the planning that went into initializing the study. By identifying the digital planetarium as both a complex and novel space based on the initial findings of the previous chapter, I settled on approaching the investigation under the guidance of GTM, which is covered in Chapter 1. I then continue with how I established my initial broad goal based on the previous chapter's recognition of my preconceptions as the researcher. This broad inquiry was deconstructed into two manageable guiding questions, which framed the data collection strategy. I then provide information on the introductory astronomy course and the particular planetarium facility that formed the core of the investigation. This is followed by the ethical considerations that went into the investigation.

3.1 Guiding Questions

New technologies, especially digitally immersive ones like VR, are often looked at to solve many educational issues. This is also the case with the digital planetarium, which appears to lend itself to new ways of teaching and learning. However, to fully understand the educational benefits of the digital planetarium, careful studies need to be done to understand it as a teaching and learning space, rather than simply relying on anecdotal and marketing discourse. I therefore opened the study with a broad inquiry as to how we can characterize the teaching and learning space of the digital planetarium in astronomy, specifically regarding curriculum design. In addition to having access to the IPDD facility for hands-on exploration and interaction, I, along with my PhAsER research group, were also able to observe a university lecturer making use of the IPDD as part of an introductory astronomy course. This provided an opportunity to explore a teaching and learning strand of a planetarium that had recently been upgraded from analog to digital.[7]

From both the marketing discourse and from educational studies carried out in the planetarium, a range of factors seemed to influence the planetarium experience with varying outcomes being reported. However, no systematic studies appeared to have been carried out that informed curriculum design. In addition, educational theories tailored to structuring activities in the planetarium did not appear to exist. This led to me initially posing the broad goal in the scope of a research project invoking the Constructivist flavor of GTM:

Characterize the digital planetarium as a teaching and learning space.

To frame the data collection strategy for such a project, I decided to deconstruct the broad inquiry and focus on two areas that are guided by the following two questions:

Guiding Question #1:
How do students engage with a digital planetarium?

Guiding Question #2:
What shapes the teaching and learning space in the planetarium?

The open-ended nature of both questions clearly lent themselves to being explored using GTM. The study was to involve two core subjects: 1) the Iziko Planetarium & Digital Dome (IPDD) and 2) an

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[7] For the background story on how I got involved with the Iziko Planetarium and the UCT/IDIA VisLab project it forms part and parcel of, see Appendix section D.

introductory astronomy course at UCT visiting the facility. In addition to our own exploratory visits, two visits were to accompany the students of this astronomy course. These two visits became two phases of the study, which I designated Student Planetarium Visits (SPV1 & SPV2). In SPV1 the lecturer for the course planned and implemented a planetarium show for the students. In SPV2 I was given permission to plan and implement a planetarium show relevant to the curriculum for the same cohort of students.

I ultimately had two main sources of data to analyze: 1) the student experience through constructed questionnaires and 2) observational data taken by myself and PhAsER group members and supplemented by unstructured interview data. These two data sources corresponded closely to the two GQs above. Using the GTM, I then analyzed through an iterative approach of constant comparison described in chapter 1 to identify broad, high-level categories from both branches of the data. Out of this analysis, theory in the form of "big picture" models emerged directly out of the data to address the guiding questions. A visual summary of this study design is provided in Figure 3-1.

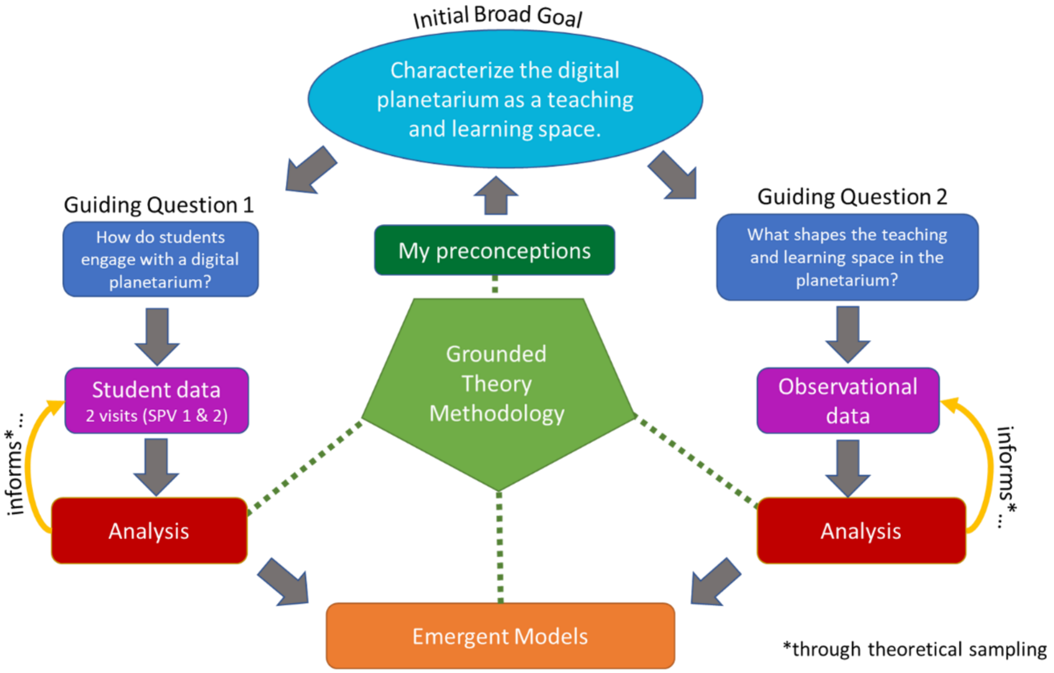

Figure 3-1. Schematic diagram of overall study design. The GTM-based investigation is split with data collection corresponding to the two manageable guiding questions that were inspired by the initial broad research goal. Student questionnaire data was collected over two phases, SPV1 and SPV2. Both student questionnaire data for GQ1 and observational data for GQ2 were independently analyzed according to GTM. From here localized pragmatic models, or substantive grounded theories, emerged.

Note that questionnaires were not designed prior to the investigation, but rather over the course of the investigation. This allowed the questionnaires and the method of their administration to be informed from prior observations and discussion as they occurred. The reasoning behind this was that we as the PhAsER group were highly inexperienced with the space and there existed no well-established questionnaire instruments for planetariums (see section 2.3.2). It was also important in the spirit of GTM to retain flexibility with data collection to elicit responses that were as broad as possible and avoid potential restraints. Questionnaire construction and administration consideration are thus covered in the SPV1 and SPV2 chapters that follow.

3.2 Introductory Astronomy Course

A regular instructional user of the Iziko digital planetarium from the University of Cape Town (UCT) Astronomy Department is the lecturer for AST1000: Introduction to Astronomy. AST1000 is a 1-semester course run by the department that is “open to all interested students as well as providing a solid introduction to those wishing to continue in astrophysics” (UCT, 2019a).

In addition to daily lectures[8] given by the course lecturer, the students are also required to attend a weekly tutorial or practical session that supplements the curriculum material. The lecturer hosts two of these supplementary sessions at the IPDD where she presents topics to the students in the space of one hour which, according to the course outline, is “complimentary to that covered in the lectures. It concerns the understanding of the visible night sky and the Celestial sphere” (UCT, 2019b). The lecturer is assisted by a planetarium staff member to operate the controls. The first planetarium visit takes place early in the first half of the course and the second visit takes place later in the second half of the course. As a facility belonging to the Iziko South African Museum, the IPDD facility is off-site more than seven kilometers from the university campus where students normally attend courses. Students have the option of taking university transport or driving to the venue for this practical session.

In the AST1000 course that took part in SPV1 and SPV2, there were 98 enrolled university students and their academic backgrounds varied from undergraduate to honors-level. Most were first-year students with some pursuing astronomy as a field of study for which the course is a requirement while others took the course as an option. AST1000 is also a course undergoing active curriculum development, so the students would occasionally fill out questionnaires regarding their experience of the course. This included other studies conducted by the PhAsER group at UCT. For example, this particular cohort of students was administered the Introductory Astronomy Questionnaire ranking instrument (Rajpaul et al., 2014) earlier on in the course as part of a separate study prior to this planetarium study. Furthermore, according to an end-of-semester feedback questionnaire, 60% of the students had not visited a planetarium prior to the current study. We can assume that the planetarium was an unfamiliar environment for most of these students.

3.3 Iziko Planetarium & Digital Dome (IPDD)

2017 saw the completion of a major renovation of the planetarium at the Iziko South African Museum in Cape Town. The 30-year-old planetarium underwent a complete conversion from an analog system to an 8K digital dome. Iziko describes the facility today as “the most advanced digital planetarium on the continent” (Marchetti & Jarrett, 2018). Justifications for the upgrade included increased capability for outreach, research, and teaching as well as the accompanying revenue boost for the museum. This included the ability to produce original, locally-developed source content such as the “Rising Star” planetarium show about South African astronomy (Macfarlane, 2021). The renovation itself was led by Western Cape astronomers Professors Michelle Cluver of UWC and Thomas Jarrett of UCT together with the staff of Iziko Museums (Cluver & Jarrett, 2018; Jarrett, 2015).

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[8] nominally 60 lectures for the course

Figure 3-2. Iziko Planetarium and Digital Dome in Cape Town, South Africa.

Regarding outreach, the new digital dome enabled additional content for the museum's public shows. Previously, shows consisted primarily of a presenter giving a scripted live tour of the night sky. The visual aid of projected stars and multiple slide projections on the dome functioned as an interactive simulation of this night sky along with occasional animations. The digital dome allows similar live presentations of the night sky in addition to a new range of visual capabilities including tours of the universe away from earth as well as fulldome planetarium films. The latter are primarily run with the "push-of-a-button" to start and stop the show, but the live shows still require live interaction by a planetarium operator to control the display of the rendered scenery on the dome and speak with the audience. The controls are done via keyboard and mouse with the digital dome as opposed to knobs, dials, and joysticks with the previous analog system. Some live shows can also be controlled via means of scripted buttons, which require less manual control by the presenter.

As the planetarium is situated in a major population center, there is a high potential for school and university students to be exposed to the facility for educational purposes that complement existing curricula. Additional capability for formal educational use, outside more commercially oriented outreach, was therefore another motivation for upgrading. The digital planetarium, previously confined to predominantly night sky simulations, could potentially include broader topics within astronomy as well as outside. How such added capabilities of the digital dome impacts its educational use was in fact one of our initial guiding considerations for this thesis project.

Another one of the driving motivations for upgrading the planetarium was the added capacity of using the facility to conduct scientific research, particularly to handle and visualize large volumes of data in coinciding with the introduction of Big Data to astronomy. This was part of the Data-to-Dome initiative spearheaded by the International Planetarium Society (IPS) with the goal of enabling researchers to more easily visualize their data in the planetarium (Kwasnitschka, 2017). UCT Astronomy became a major player in the efforts to upgrade previously analog planetariums to enable such capabilities (Marchetti & Jarrett, 2018). With the proprietary *DigitalSky-Dark Matter* (*DSDM*) visualization software (Sky-Skan, 2021) pre-installed on the system as part of the upgrade, astronomers could potentially upload astronomical data sets from compatible formats. The data sets could then be rendered into the digital scenery of the planetarium software and projected onto the dome. This goal of visualizing research data with the digital planetarium was also tied back to outreach capabilities. The dome could be potentially used to explain South African astronomy to the general public, specifically findings from the SKA and one of its pathfinders, MeerKAT. As part of the upgrade agreement, use of the planetarium is reserved for exclusive use by researchers one day per week. This timeslot is also extended to creators of local content for the dome.

3.3.1 The Facility

The planetarium at the Iziko South African Museum consists of a 15.2-metre diameter dome and can seat 142 people in the audience.

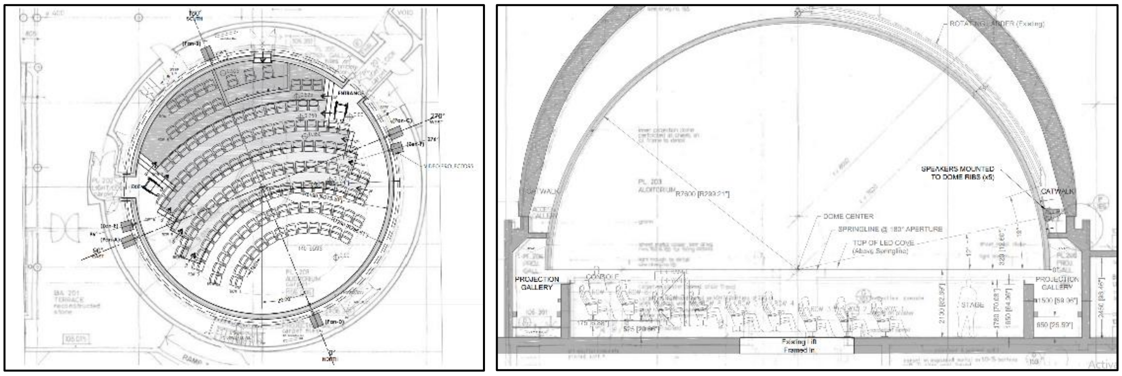

Figure 3-3. Upgrade plans for Iziko Planetarium from analog to digital system. Provided by Iziko .

Generally access to the museum wing containing the planetarium is gained via the main museum entrance although a more dedicated entrance is available close to the dome as well. Inside the museum the theatre can then be accessed from two separate audience entrances while a separate entrance exists to an alcove for storage, maintenance, and access to the operator's box.

Seating is slightly inclined with reclining chairs that point in a forwards direction towards a common point on the dome (see Figure 3-3). This common point, or sweet spot, previously mentioned in section 2.2.1, generally sits on the dome at about 50 degrees above level. A seating box in the back of the theatre contains the master computers for controlling the digital dome in addition to lights and sound. The computer clusters powering the projection system lie underneath the theatre in the basement.

3.3.2 Dome Display

Unique among most other digital planetariums, Iziko employs a two-cluster system to run its projectors. There are six 4K laser projectors that stitch together the picture on the dome. Each projector has two rendering computers per cluster[9] assigned to it. The user interacts with the software on the cluster's master computer, whether it is to show the night sky, move a virtual camera around a virtual universe,

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[9] amounting to four computers in total per projector when considering the two clusters

play a fulldome video, display research data, or otherwise engage with the software. Instead of rendering the visuals itself, the master computer instructs each pair of computers assigned to each projector to render their portion of the visuals. This is accomplished by “syncing” the same data it uses across the system via ethernet network connections. This allows resource-heavy renderings to be displayed on the dome at high resolution without noticeable lagging or degradation of the visual quality, assuming the planetarium system is correctly calibrated. There is also a dedicated computer that handles the theatre’s 5.1 sound system, giving each cluster a total of 14 computers (1 master + 2 x 6 projection + 1 audio). The images projected out of each individual projector need to be “warped” and “blended” by the system’s software, so the dome displays a final 8K x 8K pixel image that is complete and uniform[10] across the entire dome surface.

The two separate rendering clusters serve different purposes and allow isolated work and experimentation to be carried out on each, such as settings adjustments and workspace editing, without impacting the other. The “public” cluster is dedicated to outreach shows and commercial operation while the “research” cluster is dedicated to visualizing scientific data sets in addition to other exploratory purposes. The research cluster is also used as a backup for the commercial operation in case the public cluster malfunctions. Many of the shows and custom control settings are duplicated on both clusters for this reason. To make use of a particular cluster, the system must be switched over from one to the other which involves booting up the other cluster and then manually switching over the video inputs of the projectors to the other cluster with a remote control. If the audio capabilities are desired from the second cluster, then a cable needs to be manually attached for the research cluster or detached for the public cluster.

3.3.3 Software

The projection systems of digital planetariums are computer-driven and can range from a single computer to a complete cluster of multiple rendering computers. Specific software is therefore required to project visuals onto the dome. Thus, the primary software being used at any digital planetarium forms a core component and must be carefully considered.

When the Iziko planetarium underwent the upgrade, it was done under contract with the company Sky-Skan. Included with the installation of the hardware was the software *DSDM* (Sky-Skan, 2021) running in a *Microsoft Windows* operating system. All three use-cases for the planetarium upgrade, namely outreach, research, and education, currently rely on *DSDM* to operate. There is other proprietary planetarium software available in the industry as well, often included as part of an installation contract. This includes *Digistar* from Evans & Sutherland (2022), *Uniview* from ZEISS (2022), and *SkyExplorer* from RSACosmos (2022). Opensource alternatives include *OpenSpace (Bock et al., 2019)*, *WorldWideTelescope (Rosenfield et al., 2018)*, and *Stellarium (Zotti & Wolf, 2020)* , with the first two having been identified as accessible solutions to maximize interoperability for researchers using different planetariums (Faherty et al., 2019). Currently the researchers making use of the IPDD are exploring how to install *OpenSpace* and *WorldWideTelescope* onto the system as a potential alternative to *DSDM*. There is also video input that can be achieved through an HDMI cable that one can plug a

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[10] The actual uniformness is exaggerated here. Although the fulldome display is 8K overall, it is actually 6K that is uniform while the image quality degrades moderately towards the ‘horizon’ of the dome.

device such as a laptop into to display visuals from other sources. This however is limited to 1080-pixel resolution, severely downgraded from the dome system's effective 8K capability.

3.4 Ethical Considerations

As an investigation within the scope of AER, it was assumed from the beginning that I would be collecting data from social processes. This required directly interacting with people and, critical to the GTM approach, would require eliciting qualitative descriptions of their experience. It was therefore essential to adopt a protocol that would keep the investigation ethical. This section highlights the ethical precautions that were submitted, reviewed, and approved by the UCT Faculty Ethics in Research Committee. Evidence of this was included with the thesis submission and can be provided on request.

It was of primary concern that participants in the study were well aware of the processes taking place with necessary explanations and transparency. This included all people from which data was collected, including the course instructor and students. The instructor, as an active member of the PhAsER group herself, had given consent for the group to make use of her course for the purposes of curriculum development. Nevertheless, I made sure to obtain extra audible consent from the instructor prior to asking questions or observing sessions. This data from interaction with the instructor also included recording audio to capture responses, which was erased after transcription. No personally identifying information was included in the transcription.

For students in the course, it was important to develop a more involved process to receive their consent. As the course was undergoing curriculum development, the students would receive questionnaires throughout the year for numerous studies, such as the study by Makwela (2022). At the beginning of the year, students were given the PhAsER consent form reproduced in Appendix section G. This form laid out the various potential concerns that students could have regarding taking part in such studies. It gave the background of the PhAsER group and explanation of procedures that would be involved in the studies such as questionnaires. There was also clarity regarding the absence of harmful risks and a note on the confidentiality of the responses. The form also emphasized that participation was completely voluntary and that students could refuse or withdraw at any time. Students were requested to sign and submit the forms, of which nobody opted out.

During SPV1 and SPV2, students were audibly reminded of the above points prior to being given questionnaires. In accordance with the ethics form that was signed, student identification numbers accompanied responses on questionnaire sheets. These questionnaires were assigned randomized Unique Identification Numbers (UID#). Student identification numbers were then separated from the responses and entered into a secured mapping table. The responses could then be mapped to identification if needed for follow-up discussion or interviews. At the end of the study, this mapping file was destroyed, thus fully anonymizing the results.

It was also important from an ethics standpoint to consider the impact my study had on the introductory astronomy course itself. Students were taking part in the course to learn from the instructor they signed up with. Any education study should thus have minimal impact on the teaching that the instructor planned to implement. For SPV1, this was not too difficult as it primarily involved constraining the size of the questionnaire and time given for students to fill it out. Nevertheless, I did find in practice that our process of handing out and collecting papers took more time than expected, which did take away time from the planetarium instruction. I revisited and replanned this process for SPV2 to minimize the time devoted to questionnaire logistics. I also made a conscious effort in SPV2, when I took on the role of a show developer, to implement a show as relevant to the curriculum as possible. This meant consulting the course syllabus and consulting where the course was in its planned curriculum. At the time, from discussion, we also wanted to keep the instructor unaware of the content of the planned SPV2 show, which she was fine with. However, in practice, there were later signs of uneasiness from the instructor following the implementation of SVP2 regarding the show's content. This was from the expectation that more topics directly from the course would be included. We decided as the PhAsER group to provide more transparency to the instructor in future studies in which we designed the show.

4 Student Planetarium Visit 1 (SPV1)

In this chapter I document the observational narrative of Student Planetarium Visit 1 (SPV1), the baseline/preliminary study component based on the first planetarium visit for the introductory astronomy course. Members of the PhAsER group and I observed how the lecturer of the course made use of the digital planetarium to give a presentation on topics covered in lectures, particularly on the celestial sphere. In addition to our observations of the planning and implementation phases of the planetarium presentation, I also produced a questionnaire for the students to fill out at the planetarium. Development of this questionnaire was a result of discussion within the PhAsER group. A reflection interview was also conducted with the course instructor. Data sources included the detailed description of events that the group and I documented from our observations as well as student responses and interview responses. Early, low-level findings are included at the end that resulted from discussions relevant to informing the follow-up SPV2.

4.1 Preparing for Visit

4.1.1 Pre-visits

Prior to documenting the direct cases of educational use in the SPVs, I first explored the IPDD facility during several visits in which I accompanied astronomers on their dedicated research days. The purpose was to familiarize myself with the digital planetarium. Other PhAsER group members occasionally took part in these exploratory visits. The astronomer in charge of conducting data analysis in the planetarium showed me the different visuals that the planetarium's *DigitalSky-Dark Matter* (Sky-Skan, 2021) software is capable of. This included models of celestial objects that are included in the software, different grids and measurement overlays that can be turned on and off, as well as the various sets of astronomical data that had been imported by researchers up to that point. The latter included the 2MASS Redshift Survey catalog of galaxies (Huchra et al., 2012) and a volume rendering of animal tissue from a neuroscience group at Stellenbosch University (Ntsapi et al., 2019). There were a few follow-up visits for further introduction and general "tinkering" with the software to gain familiarity with its capabilities. These are detailed in Appendix section D.

4.1.2 Deliberations with PhAsER Group

Ongoing discussion regarding the data collection and analysis process occurred amongst the PhAsER group. This included key sessions following the observations of the instructor's planning phase (See section 4.2.1). This was necessary to focus the study and chart the way forward in data collection. After several iterations of discussion, scrutiny and debate, the following areas were agreed upon as the way to proceed. We identified two issues concerning the planetarium as an educational space that we wanted to capture for this study:

1) The planetarium show/experience itself and 2) The nature of probing student experience

These issues are summarized in the reproduced memo that follows:

1. Planetarium show/experience

1.a. General - Fixed/controlled things- that which we could not vary or change.

- Experience takes place at Iziko Planetarium, off-site from the UCT campus.
- This was the first visit to the planetarium for the course.

Question: *How do students engage with this experience?*

1.b. Educational content

The lecturer has an intent involving various topics she wishes to show to the students:

- Visualize the night sky and celestial sphere in "3D" from different locations on earth.
- Show how the Sun "moves" at noon over the course of the year.
- Show a few of the main constellations and how they indicate cardinal directions.
- Show precession and debunk astrology.
- Advertise the planetarium as "a nice place to go."

Question*: Several topics were included in a single experience. What do students walk away with?*

1.b.1 Educational Research focus topic

We chose to focus on a single topic that the lecturer included in her intent. By doing this we hoped to produce a method to gauge any potential changes in how students explain elements of the topic. Although not necessarily as deep as assessing how understanding shifted, we wanted a more open approach of assessing how responses in general shifted.

For this topic, we chose **visualizing the celestial sphere**. This was based on a few reasons. The celestial sphere is a common first topic in introductory astronomy courses including this specific course that lists it as a key topic on the course syllabus.

Question*: How do student responses change with regard to a specific topic?*

2. The nature of probing student experience

After deciding what we wanted to probe, we needed to decide how to construct the instrument.

2a. What to ask students

We wanted to include questions that probed:

1) how the students respond to the general planetarium experience

as well as the educational content which would include a student reflection on:

2) what they felt they learned

3) student's understanding of the research focus topic.

The first inquiry we decided would best be a combination of the students rating their experience in different "domains" of the experience (Enjoyable, Length, Difficulty, Clarity) as well as reflecting on their "best part" of the experience.

The second inquiry would have a direct question on what the student felt they learned.

The third inquiry would be looking at how a student's understanding of the celestial sphere evolved from the pre-show to the post-show.

2b. Form of questions asked

When probing a respondent's experience, it was important to separate out issues that might relate to emotional response from those that might relate to educational content. In this manner, a respondent is given the opportunity to "offload" emotional experience from their reflection on what they learned.

In the work of Tlowana (2017), in the context of a first year physics lab course, it was found that the sequence of asking questions was critical for these reasons. When questions about the enjoyment factor were posed prior to a probe on evaluation of learning, it was easier to separate out a positive learning experience from a negative enjoyment factor. Asking a single question runs the risk of conflating the two issues, which we wanted to avoid. In this case a question about experience was negative but followed up with positive insight about learning gains. Therefore, the sequence of asking these questions is important. Offloading emotion is important before asking students to reflect at a more "intellectual" level.

This is an especially critical consideration with the planetarium which, as discussed in section 2.3.1, includes a fair amount of emotional background in how people potentially engage with the facility. This includes the expectations framed by marketing discourse as well as general hype reinforced by general sentiments or nostalgia.

We thus decided when asking what students felt was the best part of the show, we put that before reflection on what they learned. Also, two forms of questions were agreed upon. Firstly, Likert-scale questions were used to rate emotional components of the experience. However, in some cases this was followed by a request to explain the choice. Secondly, we included questions that required free-response writing. For the second, the format that was chosen was based upon an assertion in order to prompt a debate as detailed by Allie et al. (1998).

With these issues in mind, I constructed a questionnaire instrument and refined it through several iterations of "mock" administration and trialing with the rest of the PhAsER group. We also decided that the most effective capture of the planetarium experience itself would take place if the students completed the pre-show questionnaire immediately before the planetarium show and the post-show questionnaire immediately after the show. I therefore decided to administer the questionnaire inside the planetarium.

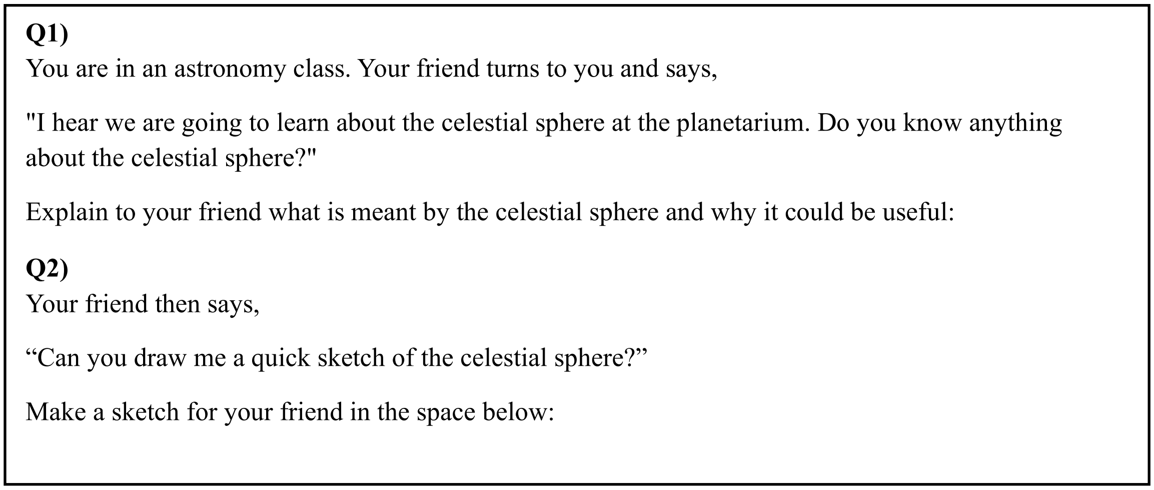
However, our pre-visit observations from last section pointed to a few characteristics of the planetarium that would have a direct impact on administering a questionnaire. One example was the absence of writing surfaces inside the planetarium theater of IPDD. Also, as this was an out-of-classroom visit, we had to ensure that the students had access to writing instruments. To address both of these issues, we purchased 100 clipboards and 100 pens that were passed out to students along with the pre-show questionnaire as they entered the planetarium. Responses were collected prior to the show. After the show, the post-show questionnaire was passed out and collected prior to the students leaving. Space was also given on the questionnaire for student university ID numbers in case follow-up questions or interviews were desired.

The pre-show questionnaire was for the evaluation of student responses regarding the topic of focus, the celestial sphere. Students were tasked with answering what they understood about the celestial sphere and why it is useful. They were then instructed to draw a sketch of the celestial sphere.

The post-show questionnaire included the follow-up to the educational topic focus with similar questions. This was given alongside a broader look at the student engagement with the general educational content as well as probing to the planetarium experience itself. The first question tasked students with identifying the “best part” of the show along with explanation. They were then asked to state what they learned along with an explanation. Both of these were elicited through peer-to-peer explanation framing based on the work of Allie and Demaree (2010). At the end of the post-show questionnaire, we included Likert-scale ‘tick-a-box’ questions for students to rate the quality of their experience. To capture a more nuanced picture of this engagement, the ratings were broken into four categories on scales of 1 to 5. These categories were enjoyment of the show (1 = not enjoyable, 5 =very enjoyable), length of the show (1 = too short, 5 = too long), understandability of the information presented (1 = very easy, 5 = very difficult), and clarity of the show (1 = very confusing, 5 = extremely clear). For the enjoyability and clarity questions we also included space for the respondent to explain their choice.

4.1.3 SPV1 Questionnaire

The full questionnaire set for SPV1 is presented in Figure 4-1 and Figure 4-2.



Q1)
You are in an astronomy class. Your friend turns to you and says,

"I hear we are going to learn about the celestial sphere at the planetarium. Do you know anything about the celestial sphere?"

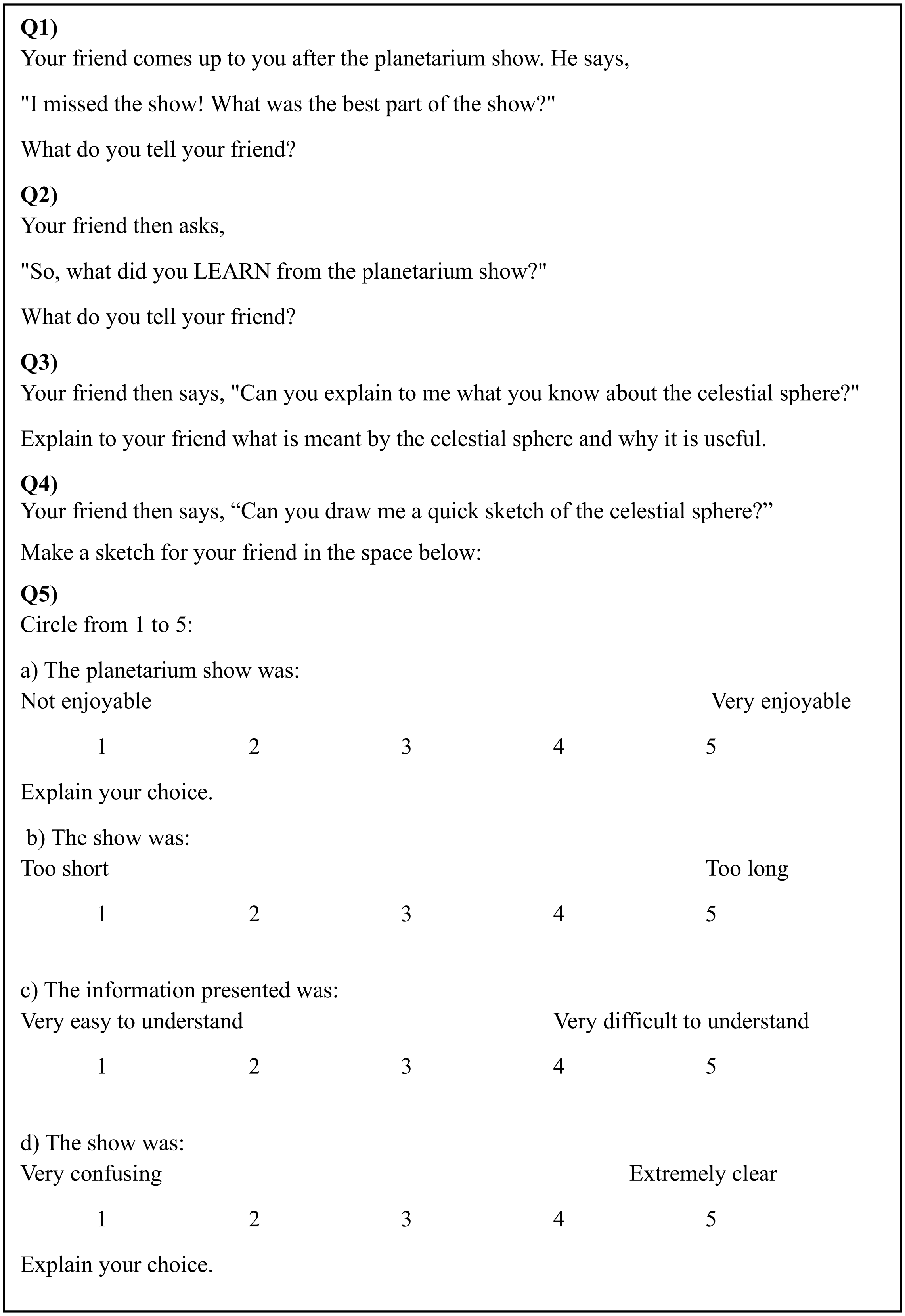
Explain to your friend what is meant by the celestial sphere and why it could be useful:

Q2)
Your friend then says,

“Can you draw me a quick sketch of the celestial sphere?”

Make a sketch for your friend in the space below:

Figure 4-1. Questions used in the pre-show questionnaire for SPV1.



Q1)
Your friend comes up to you after the planetarium show. He says,

"I missed the show! What was the best part of the show?"

What do you tell your friend?

Q2)
Your friend then asks,

"So, what did you LEARN from the planetarium show?"

What do you tell your friend?

Q3)
Your friend then says, "Can you explain to me what you know about the celestial sphere?"

Explain to your friend what is meant by the celestial sphere and why it is useful.

Q4)
Your friend then says, “Can you draw me a quick sketch of the celestial sphere?”

Make a sketch for your friend in the space below:

Q5)
Circle from 1 to 5:

a) The planetarium show was:
Not enjoyable Very enjoyable

1 2 3 4 5

Explain your choice.

b) The show was:
Too short Too long

1 2 3 4 5

c) The information presented was:
Very easy to understand Very difficult to understand

1 2 3 4 5

d) The show was:
Very confusing Extremely clear

1 2 3 4 5

Explain your choice.

Figure 4-2. Questions used in the post-show questionnaire for SPV1.

4.2 Data Collection & Summary

4.2.1 Planning Phase

Prior to the planetarium visit, the course instructor met with a tutorial instructor for the course who is also an experienced planetarium operator and employee of the Iziko planetarium. This 30-minute planning session between the instructor and the planetarium operator was observed and documented prior to the planetarium visit. The planning session was recorded and transcribed for later analysis in which different aspects of the observational data were identified. A summary of the planning phase is produced below that was compiled from the transcribed recording and the notes that I took.

The initial purpose of observing this phase was to take note of the instructor's intent, how the operator responds to this intent, and overall, how the instructor and operator collaborate to produce a planetarium show. Notes from this session would be used to construct a questionnaire for the students to be filled out before and after the planetarium experience (see section 4.1.2). It was revealed at the beginning that this would be the second year that the instructor was making use of the planetarium in its digital state. In previous years she would not require the assistance of a planetarium operator because she already "knew how to drive" in the past when the planetarium's controls were dials and knobs for the star-ball projection system.

In this session, the instructor highlighted the overall aims of the planetarium experience as visualizing the night sky and celestial sphere in "3D", showing how the Sun "moves" at noon over the course of the year, showing a few of the main constellations and how they indicate cardinal directions, and showing precession while debunking astrology. The instructor also asked if they could show "one of the adverts" in the dome as a nice intro that would be fun to show on the dome, referring to the collection of fulldome videos that the Iziko Planetarium is capable of showing. She specifically referenced one that shows different telescopes, which the operator recognized as his "favorite one" but that it doesn't "give a huge idea about the different things that the dome does". The instructor and operator agreed that the music is a really nice feature of this video. The instructor also mentioned how this specific video would appeal because the students are there for a class and the video would "maybe get them to come back… on their own." The specific video that was being referred to was *Relentless Night*, a fulldome short film produced by Sky-Skan (Sky-Skan, 2013).

The operator had other input into the planning session of the planetarium show such as when he asked if it would be okay to play music during the show that he normally includes in his own public shows because it is otherwise "boring with [him] talking the whole time". The instructor agreed on the condition that the music was "not too relaxing and puts students to sleep" following up with how the music would be "nice because it would give it a bit of a vibe otherwise it's a bit harsh just hearing a voice". There was also a notable exchange when the instructor was going through a potential sequence of showing the constellations and then the cardinal points on the dome, to which the operator confirmed "not first?" in reference to the order of showing these two features. The instructor clarified that it "doesn't really matter, but it's quite fun to see the stars and then start to bring it down to earth". There were other instances when the instructor needed to inquire about the capabilities of the planetarium visuals and the operator would then be required to respond with a constraint on what could be shown. For example, the instructor wanted to show the full celestial sphere as a grid of lines, however the operator revealed that a full grid overlay would not be possible, but other representations of the celestial sphere could be shown such as the meridian and equatorial lines with tick marks. Another technical constraint happened when the operator needed to inform the instructor about a graphical glitch that would occur for the meridian lines when the south celestial pole was placed directly overhead, so that section of the demonstration needed to be done at the north celestial pole. The instructor made a side comment that this could be due to the software being “north-centric”. The operator also needed to point out that they would need to rotate the visual at some point to make the celestial pole more visible. To this the instructor assured the operator that they must “not worry if it’s not perfectly smooth, it’s a teaching prac[tical] not a show”. The instructor also needed to ask the operator if there would be a laser pointer for her to use.

Other key observations are as follows. To demonstrate precession, the instructor wanted to include a “clockface” that would show precession as she could do this with the “old dome”, but the operator said that was not possible with the software. The operator also needed to clarify whether the instructor wanted the dome to show a nighttime sky or if daytime with the atmosphere “turned off” would be fine, to which the instructor said the latter was okay. Another instance of note was the instructor pointing out that the students had already seen and should remember the visualization of diurnal motion in class. This visualization was shown in lecture on a flat screen using *Stellarium*, but the instructor mentioned that in the planetarium “it’s better in 3D”. The instructor also made a comment of going through a list of components she would be asking the students to identify at one of the night sky locations that “it’s all a little bit exhaustive, but I think it’s good for them to do this”. Later she also said regarding the content that “it is exhaustive, but it shouldn’t take long”. Often when the planning involved a portion of the show that required visuals of the night sky from different locations, both the lecturer and the operator used terms like “we'll go to the North pole” or “trying to fly there” to indicate that shift in simulated perspective. Generally, the operator used the terms “leap” versus “fly” to indicate whether changing night sky location on the dome included a visual transition or not. The lecturer also supplied me with notes that outlined her plan for the show. These notes were also referred to throughout the planning stage with the operator, acting as a sort of storyboarding reference.

4.2.2 Course Lectures

I also took note of direct mentions of the planetarium session in lectures leading up to the visit. This was done when I attended the course lectures and recorded in writing when the planetarium was mentioned. The only notable instance of this was the day of the planetarium session, after explaining the logistics of the afternoon planetarium visit[11], was the instructor giving a preview of the show’s content. She told them that they will be “learning about the celestial sphere” and “looking at how the height/altitude of the Sun changes over the course of the year”. This was followed up with directly telling the students that the session would “hopefully… help [them] to be able to visualize in 3D a little bit better what we are doing with the celestial sphere because it is a tricky section, and we try to attack it from all angles”.

4.2.3 Planetarium Visit

I recorded and transcribed the instructor’s and operator’s narrations with an audio recorder during SPV1 for later analysis. I also wrote notes regarding the visuals presented as well as the logistics of the visit. These were reviewed later in which different aspects of the observational data were identified. A

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[11] where to meet, how to get to the venue, etc.

summary of the visit is produced below that was compiled from the transcribed audio recording and the notes that I took.

The planetarium show was presented on the digital dome to a cohort of 94 students[12]. Students gathered in front of the museum, entered through the main entrance, and then walked to the planetarium itself. Here they entered and seated themselves where they wished. Before the start, students were given the pre-show component of the questionnaire by me and PhAsER members with pens and plastic surfaces to write on. Responses were collected from students who raised their hands when finished. The lecturer requested the operator to tell students over the audio system to finish up so the show could begin after about 8 minutes. At about 10 minutes, the operator dimmed the lights of the theatre as a few more students scrambled to finish and hand in the questionnaire. Here I noticed that the planetarium lacked direct lighting for people sitting in the audience, making some students appear to strain to read the questionnaire.

The show opened with the planetarium operator welcoming the group over the audio system. The lights dimmed, the operator drew attention to the locations of the theatre exits, and then the night sky as viewed from Cape Town faded in on the overhead dome. The overlays for a few constellations such as Orion and Taurus were shown as well as close-ups of a couple galaxies. This was followed by a 3.5-minute *Relentless Night* short film of telescopes in Hawaii accompanied by relatively loud dubstep music. After the film, the operator played soft video game music over the speakers while the instructor took over the narration.

First the instructor spoke about the planetarium's use as an education and research facility because of its "ability to visualize data in 3-Dimensions" that "gives people a very different perspective". She then explained that "we are currently sitting in Cape Town" looking at what the night sky would look like without light pollution. The components relating to the celestial sphere were shown (celestial equator, meridian, poles, etc.) with cardinal directions. Occasionally, the instructor gave a brief description prior to revealing a component and asked the audience what the name of a component was. She also used a laser pointer to point out certain features of the components on the dome. It is worth noting that the presenters did not make use of a grid overlay during this section despite the *DigitalSky-Dark Matter* software having the capability. This capability was discovered by the author in a separate exploration session with the software, so it was possible that the operator did not know of it at the time.

Next, the presenters showed what the night sky, diurnal motion and celestial sphere components look like from different parts of earth. The instructor told the students that they would be "teleporting" between locations, during which the stars on the dome rotated and the audience gave auditory signals of astonishment. This happened a few times with these sounds of astonishment decreasing in intensity each time. The instructor advised students to close their eyes if they needed to, once suggesting that "it makes the teleportation experience better." This section also included the demonstration of finding the cardinal directions using Polaris and the Southern Cross. One of these teleports included the instructor asking the students "who feels like a trip to New York City?". When the presentation would "visit" a new location, the instructor would pose a few practical questions such as what declination of stars would not be visible from New York or whether a constellation would ever set. Throughout the presentation, when the night sky was displayed from a specific location, the operator would rotate the stars in an apparent diurnal

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[12] 4 of the 98 enrolled students for the course did not attend SPV1

motion, but at a quicker speed than how the stars would appear to move in real life. An interesting question was posed to the students by the lecturer where she asked the reason for this apparent diurnal motion or “why the sky looks like it is moving”. Several students audibly answered with the instructor confirming that it was because the “earth is turning on its axis.”

To show the changing height of the Sun at noon over the course of the year, the instructor started by asking about the celestial sphere components related to the ecliptic (“what do we call the point where the celestial equator and the ecliptic are crossing?”, “what is the time of day when Sun is at the highest point in the sky?”, “could we see the stars at noon?”). Then the software’s time was kept at noon while the operator cycled through different months. The instructor pointed out how the Sun changed in height in the sky as, the instructor noted, “we’re approaching the equinox” or “we move into summer”. This section also included the instructor explaining as the Sun moved in the sky “as we move again back to next year… look we’re in [next year] so time travel is possible, we’ll be heading back down in altitude towards autumn.” Here the “we move” at the beginning of the statement was used to indicate the visualization’s point in time while the “we’ll be heading” was said with a laser pointer indication to the Sun’s movement, suggesting “we” was the Sun that the instructor was referring to.

The next section started with the operator seemingly losing control of the software temporarily as the sky appeared to spin, with students laughing and expressing astonishment once more. The instructor then indicated that “now we will have some fun”. The zodiac constellations were made visible by the operator. The instructor then read the horoscope for people born under different signs and showed how the constellations lined up with the Sun differently during the time of the Babylonians versus the modern day. She then read the “new” signs that students would have with the revised horoscope. Students were heard laughing throughout this section, which was concluded with the instructor explaining that the students “were not born under the star sign [they] thought [they] were.”

The instructor closed out what she labeled “our tour” and thanked the operator for “driving” what she referred to as “this beautiful 3D dome”. The learning material was explicitly limited to the geocentric capabilities of the software primarily focused on the topic of aspects of the celestial sphere that was concurrently being taught in lectures and lasted for about 20 minutes. The entire presentation that also included a musical montage of modern telescopes, a review of constellations, a demonstration of earth’s precession, and a debunking of astrology lasted approximately 35 minutes. The lights were then brought to full brightness, and the students were instructed to fill out the second section of the questionnaire that was passed out to them. Students were given 15 minutes to complete this, after which the responses were collected as students left the planetarium.

Immediately after the session, the PhAsER group met to discuss observations. I took notes of the main points of this discussion that I reviewed later. We noted that there were a few students who talked throughout not only the planetarium show, but also during the filling out of the questionnaire[13]. There was also consensus on the notably high number of topics for a single show, even when considering that the students had already been exposed to the topics in class. We also took note that the dubstep *Relentless Night* video on telescopes was a bit intense. The chairs also made very audible squeaking throughout the show as students would adjust the recline.

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[13] I had intervened in the latter questionnaire period by reminding students we only wanted responses based on their own experiences and not that their neighbors’.

4.2.4 Interview with instructor

Following the planetarium visit, I decided to complement the compiled observations with the instructor's own thoughts on what transpired. An unstructured interview was therefore conducted by me with the course instructor. The interview was generally designed to be unstructured with very broad questions about the instructor's experience. Several of these questions I would come up with on the spot as the interview progressed. The goal was to get the instructor to speak their mind. The final list of interview questions can be found in Appendix section E. With the instructor's consent, I recorded and transcribed the audio for later reference. I also wrote notes throughout the interview. The notes and transcriptions were reviewed later in which different aspects of the observational data were identified. A summary of the interview is produced below that was compiled from the transcribed audio recording and my written notes.

First, I looked to review the aims of the instructor in using the planetarium. The same aims were identified as from the planning session, also with additional aim of introducing students to the planetarium as a "nice place to go".

I then asked why the topic of the celestial sphere is a good one to show in the planetarium. The instructor replied that one needs a curved surface above to show what the sky is doing and that being able to change the viewing location virtually is a powerful tool. She also said that the planetarium "puts you physically in [the celestial sphere] to see what's going on".

This was followed up with asking what makes the planetarium a not-so-suitable environment for the lecture that was given. The lecturer said that she would not want to teach this material for the first time in the planetarium. She added that the students had already seen demonstrations on the black board and on the overhead screen in class with *Stellarium*. The planetarium presents itself as a "third" component of teaching the topics that were covered.

When asked if there were things that could be identified as having gone wrong during the presentation, the instructor pointed out that things do often go wrong. Specifically, in SPV1, when the sky needed to be rotated to put south in front of the students, the instructor wished she explained that this would be similar to the students rotating in their seats to face the other direction. Also, the constellations did not line up exactly as intended when setting the date to Babylonian times, which the instructor says could be solved by having trial runs ahead of the actual show.

I asked if there were any follow-up materials relating to this planetarium visit. The instructor confirmed there was an exercise sheet homework assignment which, although not referring specifically to the planetarium visit, did include topics covered in the visit. It was also mentioned that despite the planetarium visit accompanying the lecture, students still struggle with demonstrating their knowledge of the celestial sphere in the exam.

The final question asked if the instructor could identify things that would indicate that the planetarium visit was effective. She said that students tend to answer things out loud more than in lecture when she poses a question, "which meant that they were following".

4.3 Early Findings

The final analysis of the data is detailed in chapter 6, however I include here early findings that emerged from discussion of our observations and initial iterations of analysis. This is another necessary component of memo-writing in GTM. According to Charmaz (2014), such memos prompt the researcher "to analyze [their] data and codes early in the research process." As this early analysis informed the design process of SPV2, I included it here to close the chapter on SPV1.

Data from SPV1 seemed to characterize the planetarium as a multifaceted environment that straddled entertainment and learning. The following "key findings" emerged:

- There are elements of entertainment in the planetarium experience, but it was not the most important/prevalent aspect for students during the visit.
- There is indication that learning took place, but the data paints a complex picture.
- This learning was particularly complex relative to the intended outcomes of the instructor who made the decision to take the students to the planetarium.
- In such a complex environment, a simple probe of before/after understanding of a topic needs to be carefully considered so the pre/post responses are informative.

The main purpose of SPV1 was to take an initial look at the planetarium's use as a tool for learning. SPV2 would take place a few weeks after this in which I was given the freedom to plan, design, and conduct my own planetarium show for the second visit to the planetarium for the same cohort of students as part of the AST1000 course practical sessions. In order to narrow down the complexity that emerged in SPV1, I moved to constrain the learning space for the student undergoing the experience. I also desired to bring forward initial emerging ideas that could be better captured through revisiting the questions of my instrument. For this I needed to make a few assumptions informed from SPV1.

As the second show would be the second planetarium visit, student expectations should lead to more productive engagement. Additionally, the complexity that was shown in the analysis from the variation in both experience and content recollection indicated that activities may need to be more constrained for an intended purpose to be achieved. In other words, intentions didn't necessarily translate into a learned outcome, but I could investigate how to achieve more directed outcomes. At the same time, a number of observational issues were also noted[14] that certainly were felt to influence the engagement. Amongst these was the environmental framing of the experience. Another issue that presented itself was the lack of usage of features unique to the digital planetarium. Additionally, although we were satisfied with our analysis process, the data gathering itself needed refinement.

The overall refinements suggested by the results from SPV1 are discussed under the following three headings: Intent & Expectations, Environmental Framing, and Digital Planetarium Capabilities.

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[14] Much of the observation analysis took place from emerging categories in line with the GTM approach highlighted in section 3.2. Example analysis of these observations can be found in appendix A. Raw data and memos from the observations are also available on request from the author.

4.3.1 Intent & Expectations

At the planning stage in SPV1, the instructor explicitly listed to the operator what her goals were in bringing the students to the planetarium. Reflection in the post-planetarium interview also reinforced this. These extracted goals, along with the implication that the instructor made the initial choice to schedule the planetarium visit, inspired the explicit claim that an instructor making use of the planetarium does so with an intent, or *Instructional Intent*. Not only does the instructor make the choice to use the planetarium to complement a broader course curriculum alongside specific goals with using the planetarium, but such goals may also include unique characteristics of the planetarium. For example, in SPV1 the dome was a unique feature that was able to display the celestial sphere, in the instructor's words, "from the inside". Such goals, as I witnessed in the planning stage, require an understanding of the capabilities and limitations of the facility. This could require an expert of the facility to be present to consult or that the instructor has access to the software or documentation for exploration.

It was also important to acknowledge possible conflicting goals. For example, showing the planetarium to students as a great place to visit can itself be a potential instructional intent as seen in SPV1. However, if this is pursued alongside educational goals, especially in a limiting scenario as a single visit, this ends up overlapping entertainment elements with educational. The telescope video was noticeably quick-paced and bright with high noise volume and dubstep music to accompany the imagery. There was also clear juxtaposition in the sudden transition of the video to the rest of the presentation of the dark night sky with the instructor's lone voice and the calming background music chosen by the operator. Entertaining elements may distract from the more important learning goals of the instructor.

Additionally, as varied as the goals were, the walk-away experience was seemingly as varied for the students (see section 6.1.1). This showed an effect of having a wide collection of topics in the same planetarium visit leading to a wide collection of outcomes for the students. After the first show, PhAsER group members made the common observation that the amount of material covered in the single presentation was a lot for being presented in the span of a single 35-minute presentation. It is important to mention that filling out the questionnaire did take more time than the instructor had planned, but nevertheless the high variety of content in the single show was noteworthy. This complex experience reflected the amount of content presented which, at least in part, was possibly tied to the variation in intended instructional outcomes. This was especially important to consider because a planetarium visit is a unique commitment. The facility is often off-site, and arrangements must be made for the students to attend. This introduces the temptation for the instructor to maximize the amount of content presented.

Student familiarity of the content presented on the dome also emerged as an important consideration. The material covered in SPV1 was not intended to be new for the students: the topics were already discussed in lecture over the two weeks prior and the instructor herself said in the interview that she would not bring students to the planetarium for the first time seeing this material. She also commented in the planning stage referring to repetition of celestial sphere components at different locations that "it's all a little bit exhaustive, but I think it's good for them to do this… it shouldn't take long".

I therefore considered the focus and scope of planetarium shows and decided to focus the topic for SPV2. I also wanted to consider how students' reflection on their experience specifically related to this initial intention of the instructor. It was agreed in the PhAsER group that choosing a single topic would be appropriately manageable rather than covering multiple topics as was done in the first show. Firstly, a constrained approach would reduce the complexity in planning and development. Secondly, the narrower focus would be more straight-forward in tracking the student experience i.e., multiple topics might introduce unforeseen interferences that could prove difficult to disentangle. I also found it worthwhile to consider simplifying the experience in other ways as well. This included acknowledgement of sensory stimuli by excluding any music or drastic shifts in styles of presentation such as the telescope video in SPV1. I also paid attention to out-of-dome priming by not revealing what the topic of instruction was to be beforehand. I also took note of the museum environment and exhibits outside the dome that may catch the attention of students before the show.

As I would be designing the show myself in SPV2, there was also the influence of my own knowledge of the planetarium and its software/capabilities on meeting that intention to consider. I noted in the SPV1 planning observations how there was a great deal of back-and-forth exchange between the instructor and the operator. This involved trying to align the expectations of the instructor with the constraints of the facility. As I would fulfill the roles of instructor, designer, and operator, it was important for me to keep a detailed record of how this manifested itself in going from pedagogical intention to the realized outcome in the planetarium.

4.3.2 Environmental Framing

In SPV1 I witnessed how the planetarium experience is potentially filled with aspects classifying it as both an entertainment space as well as an educational space. This is even reflected in the PhAsER group's own varied use of terms to denote the experience. We would use the terms "show" and "lecture" interchangeably when discussing our observations of SPV1. It was worth highlighting this dichotomy and how the atmosphere/environment itself of the planetarium impacts students' experience.

The audience in SPV1 was a cohort of university students attending a mandatory practical tutorial session, cementing the visit as educational. This could be linked with the lecturer's intention of complimenting and bolstering material learned in lecture as well as the lecturer's own role in running most of the show along with a course tutor operating the controls. The lecturer is the head of the course whom the students see every day in lecture while the planetarium operator was a course tutor who presides over other course tutorial sessions as well as homework- and exam-marking. This is enough to make the case that the planetarium in this scenario is intended to act as a direct extension of the classroom to complement a curriculum. In other words, the facility is a formal educational environment in its intended introduction to students.

However, several factors contradict this classification. Unlike the classroom, the presenters were not standing in front of students and lecturing, but rather sitting in a box at the back of a theatre and speaking over a sound system. The operator, who normally acts as a course tutor, opened the experience by telling the students where the exits are located. This is something one would not hear in a lecture but would more likely hear at a musical or movie theater. The facility itself also had major differences from the usual learning setting for students. For example, the seats in the planetarium recline and do not contain writing surfaces and the theatre must be completely dark to allow for the highest visual contrast on the dome. Normal forms of notetaking were withheld from the students during the show, making the experience a much more passive one without means of cognitive offloading. This was important considering the amount of material that can be covered in a single session. I also took note of students' interactions with each other and the lecturer. Consistent talking through whispering and side-conversations took place throughout the show. When the lecturer would ask for out-loud answers, there wasn't the ability to raise hands or give other signs indicating the desire to speak, but the lecturer asked for people to "shout out". This indicated a more informal version of a learning environment than a typical lecture.

It was important to consider this contradiction because the context in which the planetarium is introduced to students marks its role as something greater than simply a "tool", as previously noted in the Marketing Discourse findings of section 2.3.1. The facility has a much more powerful influence on the framing (Hammer et al., 2005) of the user experience; the user in this case being either the student as well as the operator and lecturer. Overall, the experience takes on the form of a field trip for students, which is generally accepted as a fun situation from memories of previous school settings. This had to be considered and explored further to investigate any impacts. I also referred back to the study conducted by Ridky (1975) that identified the "mystique effect" of the planetarium where unique elements of the planetarium were found to detract from learning.

To look at the planetarium environment further, I wanted to simplify the experience in SPV2 by limiting acknowledged "contradictory" elements to the experience. This came out of discussion with the rest of the PhAsER group. Music would be excluded, students would be separated into randomized seating to prevent conversations among friends, and an unfamiliar operator (myself) would give the presentation. I also wanted to take special note of the surrounding museum environment upon arrival as well as how students interact with it and each other. There were also certain actions we decided to take such as breaking conversation strains of students by considering structured seating arrangements.

4.3.3 Digital Planetarium Capabilities

As an immersive technology, it was worthwhile to take particular note of results that arose regarding immersive elements of the digital planetarium. Since the IPDD is a facility recently upgraded to include additional capabilities and features, I felt it would be important to deliberately highlight such features going forward.

In the case of SPV1, a recurring immersive trait that presented itself in multiple contexts was the apparent perception of 3-dimensions. This was despite the IPDD not having 3D stereoscopic capability, though the technology does exist in other planetariums. However, I could not rule out the fact that people are capable of other forms of visual depth cues outside of the stereoscopic ability of our eyes. Other obvious visual cues of depth include motion and perspective (Gregory, 2015). This was important to acknowledge, because there was a fair number of statements from the lecturer about the ability of the planetarium to show things in "3D". I took note of this in the planning and interview stages, as well as in the show itself. This was also confirmed with 13 students including the "3D" aspect of the show as the best part of the experience (see section 6.1.1). The student input here could very well have been influenced by the lecturer telling students in lecture that the planetarium would hopefully help them "visualize in 3D a little bit better". The fact that this first planetarium show was, except for the *Relentless Night*s video, primarily limited to visuals of the sky in an Earth-based (*geocentric*) perspective makes this even more interesting. Without stereoscopic capabilities in the Iziko planetarium, I could argue that there could have been other visual cues of depth, giving users a sense of 3D. However, a geocentric experience does not include these. The visuals on the dome are simply a night sky simulation controlled by the operator at the controls. Time and location of view can be changed, but the projected stars on the dome remain more or less the same at a fixed distance from the audience. The instructor explicitly mentioned several times the importance of visualizing the celestial sphere itself in 3-dimensions. This possibly hints at not necessarily a misunderstanding on the visualization capabilities of the digital dome, but simply a usage of the label “3D” to refer to the immersive nature of the planetarium experience. Such emphasis could potentially have influence on an audience’s description of their experience if they are primed.

The context of this theme from a show that was confined to the geocentric capabilities of the digital dome was important to emphasize going forward. The imagery of the bulk of the SPV1 show was reliant on a virtual perspective of the night sky that is attainable for the audience in the real world. Of course, there are enhancements such as overlaying processed images and celestial sphere components, but the anchor of the show’s content was nevertheless the night sky projected overhead. These can be considered legacy aspects that were inherited from the analog predecessors. Although the IPDD does not have stereoscopic 3D capability, it does have *allocentric* perspective capability in that it can show viewpoints and imagery from non-physical entities. This also meant the IPDD can show things that can give alternative cues of 3D. For example, a moving camera having foreground objects move faster than background objects can provide depth cues from motion parallax. The scene of the interior of a cathedral with corners of the room appearing further than the center of the ceiling can also provide depth cues from geometric parallax. These are things that classic, analog planetariums would be incapable of showing.

The IPDD at the time of the study had only possessed digital capabilities for two years. The instructor herself acknowledged being accustomed to the “old system” which would mean the planning and design of her planetarium shows would be influenced by the previously constrained capabilities. It was thus worthwhile to explore how students responded to the capabilities unique to the new digital system. This 3D/immersion theme was an interesting one to explore a bit further along with consciously making use of allocentric capabilities of the digital planetarium. Therefore, in the context of an astronomy course and keeping the content relevant, I decided to produce a show “in space” for SPV2 as opposed to keeping the content confined to the night sky view from Earth.

5 Student Planetarium Visit 2 (SPV2)

In this chapter I produce the documented narrative of SPV2, the follow-up student visit accompanying the introductory astronomy course to the planetarium. I first give an overview of the design process of the produced show, which I was tasked with for this visit. This is followed by the discussion and rationale for the accompanying student questionnaire that was given to the students to probe their resulting experience. For completeness, I also include the observational narrative of the planetarium visit itself in which the show and questionnaire were administered.

From the early results of SPV1 including the accompanying observations, it became clear that optimizing the teaching and learning space involved many factors that ranged from environmental to pedagogical content. It had not initially been obvious that the environment and the physical act of visiting the planetarium would themselves play a crucial role. One might at first be tempted to set these to zero and focus on the specifics of the subject material that form the core of the instructional planning. Following SPV1, I decided that the planetarium could not be generalized as a teaching instrument because there are a number of factors that go into the experience itself. SPV1 highlighted the potential need for further data and more powerful knowledge from cognitive theory to help predict outcomes in a more focused manner. As with museums, planetariums are often not familiar teaching and learning spaces like the classroom. There was therefore a need to be "careful" that what one is measuring from pre- and post-questionnaires might not be an accurate reflection of the targeted situation at hand. When considering the planetarium, particular attention was therefore made to how the environment was impacting the experience through further observations around what sorts of factors presented themselves during planning, design and administration.

As stated before, the lecturer of the AST1000 course schedules two planetarium visits as part of the practical components of the curriculum. Whereas the first visit takes place in week 2 of the course, the second visit accompanies week 11, near the end of the course. For this second planetarium show, I was given permission by the course instructor to plan and conduct the session. This meant a key format shift between the two shows: the second show was under the control of the researchers as opposed to us being mere observers with little to no input/interaction with the various users involved. The instructor was to also be kept out of the design phase without any knowledge prior to the show regarding the content. I met with the PhAsER group over several weeks to discuss how to frame the next study.

From the beginning we identified two main issues we needed to work out prior to administering a planetarium show with an accompanying data probe:

- Design of the show
    - Specific content area / topic for focus
    - Manner in which it was to be presented.
- Design of the student evaluation
    - Methods of conducting research
    - Questionnaire content / format

5.1 Design of Show

Bearing in mind the early findings from SPV1 (see section 4.3), the key steps in designing the show are described below. This was also an opportunity to document how an instructional intention could be met through identifying and exploiting the resources and tools available with a digital dome.

5.1.1 Choice of Topic

For the choice of show topic, I wanted a clear, single focus to keep to the desire of narrowing the show content. I also wanted the show to have a clear relevancy to the course curriculum while also including the decision to incorporate explicit digital planetarium features. The decision would also reflect my desire to have a clear instructional intent. After multiple proposals and debates within the PhAsER group, the following was decided for the show topic and intention:

Give the students a multi-perspective visualization that improves their sense of scale of the various celestial objects and distances that they encounter in introductory astronomy.

For this topic, I wanted to make an informed choice and decided on a planetarium show of astronomical distances using a zoom-style "Powers of Ten" demonstration inspired by the classic *Powers of Ten* documentary video by Eames and Eames (1977). This video demonstrated the various scales of the universe using an exponentially zooming out view of the universe. The distances for SPV2 started at a more "familiar" scale of South Africa and end at the scale of the Milky Way galaxy.

There were a number of considerations that influenced this choice of topic, several of which featured during discussion within the PhAsER group:

1) As another practical component to the AST1000 course, the chosen topic for SPV2 should be one that is directly relevant to the course curriculum. When I consulted the course overview for the UCT introductory astronomy course, it stated that the course "provides an introduction to the subject of Astronomy and our place in the Universe from the small scales of the Earth-Moon-Sun system to the large scales of distant galaxies." (UCT, 2019a) Thus, a distance show would have direct relevance to the course curriculum by demonstration of such scales. Because this second planetarium visit occurred near the end of the course, we were also confident to include a wide range of celestial objects that had been covered in class. This included planets, the Moon, solar system, stars, and the Milky Way galaxy.

2) In the study that Yu et al. (2017) had undertaken at the Denver Planetarium, a live digital dome experience was also modeled on the *Powers of Ten* video. A section of the original video was essentially recreated by a planetarium operator using the *Uniview* planetarium software to demonstrate the scale of the solar system to a cohort of university students. This was followed by a knowledge test related to astronomical distances. The SPV2 show presented an opportunity for me to explore the content of this particular study in the context of my own planetarium study. Although the show in Denver was constructed using *Uniview*, a different planetarium software, we were provided the storyboard by Yu et al. that we could use to adapt the show to the *DigitalSky-Dark Matter* (*DSDM*) software at the IPDD.

3) Sense of distance can be regarded as a concept that can be learned at multiple levels of cognitive development (Piaget, 2013). Since concepts in astronomy are also generally taught from a young age (Plummer, 2009) I could assume that a show that visualizes astronomical distances can be shown to multiple age groups. This meant that similar studies could potentially be carried out and scaled across these different age and educational levels to add new variations and follow-ups to this study using the same or similar shows. This essentially added potential for additional theoretical sampling from future studies. Meanwhile, astronomical size and distance as well as spatial awareness in astronomy are subjects being actively studied within the field of astronomy education research (Eriksson et al., 2014; Lelliott & Rollnick, 2010; Makwela, 2022; Rajpaul et al., 2018).

4) As the SPV1 show designed by the lecturer was confined to the dome's traditional geocentric capability, the second show presented an opportunity of presenting a show expanding the digital planetarium's usage to its allocentric capabilities. Instead of being an Earth-bound simulation of the night sky, SPV2 could make use of *DSDM*'s ability to render allocentric visuals from the perspective of a non-physical entity with the ability to move through space. The view of this "virtual camera" would be displayed on the dome. According to the Yu et al. study, this "type of visual zoom demonstrated in the Powers of Ten film is now commonly used in digital planetarium presentations to explore astrophysical datasets."

5.1.2 Storyboarding

The storyboarding of the show was undertaken to mock-up on paper and in words what the final show would look like. I summarize the process here.

The show used in the Denver study consisted of three segments. In the first, the virtual camera of the software starts at Earth and moves backward with a set of concentric circles spaced by 1 Earth radius presented to show scale. This movement is perpendicular to the Earth-Moon system and the instructor counts off the distance from Earth to the Moon in Earth radius units as the Moon becomes visible. In the second segment, the same is repeated with the Earth-radius grid, but pulling back the camera to show the distance from the Earth to the Sun. When the Sun is reached, a new grid replaces the old one that uses lines spaced by 1 AU and the camera pulls back to depict the scale of the entire solar system with the planetary orbits visible. The third segment is an Earth-Mars-Jupiter fly-by visual where the camera starts at Earth and flies past Mars and then Jupiter without a grid in order to "replicate the experience of walking through a scale model Solar System".

I wanted to include the same "zooming out" theme replicated in Denver from the *Powers of Ten*, but also wanted to include more objects than the solar system since at this stage in the astronomy course the students were being introduced to topics at galactic scales. I therefore decided to add new objects at further scales but keep with the spirit of the Denver show by introducing a similar scale reference system. Specifically, we were inspired by the second segment where the unit of measurement is changed from Earth radii to AU after the distance to the Sun is revealed. I adopted something similar by routinely changing the unit of measure to the distance of the current object-of-focus. For example, I showed the distance to the Voyager I spacecraft in AU, to Proxima Centauri in Voyager distances, and finally to the center of the Milky Way in Proxima Centauri distances.

Similar to the *Powers of Ten* video, every time the 10-units circle was reached, the smaller 9 single units would disappear, and the 10-unit mark would become the new unit. This would continue for the 100's, 1000's, etc. until the milestone object was reached, thus resetting the unit scale. Labels were also included on the 10-unit marks. The rationale behind this was this would prevent the number of measurement units from getting too big while at the same time keeping the units relative to something based back in something more "local" which is the Earth's radius. By calculating out the distances, the required distance circles would look something like what is demonstrated in the portion of the storyboard shown in Figure 5-1.

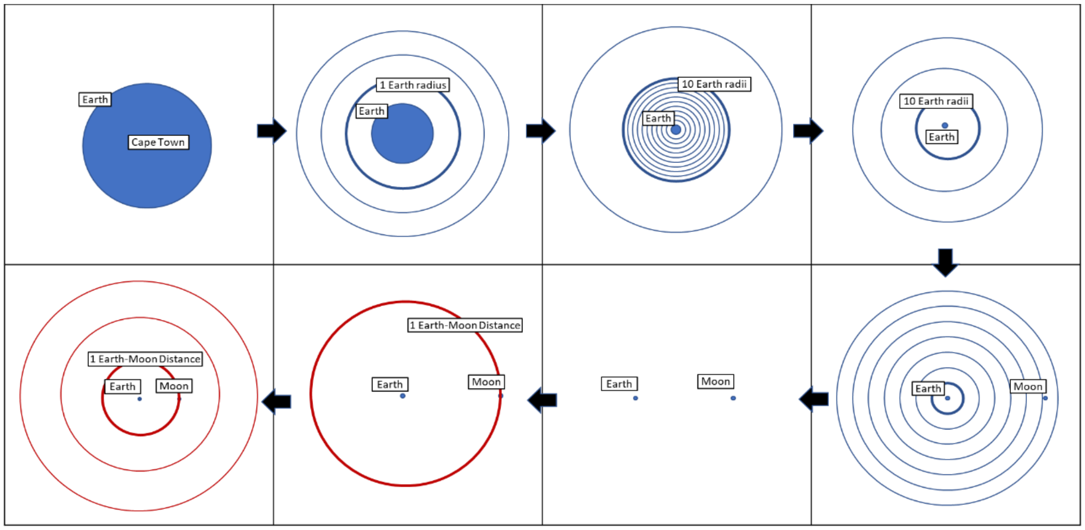

Figure 5-1. Storyboard for segment of segment 1 show component of SPV2. Virtual camera zooms out perpendicular to the path between objects of focus. Concentric circles that exponentially increase their spacing by 10 are based on spacing of previous objects of focus.

The second segment of the SPV2 show was also influenced by the Denver show, specifically the "walking through" segment. This segment also demonstrated distances between the celestial objects mentioned above. However, instead of the camera backing away perpendicular to the path between the objects, the camera backed away along the path itself as a "walk-through", but with its view always pointed towards Cape Town on Earth. Objects then appeared into view from the back of the planetarium to the front as the camera slows down at each milestone. Unlike the first segment with visual concentric circle grids to indicate distance, a digital numerical counter was displayed at the front of the dome that used the same units as the previous segment depending on the objects of focus. This was done because after tinkering with *DigitalSky-Dark Matter (DSDM)*, I found that the grids were difficult to see as the camera moved through them in parallel, defeating the purpose of having them for visual aid. An example of a portion of segment 2 is shown in Figure 5-2. The "coming into view" effect I created was also interesting to include because according to a study from Hillstrom and Yantis (1994), the most powerful orienting response for our visions come from things that "emerge" into the visual field. The idea behind the two similar show segments with different representations (perpendicular vs. parallel camera movement) was to have a predominately 2D demonstration confined to the front of the dome for segment 1 and a more 3D demonstration that included motion parallax for segment 2. This was hoped to result in two different yet comparable experiences for the students.

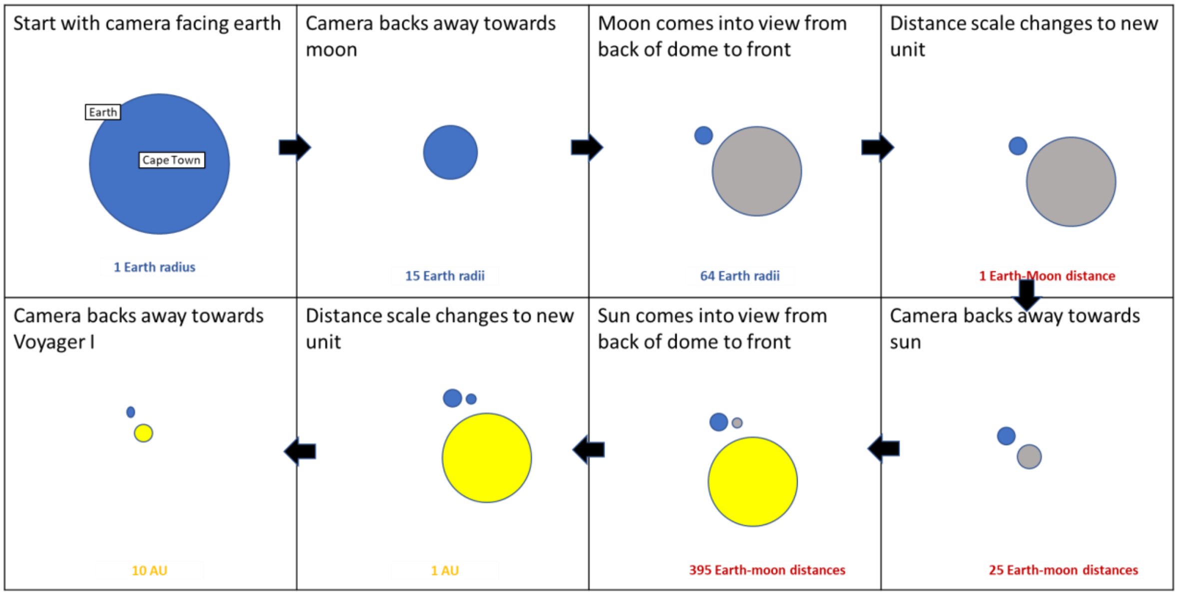

Figure 5-2. Storyboard for segment 2 show component of SPV2. Virtual camera zooms out parallel to the path between objects of focus. A digital distance counter based on spacing of previous objects of focus is displayed at the front of dome.

A few objects were added in for bonus visual cues like the ISS orbit, planetary orbits, Voyager's path trail, Orion constellation's outline, and a volumetric Milky Way representation. These were used because during the camera's movement between some objects, with just a field of stars there would be little to indicate that the camera was moving. The Orion constellation remained stationary in the background from Voyager to Proxima Centauri for example but would be warped as the camera moved between Proxima Centauri and the Galactic center.

The idea between the two different style-of-show segments was that the first relied primarily on "2D imagery" with changing scale being expressed through the shrinking in surface area of the distance grid confined to the front section of the dome. The second show relied on "3D imagery" with the planetarium scene being displayed as moving along a path linearly with objects appearing behind the audience and moving into view from the peripherals towards the front of the dome. To achieve a tighter focus of content and stimuli, no music was to be used in this show. I wanted to focus on the visual aspects of the planetarium and limit other secondary stimuli. There would only be audio in the form of the researcher explaining the visuals on the screen.

Much of the storyboarding was done with instances of consulting with planetarium staff and perusing through "stock" visuals that are included in *DSDM* that gave me an idea of what the software is capable of. The manuals and documentation for the *DSDM* software was difficult to incorporate into this process as it only seemed to be accessible through the software itself[15] which I initially had limited access to. Also, the documentation, although moderately helpful, was not sufficient in fully understanding the capabilities or even how to utilize these capabilities. Therefore, much of the above storyboarding was done simultaneously with the development described in the next section. A script was also written that went through several drafts and iterations. Also, in the spirit of the narrow-focus goal, we kept language simple and direct while also paying attention to the information presented. Interaction with students

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[15] no physical booklets or pdfs

such as the instructor asking for out-loud answers in SPV1 was also avoided. The script can be found in the Appendix section F.

5.1.3 Development

It is important to note that the *DSDM* software at IPDD is only available through licenses with the company Sky-Skan that installed the digital system, which is quite common for these types of proprietary software[16]. It is therefore often not possible to access the software outside the planetarium for show development, practice or gaining familiarity. This situation presented itself in my own use-case as I was required to book sessions on Mondays to use the planetarium for exploratory use. Over time this became unfeasible, so we purchased another license to install the *DSDM* software on the Cobra display in the IDIA/UCT Visualisation Lab on UCT campus. The Cobra is a 66° x 150° curved immersive display developed by Cobra Simulation Limited (2017) that uses a curved mirror to project an image from a *Microsoft Windows* PC (see Figure 5-3). It is worth mentioning that this is not a common use scenario and the Sky-Skan company needed to arrange special remote desktop installation procedures along with virtual meetings to calibrate the software on the Cobra. The lack of accessibility to this sort of proprietary software was an unexpected barrier for the group and I made note that other users will not necessarily have the same accessibility to the software that we were able to obtain.

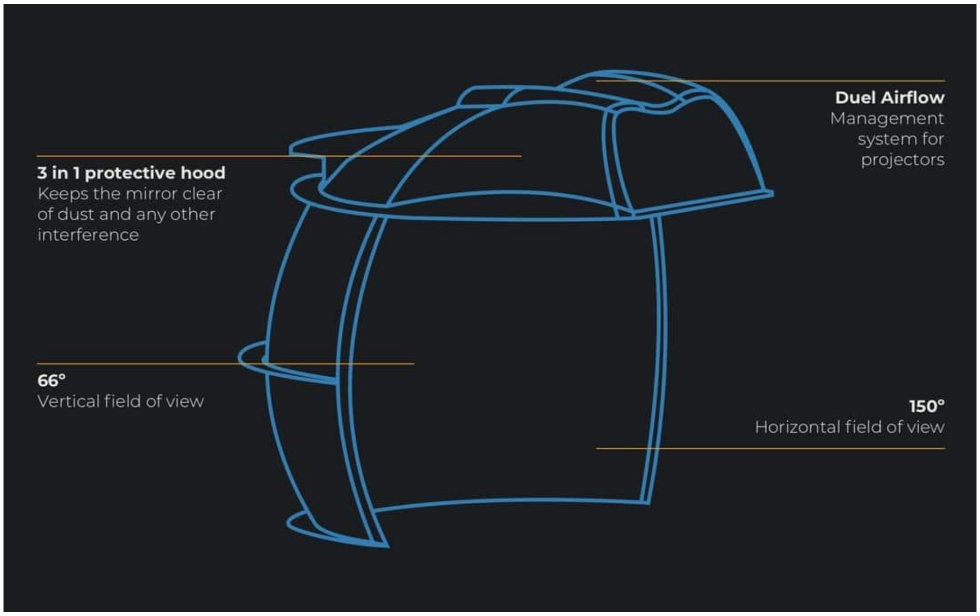

Figure 5-3. Technical diagram of the Cobra display, provided by UCT (2021). The Cobra provided a space to plan and develop the planetarium show for SPV2. This required an expensive DSDM license, however.

Although the curved display of the Cobra display does not provide the same viewing interface as the digital planetarium[17], it did allow more of the “fisheye” image of the entire planetarium dome to be displayed at once in comparison to a standard flat display. This local campus setting was very helpful for the development process. Trial-and-error exploration and experimentation of software features could

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[16] *Uniview*, *Digistar*, etc.

[17] The Cobra display is a curved screen sitting directly in front of the user with extension to the peripherals while the planetarium extends its display all the way to behind its users.

be undertaken in a more flexible setting than the planetarium itself that must be booked in advance and traveled to for use.

An interesting aspect I was advised to watch out for by planetarium staff was the “sweet spot” on the dome (see section 2.2). I was told that 50 degrees from the horizon directly in the middle front of the dome was designated this sweet spot for Iziko. As I designed the show on the Cobra display (see Figure 5-4), I used a grid overlay of the dome that indicated where the various elevations and horizontal angles on the dome were to know where the sweet spot. This also indicated when things would be located near the horizon versus zenith and in front of the audience versus at the visual peripherals and behind.

Figure 5-4. Designing the planetarium show for SPV2 on Cobra display in the IDIA/UCT VisLab.

I initially wanted to set up the show “from scratch” to assess the difficulty of setting up scenes and objects for shows in *DSDM*. However, it was rather tedious, especially considering the lack of sufficient interface documentation or an API on how to make full use of the software’s scripting capabilities. Instead, development primarily involved finding an object or script already included in the software and adapting it to our purposes. This was recommended by planetarium staff members in addition to astronomers already using the dome for dataset visualization. There were a few features of the software that were very useful in designing and conducting the show. Scripts could also be adapted to move the virtual camera in the scene to specified points at specified times that could then be triggered by a button in the user interface (see Figure 5-5). This allowed quick movement between sections of the planned show by the click of a button. A representative of Sky-Skan also confirmed that reverse engineering assets was the most direct way of creating new things and there was no “all in one” manual or API. This was limiting in that consistent “tinkering” with the software became necessary to find what the software was capable of doing before then implementing a scenario from the storyboard. This is almost paradoxical in that a new user needs to tinker with the software to discover its capabilities, but the planetarium does not offer itself as such an accessible space with the necessity of booking the facility or acquiring another expensive license for the software.

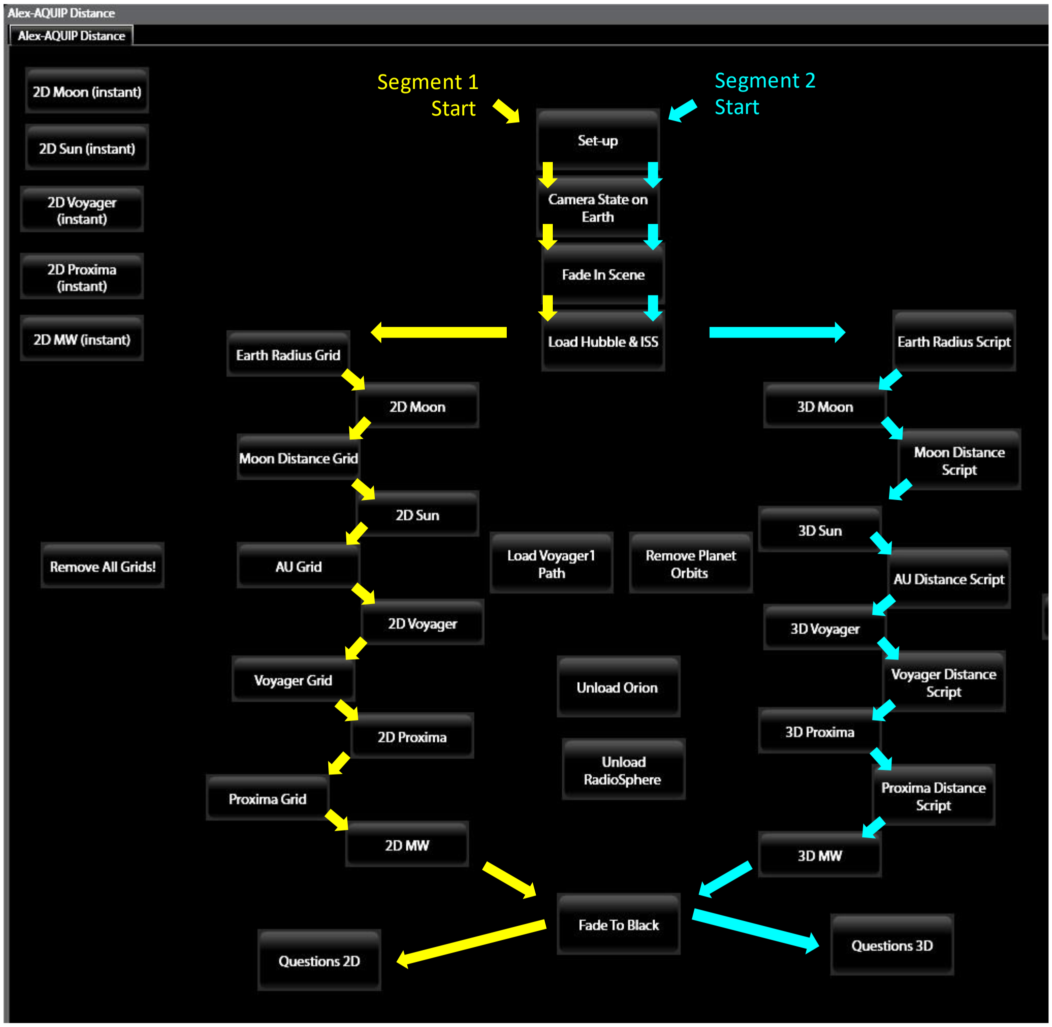

Figure 5-5. DSDM interface (Sky-Skan, 2021) with custom script buttons allowing automated components for show in SPV2. Arrow annotations overlayed show the flow for both segments 1 and 2 that I as the operator would follow by clicking each button to activate the appropriate script.

Instead of having a completely automated show, which did not seem possible as the "show designer" feature of *DSDM* was not useable[18], I put into a custom interface a series of buttons that would move the camera to the next object while keeping it looking back at Earth. To do this, I would "fly" to the object in the scene, point the camera back at Earth, then save the camera location and orientation for the script to target. The activation of the script would then be triggered by the various buttons on the interface. This required of course that I could only use a "paused" universe where the objects were fixed in place throughout the show as opposed to enabling the software to simulate the movement of celestial objects.

One issue I discovered in implementing my storyboard was the tweaking of the camera movement, so it was not too quick in any of its virtual movements, whether rotational or translational. This

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[18] in this version of *DSDM*

demonstrated another advantage of designing the planetarium show in the Cobra wrap-around display in that simulation sickness could be predicted without testing on the full dome. It was with my method of saving camera locations executed by script that made it necessary to pay attention to the camera movement for each object. Moving the camera to farther and farther objects, themselves being very different scales in size[19], made the accelerating and decelerating of the camera very diverse and unpredictable. In *DSDM* I could set the time it takes for the camera to move between two locations as well as the time it takes to accelerate to full speed and decelerate to a stop, although the latter adjustments are confined to linear velocity ramping. This took a surprising amount of time to get "right" in that the show did not feel that it was taking too long but at the same time the camera movements were not so quick as to cause simulation sickness.

There were a few situations encountered in adapting previous content in the software through the "reverse engineering" process. When I wanted to create a grid of concentric circles spaced by the length of Earth's radius, I looked through *DSDM*'s interface to find a similar object of a grid of concentric rings to demonstrate 10 lightyears and made a copy. I then went into the raw data file[20] and scaled the values to coincide with 10 rings separated by Earth radii. I then repeated the process for sets of rings scaled by 10, 100, 1000, etc. depending on the value of the unit to get to the next object. This of course was then repeated for Earth-Moon units, AU, Voyager trips, and Proxima Centauri distances. Similarly, even though a limited help document exists for the use of JavaScript for scripting in the DM documentation, no detailed API could be found. Instead, an example of a "distance" counter script was found and rewritten to include the units relevant for our show.

One of the objects I also wanted the users to encounter was Proxima Centauri, the closest star to the Solar System. However, I could not just "fly" the camera to a model of the star in the rendered Universe as the stars were visible as parts of single multi-particle objects. Instead, I needed to place a premade model of a red dwarf at the correct place 4.6 lightyears away (or 1800 Voyager I trips). It was interesting to run into this issue as I already had experience with *WorldWideTelescope (Rosenfield et al., 2018)*, a free, open-source data visualization software suite that some planetariums make use of. In *WorldWideTelescope* there are individual models of real-world stars located at their correct positions that the camera can be flown to. However, in *DSDM*, a particle object places dots where the stars are correctly located, but the individual dots cannot be focused on for interaction or close viewing.

The development of the show was kept hidden by me from the other PhAsER researchers so a blind trial show could be conducted in the planetarium prior to going live with the students. In this way an experience close to that of the students could be emulated.

5.1.4 Piloting

Before presenting the show to the students, the PhAsER group booked a trial session at the planetarium the week before. The intention was to see how the show looked on the dome and to refine the content. I was to act as planetarium operator and run the show by myself, so I needed an introduction on how to get the planetarium system up and running. The IPDD itself is powered by two separate "clusters" of computers. One is meant for shows given to the public while the other is dedicated to research and experimentation. As I considered our use of the planetarium in the research category, I was advised to

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[19] Sun to Voyager 1 to Proxima Centauri for example

[20] *.lines* file format

use the latter cluster. This was also motivated by the need for me to transfer files of the completed distance show from the Cobra at UCT to the IPDD system. Note that this generally would not be a scenario for "typical" users of the dome as access to the software would have involved extra licenses with the associated costs, so development would often be confined to the dome itself. The "public" cluster is generally active on days where the planetarium is not reserved for researchers, so for our use I was required to switch over to the research cluster on the day of administrating the distance show. This required a training session by planetarium staff to show the proper procedure of plugs and switches to change.

Certain details regarding the experience were of note. It was important for me to experience how the digital planetarium visuals transferred from being designed on the Cobra display with the aid of an angle grid overlay to the actual dome. This worked surprisingly well with only minor adjustments to the position of some objects and the label. We also realized that the show was difficult to watch at certain angles in the planetarium and that the movement of the camera was too fast in some areas, causing simulation sickness. The former was addressed by blocking off the seats at the extreme edges of the theatre[21] so students would be clustered more around the center seats. Note that this was only possible because we knew the planetarium would not be at capacity with fewer than 80 students planning to attend and the theatre having 142 seats for the audience. It was here we also realized that the seating position, as influence to viewing angle, is a far from trivial variable for audience experience. In the context of a learning environment, this could be very important as students may not have the same experience depending on where they are seated in the theatre. Planetariums are more often than not built to hold an audience of multiple viewers located at different angles, distance and even heights to different parts of the dome. This suggested the introduction of a new variable in my study of varying experience based on position in the planetarium. This was a straightforward addition as we already planned on placing questionnaire response sheets under seats for students to use, so we simply added the seat number to the sheets ahead of time. This would provide possible future analysis of experience corresponding to seat location and viewing angle. Unfortunately, the Iziko Planetarium does not have numbered seats in the dome, so we needed to assign these numbers ourselves. We go more into detail considering planetarium seating in Appendix B.

We also took note that IPDD has a "Scale of the Universe" exhibit on the outside of the main left-side planetarium entrance. To avoid priming students with content related to the theme of the show, I decided to use the right-side entrance and assign a PhAsER member to keep students away from the entrance where they would queue in a hallway. One student was permitted to proceed every 5 seconds. Another PhAsER member stood inside the planetarium to assign random rows to students as they entered, for reasons given in the next section.

5.2 Probing Student Engagement

Several changes went into the student evaluation tool from our experience in SPV1. This came from discussion and debate within the PhAsER group. We also made efforts to refine the data collection process itself. As an exploratory project employing GTM, it was important to refine our data collection methods following SPV1. This included identifying and criticizing what did not work as well as recreating

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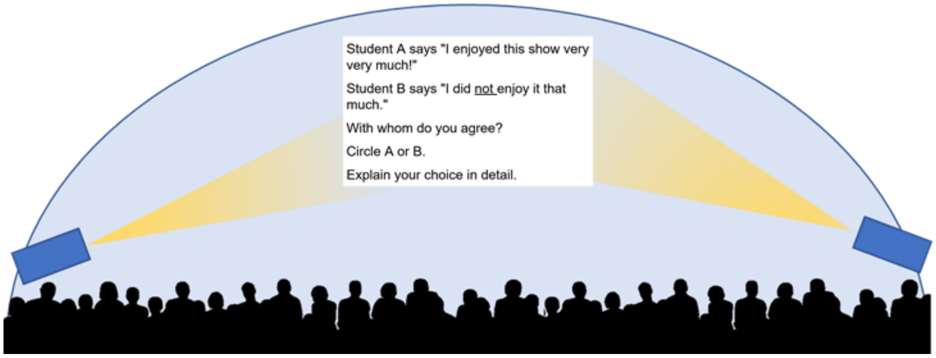
[21] This included the front row, sides 2 seats in and pocket of seats next to the operator box in the back

identified successes. For example, the inclusion of clipboards and pens made the process more convenient for students.

First, for SPV2 I wanted to ask students about their experience directly after each segment of the distance show to maintain a more focused, higher resolution probe. However, this introduced the possibility of a chaotic scenario of passing out and collecting questionnaire responses which could lead to planetarium time being dominated by questionnaire administration. This was something that could potentially detract from the actual planetarium experience of interest while also taking up valuable time. To streamline this process, I thus decided to distribute the two parts of the questionnaire under the seats of the planetarium prior to the show.

Furthermore, to counter the general trend of students talking during the show and questionnaire, it was decided to split up the students into randomized seating. This was suggested to decrease the likelihood that friends and acquaintances sat near each other, thus disrupting possible conversation strains originating from outside the dome and inside during the show. Several proposals were given on how to do this, including asking students to separate by themselves, giving students a paper with a number on it that corresponded to a seat that they could find, or having a PhAsER member stand at the theatre entrance and point to random rows as students entered. We went with the latter option as it was relatively straightforward to implement.

One crucial component of SPV1 related back to the physical “visit” aspect itself. There was limited time, the instructor wanted to make the most of that time, and we, as researchers, did not want our data collection to impose on this. The latter point was critical in that we of course wanted to be invited again by the instructor to partake in research, but also, we did not want to minimize the impact the data collection process has on the very experience we are trying to probe. Passing out and collecting questionnaires from students took a lot of time, for example, which we acknowledged as a problem of the tight seating arrangement and number of students. Also, despite the lights being on during the questionnaire phases, the dome prevented clear direct lighting which caused some students to strain a bit in reading the questions. I therefore wanted a more direct method of getting questionnaires to students as well as a simple collection procedure. I also thought it worthwhile to make the evaluation process “smoother” by minimizing how much it detracts from the planetarium experience under review. For further efficiency, I decided to display the questions for the questionnaire on the dome itself that could then be read out loud by me as the operator (see Figure 5-6). The questionnaire sheet itself could thus be kept very minimalist with no information revealing what the other questions would be (see Figure 5-7) until I would read them on the dome. After giving students a set amount of time for each question, I would then ask students to place their responses underneath the seats. With collection taking place at the end after students leave, the process would be a lot quicker and the evaluation itself would not play as prominent of a role for students’ experience.


Student A says "I enjoyed this show very very much!"

Student B says "I did not enjoy it that much."

With whom do you agree?

Circle A or B.

Explain your choice in detail.

Figure 5-6. Demonstration of student evaluation question projected onto planetarium dome for SPV2.

With the logistics sorted, we also needed to discuss the content of the questionnaire itself. First, we had critiques of our previous probing instrument. Of note was the absence of responses in SPV1 that mapped to the "advertise the planetarium as a nice place to go" intention by the instructor. Although this did not indicate that this intention was not satisfied, it did provide a window into what sort of intentions qualified as learned content to a student in the context of this particular visit to the planetarium. We saw a shortcoming in the instrument in that it did not contain room to probe this "considered opinion of the planetarium" as a learning space. The question probing the experience through asking about the Best Part was too visceral, and the question probing the learning content did not offer the space to answer this. We could have, for example, provided a question along the lines of "Your friend has an afternoon free, would you recommend they visit the planetarium to watch a show."

We also found the focus on a specific conceptual shift did not provide as much insight as we had hoped for. The questions regarding the celestial sphere produced what could be described as rote responses. A more appropriate question would need to be something that students were not too familiar with before coming to the planetarium. However, for SPV2, we chose not to include content specific questions to gauge shifts in understanding. The motivation for this was that Yu et al. (2017)'s study already indicated what sorts of shifts in knowledge occur for students in a similar digital planetarium show on distance.

Furthermore, we decided to focus on the self-described experience of the students more closely. The Likert-scale questions were also scrapped as we wanted to have a closer focus for the students on how they qualitatively assessed their experience rather than a straight quantitative rating. For this I still used an "offloading" forced-choice feedback question that allowed the participant to express their enjoyment or lack of enjoyment, from which an explanation would follow.

This questionnaire would thus focus on how students felt about the show and how students engaged with the educational content inquiries as a guide. I simplified this to a comparison of enjoyment and learning with an assessment of how the two overlap when a student recalls their experience from the show. For enjoyment, I explicitly asked the student to agree with either a student who liked the segment or a student who disliked the segment. For learning, instead of including a content specific question, I expanded this inquiry into what a student would explain to a friend what the show was about as well as agreeing with a student who learned more from the first show or with a student who learned more from the second show as well as an accompanying explanation.

We also hoped we could probe the qualitative explanations to see how students engaged with the learning content and how it compared to the students' explanations of enjoyment. Also, by asking whether there was enjoyment or not, the student would hopefully be able to express in writing more negative aspects of the experience, giving us insight at a finer resolution. From a GTM perspective, this would essentially broaden the "richness" of the data by providing more of a window to the participants' views, feelings, and intentions (Charmaz, 2014). In SPV1 this was limited because the corresponding question was asking simply what the student thought the "best part" was.

Like in SPV1, the questions were to be in the peer-to-peer explanation framing. After each show segment, students were to indicate if they enjoyed the segment with an explanation and explain what the segment was about. An extra question was included at the end for students to indicate which show segment they learned more from with an explanation. This was intended to elicit more show content recollection from the student. Similar to SPV1, the questionnaire was refined through several iterations of "mock" administration, trialing and discussion with the rest of the PhAsER group.

5.2.1 SPV2 Questionnaire

The final questions administered to the students are shown below, alongside an example of a response sheet:

Q1 (featured after both show segments)

Student A says "I enjoyed this show very very much!"

Student B says "I did <u>not</u> enjoy it that much."

With whom do you agree?

Circle A or B.

Explain your choice in detail.

Q2 (featured after both show segments)

Your friend missed the show and asks you what it was about.

Write down what you would tell your friend.

Q3 (featured only after the second show segment)

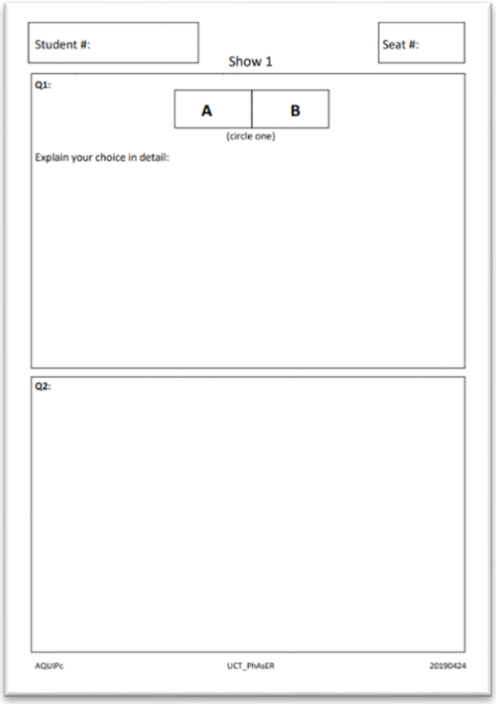
Student A says "I learned more from the first half of the show."

Student B says "I learned more from the second half of the show."

With whom do you agree?

Circle A or B.

Explain your choice in detail.



Student #:

Seat #:

Show 1

Q1:

A | B

(circle one)

Explain your choice in detail:

Q2:

AQUIPc UCT_PhAsER 20190424

Figure 5-7. Final questions for SPV2 are shown alongside the response sheet for questions 1 and 2.

5.2.2 Data Collection & Summary

When the PhAsER group arrived at the planetarium on the day of SPV2, the museum had just ended a public show. We were only allowed a 10-minute window to prep the planetarium before the scheduled start. We spent this time putting the writing boards and pens on seats to mark where students should sit with the numbered questionnaire sets underneath. During this time, I realized that the blueprints to the planetarium did not exactly match the actual layout with some seats missing, so I adapted the seat layout numbering. The final layout is shown in Figure 5-8.

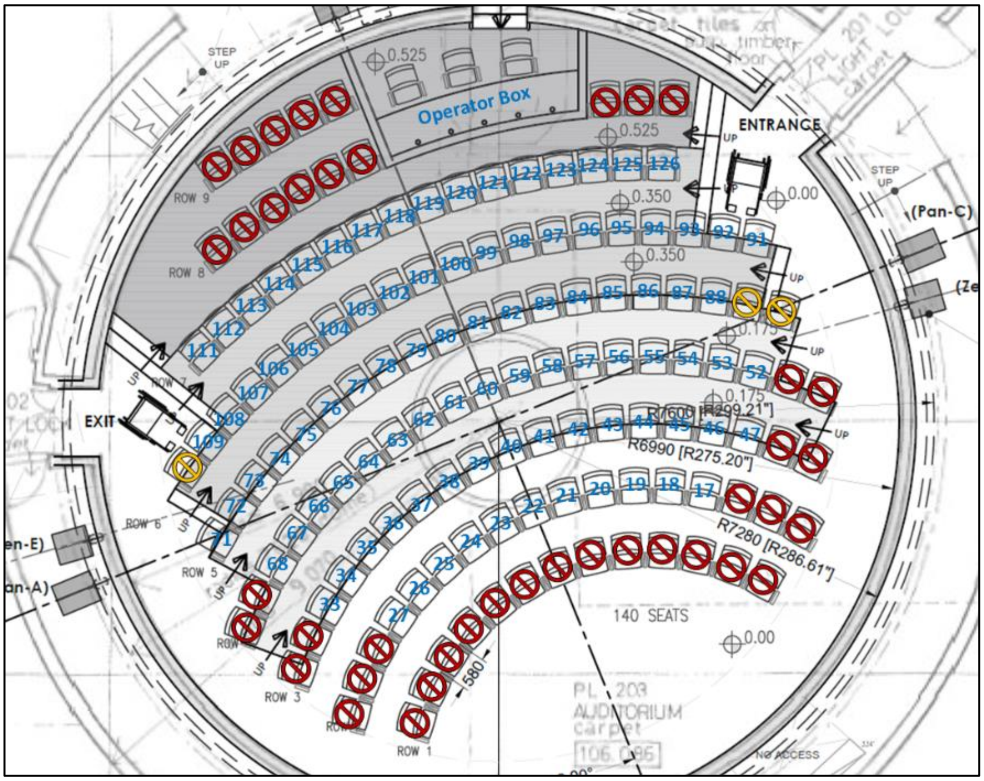


Figure 5-8. Final seating layout with assigned number used in SPV2. Seats blocked out in red were decided to not be used by the group prior to the show. Seats blocked out in yellow were discovered to be missing entirely on the day of the show.

Students entered the museum, queued in the hallway and one student entered the planetarium every five seconds with them being assigned to rows by the designated PhAsER members. The students tended to automatically sit in the middle of the row instead of going all the way to the end. This caused bottlenecks of students finding a seat as they moved past already-seated students, so for efficiency we needed to instruct students to go all the way to the end of marked seats.

The “switching over” of the system from the public to the research cluster went relatively smoothly, however one button was missed that prevented a picture being shown on the dome. I realized this as students were filing into the planetarium. The planetarium controls allowed me to slightly dim on the visuals from the *DSDM* software so I could troubleshoot without the image being fully on the dome.

Once everybody was seated, I, acting as the planetarium operator, dimmed the lights and welcomed everybody to the planetarium and revealed that the audience would be shown a two-segment demonstration on astronomical distances. Specifically, the words used were that “we are going to take a look at the range of relative distances we encounter in astronomy”. Moving from button to button linearly on the custom interface worked well, although it did require constant awareness of timing with the script. No manual adjustments of the position of the camera or objects were necessary. After about 9 minutes the first segment concluded, the lights were brought to full brightness, and I requested the students to retrieve the first questionnaire answer sheet from under their seats. Each question was read aloud while projected on the dome and the students were told to take 90 seconds to record their responses. I noticed students were still writing at the 90 second mark for both questions, so I gave another 30 seconds. After the first questionnaire was completed, students were instructed to place their filled-in response sheets under their seats. The lights were then dimmed, and the second segment started. In summary the first segment of the show was run without an issue.

The second segment went well like the first in terms of executing what was planned through the custom user interface (see Figure 5-5). There was a noticeable sigh expressed by one of the students during the transition between Voyager I and Proxima Centauri. There were no sounds of astonishment or awe from any instances of the rotating or moving camera like there were in the first show. The noise originating from the students was surprisingly minimal. The initial intent of the separation of students at random seating placement was to interrupt conversation strains that may occur between friends and acquaintances, taking attention away not just from the show, but also the questionnaire. This ended up being more successful than anticipated with very little words exchanged between students. In general, the theater was very quiet when I was not saying anything. There were one or two instances of very hushed whispers and occasional coughing. One thing that really stood out compared to the first show was excessive squeaking of the chairs, possibly from fidgeting students.

At the end of the 10-minute second segment, the visuals were dimmed off and the alcove lights were brought back on. The students were instructed to take the second responses sheet out from under their seats. Students were again given about 2 minutes per question and told to put the completed response sheets under their seats. The students were then thanked for coming and told that they could leave. All the students then left with some staying behind to chat with the lecturer about the show. This included one student who was upset with the content. In total, the students were in the planetarium theater for about 31 minutes.

The PhAsER group met at the back of the planetarium after the students departed to exchange observations. We agreed that using the one entrance was probably not necessary given the inconvenience of filling up the theatre efficiently. It was suggested that using both entrances would probably be best as students tended to sit in the middle of the rows automatically. We also agreed that the preparation time of putting down questionnaires and switching the planetarium clusters needed more than 10 minutes. Everybody again reported on the very squeaky chairs.

The show ended up taking about 10 minutes for the first segment, followed by 5 minutes to answer the first set of questionnaire questions. I read the questions out loud from the dome and told the students they would receive 90 seconds to answer the question. About 2 minutes were given as I could see that most of the students were still busy writing after 90 seconds. The second segment took about 9 minutes followed by about 7 minutes to answer the second set of questions. Overall, the experience was about 19 minutes of content and 12 minutes dedicated to the questionnaire.

6 Results

In this chapter I describe the final analysis that went into the questionnaire and observational data results through the GTM. I designate this as "final" analysis because, as was shown in the previous chapters, the GTM process meant that analysis happened consistently throughout the data collections process through constant comparison. The SPV1 and SPV2 chapters thus included instances of local analysis that were included as they guided further data collection. I then summarize the initial relevant findings of the investigation as a whole. Following the GTM, the categories that emerged from the analysis are then theorized into two "localized, pragmatic models" or two "Grounded Theories" to address the initial manageable guiding questions. These models emerged through my own findings from the data but were also supported by consistent and thorough discussion with the PhAsER research group. A proposed synthesis of these models is presented at the end of the chapter which will be further expanded in subsequent chapters through the addition of a theoretical supplement.

6.1 Questionnaire Data

6.1.1 SPV1 Student Responses

Following the first planetarium intervention, the pre- and post-show questionnaire responses were gathered, and respondents were assigned randomized Unique Identification Numbers (UID#). Each UID would have an associated pre- and post-show questionnaire corresponding to a single student, so an individual student's responses could be tracked from pre- to post-show. The sheets were then separated and scanned-in individually to create pdf files of the responses. In order to ensure anonymity, the student university ID numbers were blocked out with a standalone mapping spreadsheet created to connect UID with student ID. Final PDF files were separated by UID, and the pre- and post-show responses were combined (see Figure 6-1).

As the questionnaire/instrument elicited two types of responses: 1) Likert-scale choice and 2) qualitative writing, I divide descriptions of their analysis going forward.

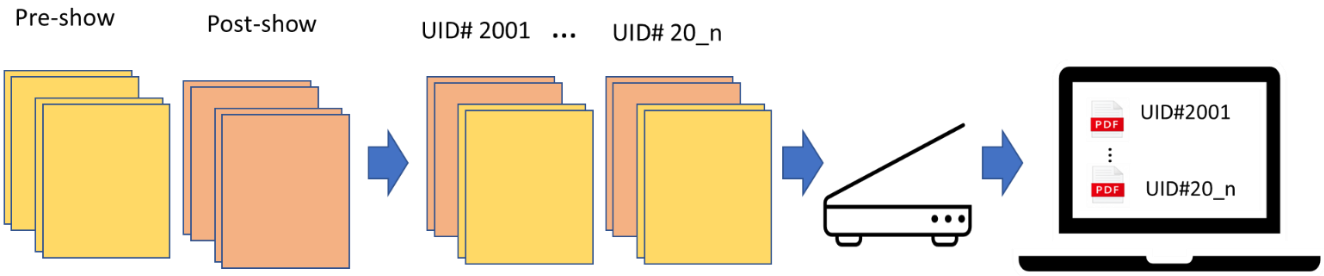
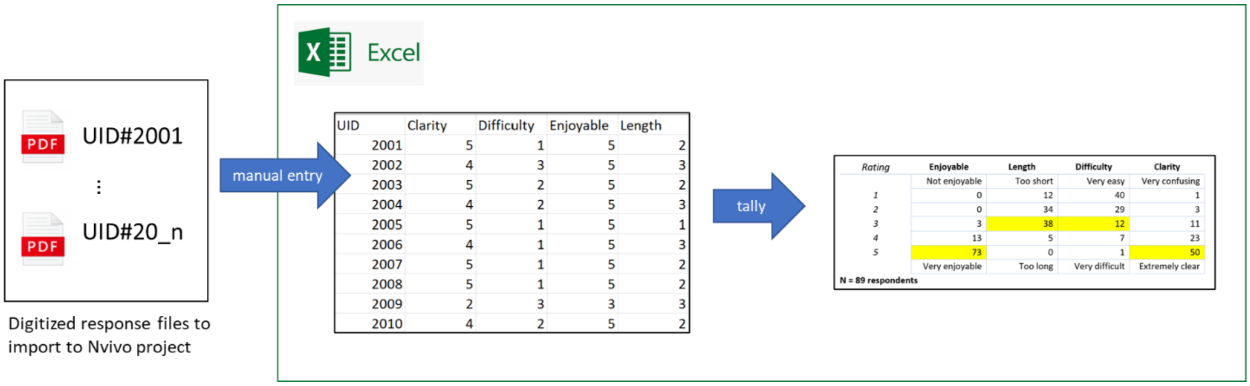


Figure 6-1. Process of digitizing student responses for SPV1. Responses are split and recombined according to individual students. They are then scanned and stored as pdf files according to the UID of each student.

Likert Scale Tallies

The Likert-scale choices were analyzed by manually entering in the responses on a spreadsheet and tallying the totals for each category (see Figure 6-2).



UID	Clarity	Difficulty	Enjoyable	Length
2001	5	1	5	2
2002	4	3	5	3
2003	5	2	5	2
2004	4	2	5	3
2005	5	1	5	1
2006	4	1	5	3
2007	5	1	5	2
2008	5	1	5	2
2009	2	3	3	3
2010	4	2	5	2

Rating	**Enjoyable**	**Length**	**Difficulty**	**Clarity**
	Not enjoyable	Too short	Very easy	Very confusing
1	0	12	40	1
2	0	34	29	3
3	3	38	12	11
4	13	5	7	23
5	73	0	1	50
	Very enjoyable	Too long	Very difficult	Extremely clear

N = 89 respondents

Figure 6-2. Process to tally up Likert-scale student responses.

The results are presented here:

Rating	**Enjoyable**	**Length**	**Difficulty**	**Clarity**
	Not enjoyable	Too short	Very easy	Very confusing
1	0	12	40	1
2	0	34	29	3
3	3	38	12	11
4	13	5	7	23
5	73	0	1	50
	Very enjoyable	Too long	Very difficult	Extremely clear
no response	5	5	5	5

Table 6-1. Likert-scale response tallies (total = 94 students). Green cells indicate "ideal" positive responses for the four questions given the context of the planetarium experience.

I highlighted green the rating levels to denote "ideal" positive responses given the context. For example, "very enjoyable" at rating 5 would be a positive response for the Enjoyable category while a rating 3 midway between "Too short" and "Too long" would be a positive response for the length of the show category. Difficulty is not as straightforward to declare an ideal positive response. However, in the context of the planetarium session being a learning setting used as part of a broader curriculum, we mark the midway point between "Very easy" and "Very difficult" as ideal.

I noted that out of the 89 students who responded[22], 97% found the experience enjoyable. 43% found it at the ideal "not too short & not too long" middle ground with 52% of the respondents at the "Too short" side, but a plurality rated it at the ideal midpoint with 43% of the respondents. 78% of respondents found the difficulty of the show material to be at the easy end with only 13% rating it at the ideal midpoint. With regards to the clarity of the presentation, 82% of respondents rated the show as clear as opposed to confusing.

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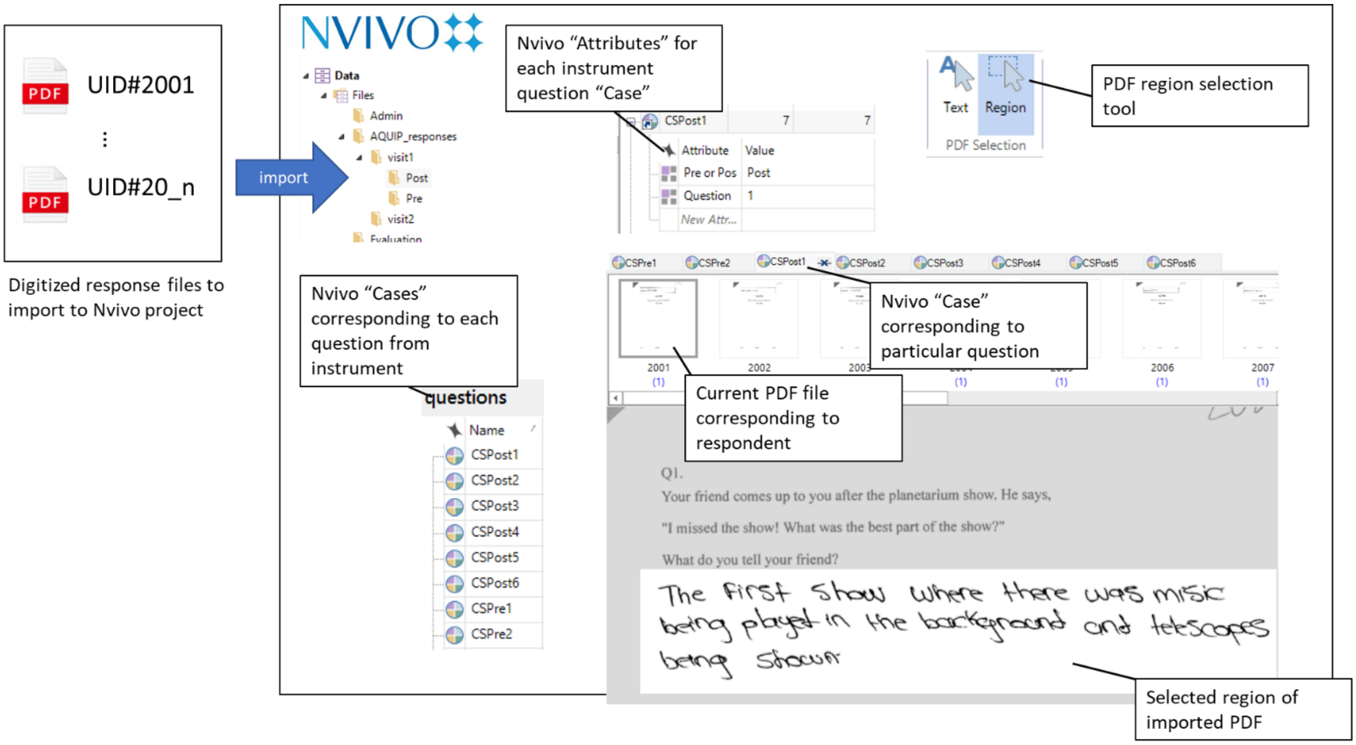
[22] 5 students did not fill out this section of the questionnaire

With the general pattern of responses being clustered around the ideal positive responses, I was confident that the planetarium experience was an engaging one on the part of the student. The length skew suggests the 35-minute experience was a bit too short for students. The “very easy” clustering suggests the material was either not challenging for the students or the show was extremely effective in reducing the difficulty of the material.

Student Written Responses

The written responses to the student questionnaire were analyzed using the constant comparison iterative coding process of GTM. The pdf files of the responses were first loaded into the qualitative data analysis software *NVivo*. Using the software’s PDF Region Selection feature, I could then select and categorize regions by question number (see Figure 6-3). These categories take the form of *NVivo* “Cases” that are a unit of observation that can be categorized with “Attributes”. For example, I made Cases for each question on the questionnaire that contained attributes of whether the question was on the pre- or post- show questionnaire as well as which number question. I also included a respondent Case that had Attributes of UID#. This essentially allowed quick sorting and querying of the data, allowing myself and others to sort through individual questions and make comparisons, such as pre- and post- show responses regarding the celestial sphere.



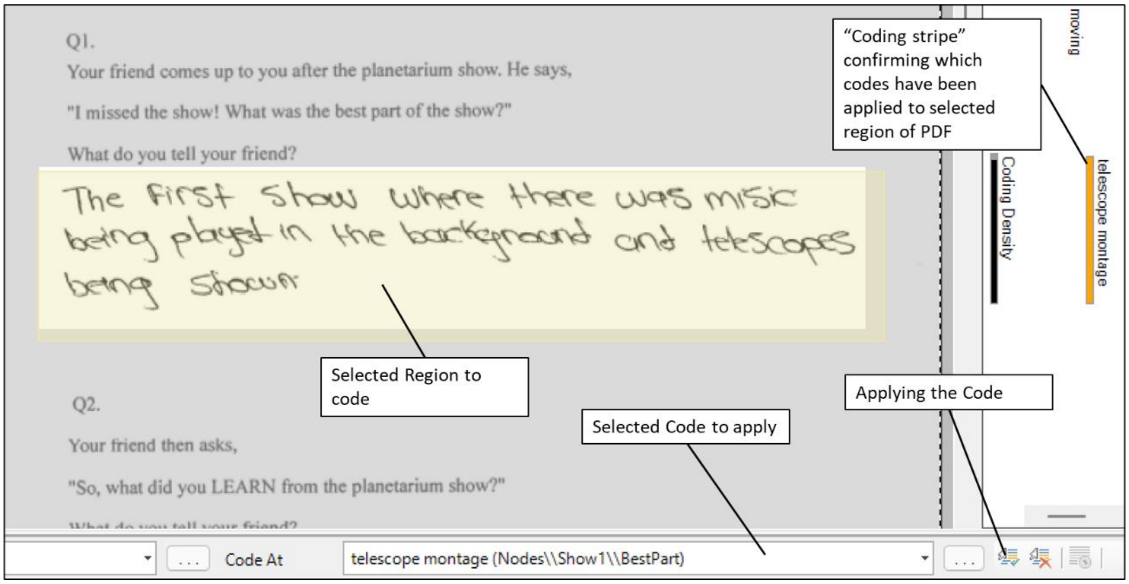
Q1.
Your friend comes up to you after the planetarium show. He says,
"I missed the show! What was the best part of the show?"
What do you tell your friend?

The first show where there was misic being played in the background and telescopes being shown

Figure 6-3. Process for analyzing qualitative student responses in NVivo. PDF files were imported to the software and assigned cases according to the question answered. The responses were selected to be assigned initial open codes according to GTM process.

With the qualitative written responses assigned as Cases based on question and respondent, I could then review and compare them while documenting the emerging categories. This occurred in a similar manner to assigning Cases but rather involved assigning Codes[23]. For example, several respondents would say the best part of the show was seeing how things change or move over time, to which I would assign a common Code. As these ideas emerged while moving through the UID#'s of the individual questions, I could assign the selection a Code in NVivo.

An example is shown in Figure 6-4 with the first respondent UID#2001 from the first post-show question concerning their favorite part. They refer to the opening telescope montage video, which I coded as "telescope montage":



Q1.

Your friend comes up to you after the planetarium show. He says,

"I missed the show! What was the best part of the show?"

What do you tell your friend?

The first show where there was misic being played in the background and telescopes being shown

Q2.

Your friend then asks,

"So, what did you LEARN from the planetarium show?"

"Coding stripe" confirming which codes have been applied to selected region of PDF

Selected Region to code

Applying the Code

Selected Code to apply

Figure 6-4. Example coding scenario in NVivo. The response is selected and either a previous Code is applied or a new one is entered.

In many situations, the response was complex. A respondent therefore could have given a response that was coded in multiple categories by the researcher. For example, in the instant with UID#2001 shown above, the students mention music as their favorite part. I coded that response under "music", but the student also referred to the telescope montage video. This led me to analyze based on the number of identified ideas expressed by students regarding their experience with individual students being able to express multiple ideas.

Best Part

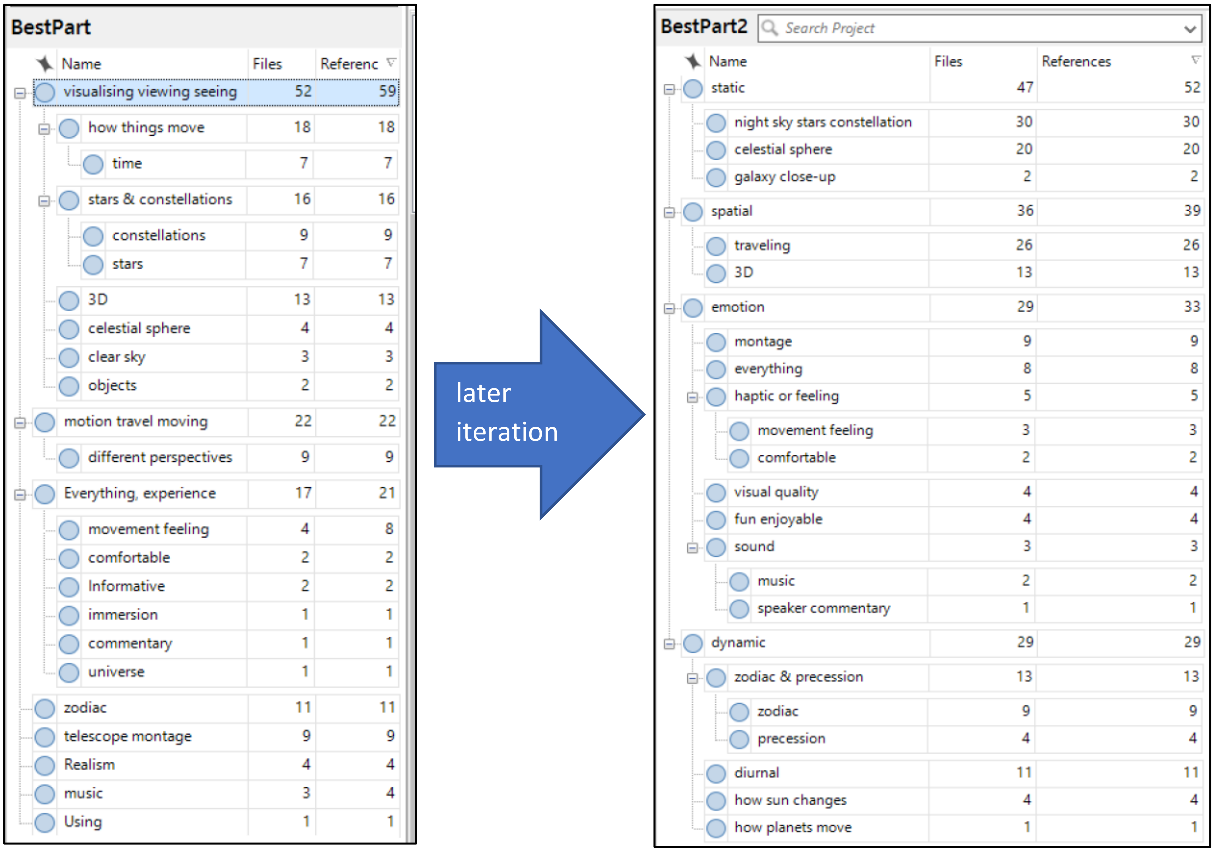
The first question (Q1) in the post-show questionnaire was posed as follows:

> Your friend comes up to you after the planetarium show. He says,
>
> "I missed the show! What was the best part of the show?"
>
> What do you tell your friend?

---

[23] The term "Codes" here (capitalized) are an *NVivo* term, though they do correspond to GTM codes in how I used them.

I show in Figure 6-5 an early collection of codes from an initial pass-through of the responses.



BestPart

Name	Files	Referenc
visualising viewing seeing	52	59
how things move	18	18
time	7	7
stars & constellations	16	16
constellations	9	9
stars	7	7
3D	13	13
celestial sphere	4	4
clear sky	3	3
objects	2	2
motion travel moving	22	22
different perspectives	9	9
Everything, experience	17	21
movement feeling	4	8
comfortable	2	2
Informative	2	2
immersion	1	1
commentary	1	1
universe	1	1
zodiac	11	11
telescope montage	9	9
Realism	4	4
music	3	4
Using	1	1

BestPart2

Name	Files	References
static	47	52
night sky stars constellation	30	30
celestial sphere	20	20
galaxy close-up	2	2
spatial	36	39
traveling	26	26
3D	13	13
emotion	29	33
montage	9	9
everything	8	8
haptic or feeling	5	5
movement feeling	3	3
comfortable	2	2
visual quality	4	4
fun enjoyable	4	4
sound	3	3
music	2	2
speaker commentary	1	1
dynamic	29	29
zodiac & precession	13	13
zodiac	9	9
precession	4	4
diurnal	11	11
how sun changes	4	4
how planets move	1	1

Figure 6-5. Codes combining and rearranging as higher-level categories in later iteration within NVivo. Hierarchical structure reveals added abstraction as commonalities in codes are identified, culminating in "key-ideas" explained below.

The coding process ran through several iterations (see Figure 6-5) by me in which I would take a subset of the data[24] and move through the set multiple times to populate a list of codes before introducing another subset of response sheets. The resulting codes with examples would be reported back to the PhAsER team. Assigned codes would either be agreed upon or disputed within PhAsER. This process would then achieve higher levels as codes were either discarded for not being robust enough or combined through identified similarities. This would also involve splitting and recombining codes. For example, initially there were categories based on students experiencing something moving, but sometimes this was in the sense of "the room felt like it was moving" while for others it was the apparent diurnal motion of the stars. One idea indicated a learning element, the other idea more related to a fun experience. These would be split into two categories with one the experience of a dynamic concept in astronomy and the other a fun haptic feeling of movement. This process was repeated until there was consensus achieved to the level of 90% in the PhAsER group with the high-level key ideas that emerged.

From coding the Best Part, I identified 153 total ideas expressed by the 94 respondents for what they considered the best part of the experience. Among these, I categorized 4 emergent categories as Static Astronomy, Spatial Knowledge, Dynamic Processes and Emotional or Positive Experiences. Static

---

[24] A subset would usually be about 20 response sheets out of the 94.

Astronomy were responses coded as observational astronomical ideas that were not involving dynamic processes, such as identifying constellations, galaxy imagery, and the view of the night sky. Spatial knowledge involved ideas explicitly related to how students understood their position in space, such as the 3D aspects, differing perspectives, and teleporting to different locations. Dynamic Processes involved astronomical ideas of the time-dependent domain, such as how constellations changed, diurnal motion, and the Sun's changing position throughout the year. Emotional was related to a general positive experience that was referring to pleasant elements of the show, such as the music, telescope montage, and the comfort of the seats. Despite this apparent divergence of views, it can be seen from the color-coding in Table 6-2 that more consolidation was possible into high-level key ideas.

Emergent Category	**Example codes**	**Example Responses with (UID#)**	**n**
Static Astronomy	Constellations, galaxies, night sky	(2049): "Seeing the constellations in the night sky" (2014): "We got a clear visualization of the celestial sphere" (2004): "Being able to visualize the night sky without the light pollution in Cape Town"	52
Spatial Knowledge	3D, different perspectives, traveling	(2012): "Visualizing the celestial sphere in 3D" (2078): "Using the dome to visualize the night sky on different parts of the earth" (2075): "Teleporting around earth, great journey"	39
Dynamic Processes	Precession, zodiac, diurnal motion, Sun changing	(2088): "Seeing the shift of star sign constellations over time" (2064): "Seeing the stars rise and set at the equator" (2003): "Visualising the progress of the Sun on the meridian over the course of a year"	29
Emotional (positive experience)	Music, advertisement video, general positivity, comfort	(2061): "Actually when the FFVI OST started playing" (2015): "Watching the video of the telescopes" (2036): "There was not best, it was all amazing"	33
Total Ideas	🟦 = key idea of Learning Elements 🟧 = key idea of Entertaining/Affective Elements		153

Table 6-2. Mid-level emergent categories emerging from student reflection on 'Best Part'. These shared similarities labeled high-level "key ideas". Blue indicates key ideas of Learning Elements and Red are Entertaining/Affective Elements. Example low-level codes and student responses of the mid-level categories are also included along with how many student ideas fell under these categories.

The first of these key ideas was aspects related to learning. These were related to the teaching material of the show. This included seeing how astronomical objects would change (dynamic processes), how things looked from different perspectives on earth (static astronomy), as well as an alternative spatial experience of 3D (spatial knowledge). Most of these emergent categories of learning ideas are at a course-grain level and not fine-grained. The largest of these are related to motion, which is the most difficult thing to achieve in a static textbook for example. These elements mostly refer to affordances of the planetarium that would not be from many other sources in the course (textbooks, PowerPoints, whiteboard, etc.) This we label the Learning Experience. Note that I included 3D in this key idea because it was an explicit instructional intent that students experience 3D in the dome. This is important because in other contexts 3D experience can be considered a gimmick for entertainment such as a 3D movie or dazzling visuals.

The second key idea was the entertaining or affective element of the experience. These were related to the emotional experiences of the students. This included comments on the visual quality, music, the telescope montage video and broad indicators of the experience of the entire show being a positive engagement. This I labeled the Novelty Experience related to emotional, affective thought (Immordino-Yang & Damasio, 2007). From this I combined the ideas and considered their respective portions among the total number of ideas expressed by respondents as shown in Table 6-3.

	Key Idea
78%	Learning Experience
22%	Novelty Experience

Table 6-3. Combined broad key ideas from student reflection on 'Best Part' of SPV1 with percentage of ideas they comprise.

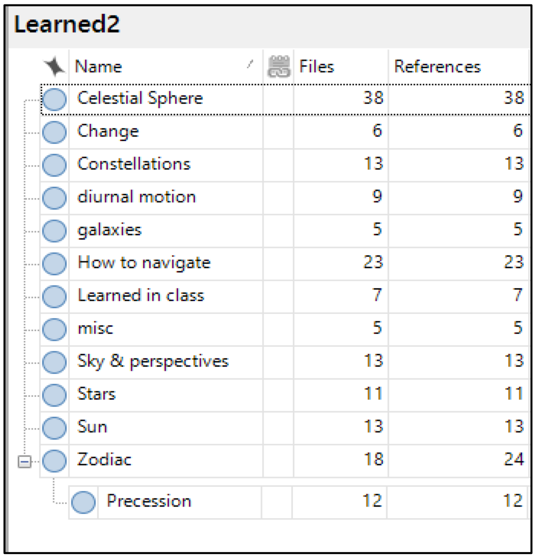
So, when asking students to tell their friends what their favorite part of the experience, the vast majority of ideas expressed skewed towards the learning aspects.

What was Learned

The second question (Q2) posed to students in the post-show questionnaire was:

> Your friend then asks,
>
> "So, what did you LEARN from the planetarium show?"
>
> What do you tell your friend?

I followed a similar approach concerning this question. I would code, discuss and debate with the PhAsER group, and reassess codes iteratively until key ideas emerged to a level of at least 90% consensus with the group. Figure 6-6 shows what emerged in *NVivo* from the question on what the student thought they learned from the experience.



Learned2

Name	Files	References
Celestial Sphere	38	38
Change	6	6
Constellations	13	13
diurnal motion	9	9
galaxies	5	5
How to navigate	23	23
Learned in class	7	7
misc	5	5
Sky & perspectives	13	13
Stars	11	11
Sun	13	13
Zodiac	18	24
Precession	12	12

Figure 6-6. List of early codes in NVivo from student responses reflecting on what was learned.

From this list, through multiple iterations of coding and combining, I end up with the following categories in Table 6-4. I found these ideas to correspond to the instructor's indicated intentions from sections 4.2.1 and 4.2.4, which I color-coded accordingly. These colors along with their percentages of total ideas are indicated in Table 6-5.

Emergent category	n	Example Responses with (UID#)
Celestial Sphere or its components	42	(2003): *"I have a better understanding of the altitude, latitude, & declination associations"* (2024): *"…It helped me visualize the sphere shape"* (2044): *"…How to better understand the celestial sphere"*
How to navigate using sky	22	(2044): *"Some navigational tools…"* (2022): *"How to locate my North celestial and South celestial pole"* (2070): *"How to find South for the Southern Cross and pointers"*
Processes of Precession and its impact on Zodiac signs/horoscope	18	(2080): *"…Knowing that I was not born under Gemini"* (2025): *"I am not a Scorpio. Precession affects it more drastic than I realize."* (2018): *"I learnt that I won't be a Taurus soon :("*
Constellations	13	(2043): "…. *I understand the position of the constellations better"* (2056): *"Where constellations are in the sky…"* (2092): *"I learned about constellations, more about how to imagine the coordinates of the stars and some other objects including constellations"*
Geographic location to sky connection	13	(2015): *"I got to see how the sky over Cape Town looks like"* (2078): *"How to visualize the night sky at different points on the earth"* (2047): *"If you are a dark place without city lights you see our two galaxies"*
How the Sun moves	13	(2001): *"…saw how the Sun actually travels in the sky"* (2038): *"…the Sun is at a lower altitude during winter"*
Diurnal motion	9	(2064): *"I learnt how to visualize the rotation of the earth"* (2079): *"How the stars are experienced as moving across the sky in relation to the celestial sphere"* (2010): *"A proper visualization of the diurnal motion…"*
Things "learned in class"	7	(2042): *"It was mostly revision of what we learned in class"* (2059): *"Didn't learn anything new because we did it in class but it was great to see it"* (2049): *"We went over the things we did in class and showed it on the dome"*
Total ideas	137	

Table 6-4. Mid-level emergent categories emerging from student reflection on what they learned. These shared similarities which corresponded to the initial intent of the instructor, which I labeled broad categories of "instructional Intent". Colors correspond to these Instructional Intents according to Table 6-5. Example responses for these mid-level categories are also included along with the number of ideas that belonged to each category. Note that the 'Things learned in class' category emerged from responses in which students did not give more detail on what the specific things were.

	Broad Category corresponding to Instructional Intent
47%	Visualize the night sky and celestial sphere in “3D””
26%	Show a few of the main constellations and how they indicate cardinal directions
13%	Show precession and debunk astrology
9%	Show how the Sun “moves” at noon over the course of the year
5%	Not corresponding to specific instructional intent

Table 6-5. Combined broad categories from student indication of learning with corresponding percentage of total ideas expressed.

The night sky and celestial sphere stood out as the dominant topic of what students indicated they learned from the show with almost half of ideas corresponding to this. This was followed by about a quarter of ideas associated with constellations and their indication of cardinal directions. Demonstrating precession and how it relates to the zodiac/astrology along with the movement of the Sun were both low at around a tenth each. These all combined to 95% of expressed ideas corresponding to specific instructional intents with useful insights. The remaining 5% of expressed ideas were considered uninformative as they did not yield any additional insights beyond referring to general similarity of what was learned in lectures.

Celestial Sphere Probe

The pre-show question included the following (Q2):

> Your friend then says,
>
> “Can you draw me a quick sketch of the celestial sphere?”
>
> Make a sketch for your friend in the space below.

While the post-show included the following (Q4):

> Your friend then says, “Can you draw me a quick sketch of the celestial sphere?”
>
> Make a sketch for your friend in the space below.

With *NVivo*, similar to the response coding above, I could code regions as responses to specified questions in the questionnaires. With the files themselves being coded to the UID of the students, I could undock the NVivo tabs corresponding to the pre- and post-show drawings of the celestial sphere. These I could then directly compare and easily flip through each student’s responses (see Figure 6-7).

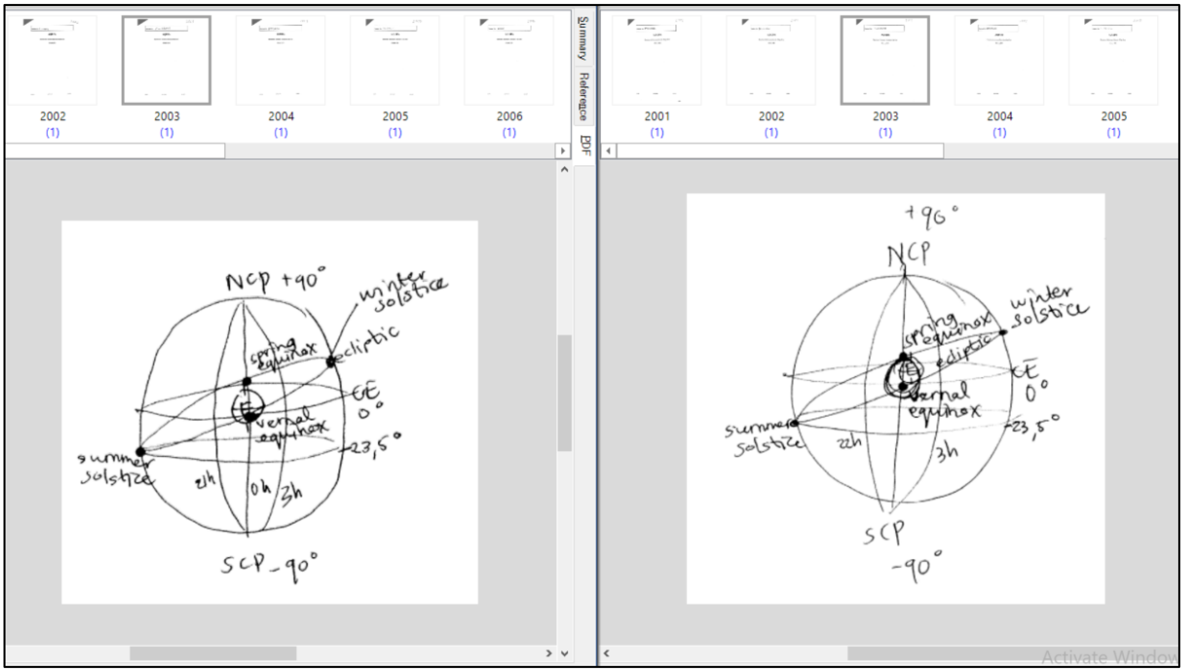


Figure 6-7. Using NVivo to directly compare pre- and post- celestial sphere diagrams drawn by students.

Data collected for this question tended to be relatively uninformative. This section was taught prior to the planetarium in lecture and covered in homework assignments. It was clear that these students were recalling both explanations and diagrams from the formal teaching that had been done on this topic. I decided to apply a rating system of diagram quality. This was done on a 1-4 system based on what was included in the diagram. If a basic sphere was drawn, a 1 was given. A set of 3 items included then determined how much was added to this initial rating. These were 1) the inclusion or indication of earth at the center of the sphere 2) sufficient components of the celestial sphere such as the celestial poles/equator and 3) clear indication that the celestial sphere is a coordinate system. Examples are provided in Table 6-6.

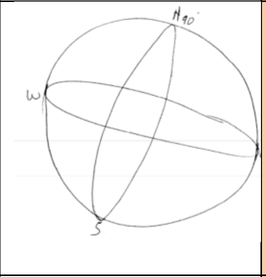
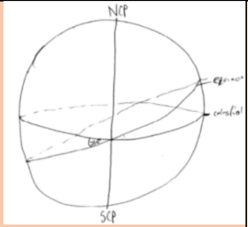
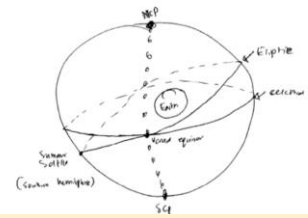
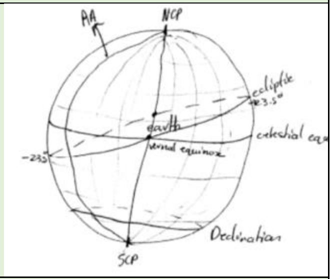
UID#	2016	2048	2011	2023
Example Diagram				
Includes	- Sphere - Incorrect components	- Sphere - Correct components	- Sphere - Correct components - Earth	- Sphere - Correct components - Earth - Clear indication of coordinate system
Rating	1	2	3	4

Table 6-6. Example celestial sphere diagrams for 1-4 rating system. Color corresponds to the levels of the rating. Example diagrams with the associated student UID# are included as well as requirements for receiving that rating.

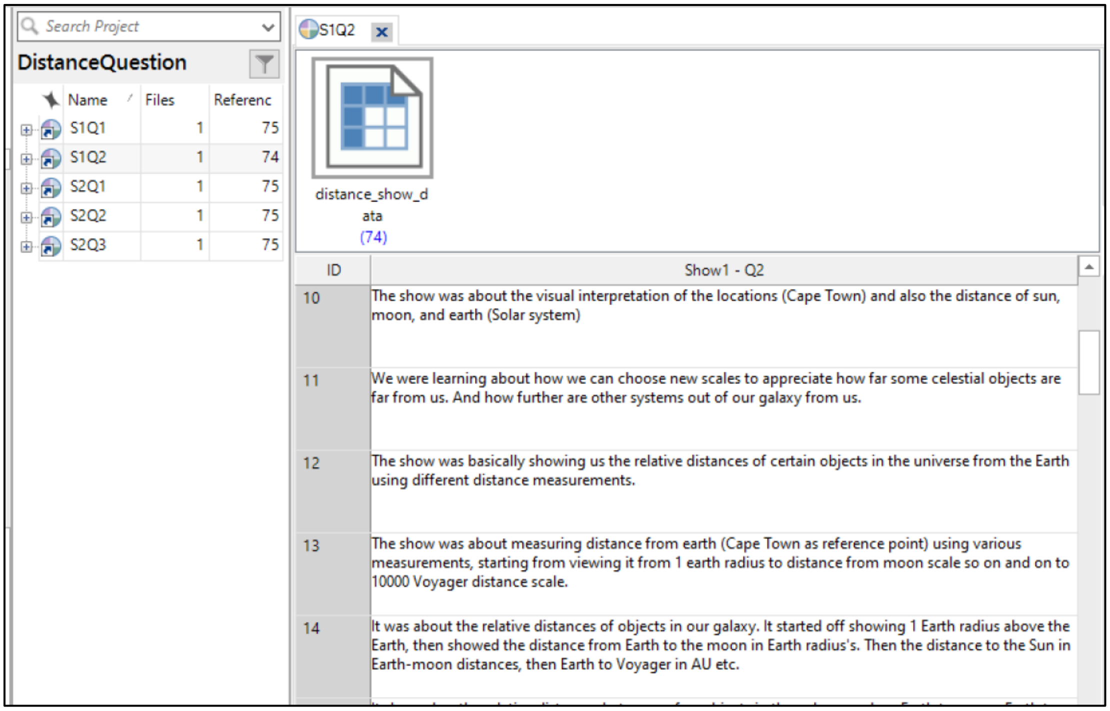
I conducted several pass-throughs of the responses to assign ratings, accompanied by discussion with the PhAsER group when responses were not clear to code. Again, I relied on a minimum of 90% consensus with the group to assign a rating. If this was not reached, we would discuss, debate, and reassess. I ended up with the results in Table 6-7. There were no big shifts from low (1-2 rating) to high (3-4 rating) quality diagrams, which came mostly from inclusion of the celestial sphere coordinates requirement. There is a much more obvious degradation in quality among the high-quality diagrams with no significant change among low quality diagrams. A more thorough analysis of how students understand the celestial sphere, especially in the context of immersive instruction, would be worth looking at more closely in a future study. However, this inquiry was set aside.

Rating	Pre-show quality n (%)	Post-show quality n (%)	Combined quality	Pre-show combined quality	Post-show combined quality
4	48 (51%)	31 (33%)	High	89%	86%
3	36 (38%)	50 (53%)			
2	10 (11%)	12 (13%)	Low	11%	14%
1	0 (0%)	1 (1%)			

Table 6-7. Results of student celestial sphere diagram quality ratings between pre- and post-show. (total = 94 students). These ratings were combined into low quality (1 & 2) and high quality (3 & 4).

6.1.2 SPV2 Student Responses

For the data reduction process from student responses of SPV2, I again made use of *NVivo* but also incorporated scripting in Python. Just like in the previous section, I digitized the responses from the questionnaire and grouped them by an anonymous number to identify the individual. In this case, since I already had seat number, that functioned the same as the UID# from SPV1. I blocked out the university student ID numbers of the students and produced a mapping file of seat number to student number that was filed away. After importing the PDF files into *NVivo*, I created Case classifications for SPV2 that corresponded to question and respondent. The respondent Cases included attributes of seat number as well as how they answered the “A or B” forced-choice response questions indicating whether they enjoyed a segment, and which segment they preferred in the Case of the final question. Also similar to SPV1, I went through the written responses and coded them based on similar themes or categories. This time however I tried a more involved method of manually typing the responses directly into a spreadsheet (see Figure 6-8).

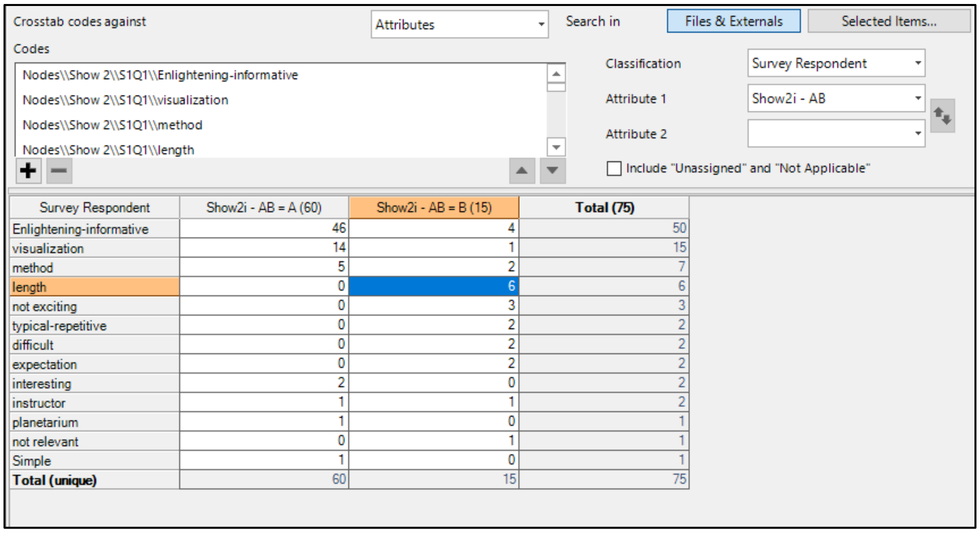


Name	Files	Referenc
S1Q1	1	75
S1Q2	1	74
S2Q1	1	75
S2Q2	1	75
S2Q3	1	75

ID	Show1 - Q2
10	The show was about the visual interpretation of the locations (Cape Town) and also the distance of sun, moon, and earth (Solar system)
11	We were learning about how we can choose new scales to appreciate how far some celestial objects are far from us. And how further are other systems out of our galaxy from us.
12	The show was basically showing us the relative distances of certain objects in the universe from the Earth using different distance measurements.
13	The show was about measuring distance from earth (Cape Town as reference point) using various measurements, starting from viewing it from 1 earth radius to distance from moon scale so on and on to 10000 Voyager distance scale.
14	It was about the relative distances of objects in our galaxy. It started off showing 1 Earth radius above the Earth, then showed the distance from Earth to the moon in Earth radius's. Then the distance to the Sun in Earth-moon distances, then Earth to Voyager in AU etc.

Figure 6-8. Digitized student responses being analyzed in NVivo.

Coding the responses included, as with SPV1, discussion and iterative reassessment of coding within the PhAsER group. When disagreements came up, debate would follow until a minimum of 90% consensus was achieved. I could also use the Cross-tabulate tool of NVivo to produce intersection matrices to visualize where responses overlapped (see Figure 6-9). For example, a series of responses could be coded under “Method used in the presentation” which the cross-tabulate could then indicate how many and which responses were coded here that enjoyed the show and those that did not enjoy the show. The result was a series of matrices that tallied the total number of respondents that are coded under a certain category for those who enjoyed a segment of the show and for those who didn’t. This was in addition to the total tally number of respondents for that Code as well as the totals for those who enjoyed a segment and those who did not (or from which segment they learned more from). Further analysis was done with Python on cross-referencing response Codes with seating position in the planetarium. This was set aside, but early results can be found in Appendix section B.



Crosstab codes against: Attributes

Search in: Files & Externals

Codes

Nodes\\Show 2\\S1Q1\\Enlightening-informative
Nodes\\Show 2\\S1Q1\\visualization
Nodes\\Show 2\\S1Q1\\method
Nodes\\Show 2\\S1Q1\\length

Classification: Survey Respondent

Attribute 1: Show2i - AB

Attribute 2:

☐ Include "Unassigned" and "Not Applicable"

Survey Respondent	Show2i - AB = A (60)	Show2i - AB = B (15)	Total (75)
Enlightening-informative	46	4	50
visualization	14	1	15
method	5	2	7
length	0	6	6
not exciting	0	3	3
typical-repetitive	0	2	2
difficult	0	2	2
expectation	0	2	2
interesting	2	0	2
instructor	1	1	2
planetarium	1	0	1
not relevant	0	1	1
Simple	1	0	1
Total (unique)	60	15	75

Figure 6-9. Using Cross-tabulate tool of NVivo to find where responses overlap depending on if student marked that they enjoyed or did not enjoy part of show.

Enjoyment of Segments

I first simply tallied the responses from whether students indicated they enjoyed segments 1 and 2. The results are shown in Table 6-8 & Table 6-9.

	Enjoyed Segment 1	**Did not Enjoy Segment 1**	**Total**
Respondents	60	15	75
Percentage	80%	20%	

Table 6-8. Results of student indication of whether they enjoyed segment 1. Color corresponds to enjoyment.

	Enjoyed Segment 2	**Did not Enjoy Segment 2**	**Total**
Respondents	46	29	75
Percentage	61%	39%	

Table 6-9. Results of student indication of whether they enjoyed segment 2. Color corresponds to enjoyment.

80% of the students claimed to have enjoyed the first segment while 20% indicated that they had not enjoyed it. Meanwhile there was a decrease in indicated enjoyment for segment 2 where 61% claimed to have enjoyed segment 2 and 39% did not enjoy it. However, what was more important were the reasons for their tick-a-box responses, which were identified using the coding and categorizing approach described above.

The tables below (Table 6-10 & Table 6-11) summarize the ideas that were stated by the students for explaining their enjoyment of segment 1. They are arranged as follows. The first table summarizes and categorizes the positive comments while the second table summarizes what we interpreted as negative. It should be noted again that more than one idea can be associated with each student. It should also be noted that the assignment of positive and negative categories was done independently of whether the student indicated whether they enjoyed/did not enjoy the segment by circling A or B respectively. Thus, in some cases, a student may have indicated that they enjoyed the show but included reasons why the show was not enjoyable in their explanation. The tick-a-box was occasionally used as a guide, however, if the response itself did not give a clear indication of positive or negative enjoyment. For example, if the student responded, “*The show was very short*”, this was ambiguous until we included that knowledge that the student also circled B, indicating that they did not enjoy the show, so the show being short could be associated as a negative enjoyment aspect. Similar to the analysis in SPV1, our iterative coding and discussion protocol continued until key ideas emerged, which are color-coded in the table.

Emergent Positive Category	**n**	**Example Responses (seat #)**
Show gave a sense/perspective of scale	40	*(78) It showed us just how big the universe is compared to us. It showed me that there's still a lot to learn about it.* *(34) I was able to visualize how far other objects are away from the Earth.* *(17) This showed me how vast just our galaxy is. There is so much out there that we only live in this tiny Earth that is even negligible when it comes to the milky way. Fascinating man!!*
Learned about distances or measurements	22	*(98) I enjoyed it too. It's interesting to learn about the distances of stars and the centre of our galaxy on a relative scale.* *(127) I learn how scientist measured the distances away from our planet.* *(33) It showed me that units of measurement are flexible and any fixed object away from a reference point can be used as a unit of measurement…*
Reference to method or concept used to demonstrate scale/distance	14	*(79) The scaling of distance using various distances helped.* *(24) I enjoyed the visual representation of the distances between points in space…* *(21) Nice way of quantifying massive distances in the Milky Way into understandable units.*
Graphics or visuals were nice	7	*(56) The graphics were cool and the visualizations peeked my interest…* *(76) …it was more of an informative session with pleasing graphics and a lot of eye candy* *(116) …It was beautifully illustrated.*
Show was fascinating or interesting	6	*(105) It was interesting* *(63) I got to see something interesting….* *(17) …Fascinating man!!*
Show was informative or educational	4	*(59) It was informative…* *(63) … I learned new things…* *(41) …It was also educational.*
Relevancy to course/curriculum	2	*(61) I was looking how far the things we have discussed in lectures and with my mates.* *(85) As much as we talk about these things in lectures, it's nice to get a sense of how it really looks…*
Contribution of the planetarium environment	1	*(41) It isn't everyday that you get to go to the planetarium. So anything they show us here is good…*
Show was simple	1	*(102) …Not complicated or too theoretical*
Presenter was effective	1	*(112) Because the instructor explains everything very well…*
Total positive ideas	98	

🟦 = key idea related to learning
🟩 = key idea of general positive experience

Table 6-10. Mid-level emergent categories of elements that contributed to student enjoyment of SPV2 Segment 1. These categories shared similarities labeled as high-level key ideas. Blue indicates emergent categories as key ideas related to learning. Green indicates emergent categories containing key ideas of a general positive experience (see Table 6-14). Example student responses of the mid-level categories are also included along with how many student ideas fell under these categories.

Emergent Negative Category	n	Example Responses (seat #)
Segment was too short	5	*(27) The show was very short.* *(38) The show was brief…* *(125) The show was too short…*
Not entertaining or exciting	5	*(38) …As it sits, I was not particularly entertained.* *(76) as far as entertaining, it was more of an informative session* *(86) It was informative but not particularly interesting or exciting. It was a nice way to show relative distances, but it wasn't an enjoyable show.*
Teaching method or concept used	3	*(37) …scaling continuously doesn't necessarily help in giving a sense of distance.* *(53) I don't like how the distance was measured from objects relative to one another rather than using fundamental measurements such as km or light years* *(94) …It would also have been better if they showed all the objects in sort of a linear scale since it was somehow harder to relate.*
Could not keep up with content	2	*(94) I was not quick to catch the scale. If it was shown slowly I would have appreciated it very much…* *(118) I tried to keep up…*
Content was tedious or repetitive	2	*(37) I have seen multiple shows of this nature. Yes it is amazing how small the Earth and therefore humanity is in comparison to the universe, but when it is repeated multiple times it gets tedious.* *(95) We've been shown these details before….*
Material was difficult or complicated	2	*(54) …difficult to conceive even the shortest distance given* *(118) …I didn't understand the distance that we were talking about. At same is the Earth and the Sun distances then I got lost.*
Expected something else	2	*(122) …I thought I was going to learn more about visual astronomy.* *(125) …there are more things would have liked to see.*
Student did not learn	1	*(38) …did not vastly expand my knowledge about the Universe….*
Not relevant to course or curriculum	1	*(56) …I'm wondering why we were shown this because I don't see how it furthers our course content.*
Comments on presenter	1	*(95) … the presenter seemed bored explaining the details…*
Total negative Ideas	24	🟪 = key idea of ineffective educational experience 🟨 = key idea of bland experience

Table 6-11. Mid-level emergent categories of elements that detracted from student enjoyment of SPV2 Segment 1. These categories shared similarities labeled as high-level key ideas. Orange indicates emergent categories associated with the key idea of a bland experience. Pink indicates emergent categories associated with the key idea of an ineffective educational experience (see Table 6-15). Example student responses of the mid-level categories are also included along with how many student ideas fell under these categories.

As can be seen in the above tables, the total number of ideas is 122 from 75 students. Almost 80% (98/122) of the ideas expressed were positive while 20% (24/122) of the ideas expressed were interpreted as negative (or non-positive).

The positive sentiments are related to a wide range of different ideas. The vast majority of positive comments (83/98), comprising 85%, were specific issues related to learning (content, concept, relevancy, etc.). These were highlighted blue in the table. The remaining (15/98) comprising 15% of these comments were general positive comments about the experience including pleasing visual graphics, the show being interesting, and the pleasant planetarium environment. These were highlighted green.

Among the negative experience ideas, two categories emerged. The first category can be labelled as a bland experience where students came to the planetarium with a certain set of expectations but felt disappointed or not particularly inspired by the segment. About 58% of negative ideas (14/24) were associated with this and were highlighted in orange in the table. The second category relates to the content of the educational experience. Here we have two subcategories. The first relates to the actual educational content including again the method of how the show teaches distance or the complexity or irrelevancy of the instructional material covered. The second subcategory relates to the delivery of this content in terms of pacing and the instructor. This category included 42% of negative ideas (10/24) and these were highlighted pink in the table.

The process was repeated for question 1 of segment 2 in which students explained why they indicated they either enjoyed or did not enjoy segment 2. Student responses were coded into categories of ideas, separated based on being positive or negative enjoyment aspects. Again, the coding was done independently of whether students indicated they enjoyed or did not enjoy the show with the A/B answer, but this was used as a guide if the explanation was ambiguous.

The following two tables summarize these emergent ideas. Table 6-12 is for positive ideas related to enjoyment and Table 6-13 is for negative ideas related to enjoyment:

Emergent Positive Category	n	Example Responses (seat #)
Gave a sense/perspective of scale	18	*(20) It put the distance of certain objects in space into perspective* *(24) … It perfectly captured the vastness of space- which is horrifyingly big….* *(116) The clear display of objects in the solar system helped to build a more clear image of the size and relative distances between Earth and other objects.*
Reference to method or concept of demonstrating distance	14	*(21) Nice way of quantifying massive distances in and out of the Milky Way into understandable units.* *(38) … displaying a counter helped really drive home…* *(92) I really liked how this show showed the objects in more detail and close up. Also, giving the number with the reference (e.g. 12000 Proxima Centauries from CT) helped me comprehend distances better.*
Pleasing graphics and visuals	12	*(41) It was visually stunning…* *(59) It gave a good graphical illustration of the distances between various celestial objects and Earth.* *(73) The visuals were just so amazing on this one*
Student learned about Distances	11	*(91) The show assisted me in visualizing the distance of Moon, Sun, Voyager and Proxima Centauri above Cape Town* *(105) It was a good show that gave information on the distances.* *(118) It was very interesting you could see difference distance of the Moon, Sun, galaxy above Cape Town radii*
Got a more personal or up-close view	8	*(60) …allowed you to perceive it on a more personal level.* *(67) The visual detail of the show made it enjoyable…* *(114) It was nice to be able to see the objects in the galaxy as the view gets further and further showing the relative distances*
Content was interesting or fun	7	*(79) The show was interesting and fun to watch.* *(101) It was very interesting to see these things about the universe.* *(107) I enjoyed the show because seeing how high different objects are above us and how the Earth got smaller till it disappeared was exciting and enjoyable.*
Presenter was effective	2	*(112) The instructor explains everything about distance above Cape Town (How far you from) Proxima Centauri* *(81) …Well explained to the fullest precision*
Mention of moving feeling	1	*(72) Very realistic, felt as if moving through space…*
Total Ideas	73	

🟦 = key idea related to learning

🟩 = key idea of general positive experience

Table 6-12. Mid-level emergent categories of elements that contributed to student enjoyment of SPV2 Segment 2. These categories shared similarities labeled as high-level key ideas. Blue indicates emergent categories associated with the key idea related to learning. Green indicates emergent categories containing key ideas of a general positive experience (see Table 6-14). Example student responses of the mid-level categories are also included along with how many student ideas fell under these categories.

Emergent Negative Category	n	Example Responses (seat #)
Content was repetitive or tedious	20	*(25) It was sort of a repetition of show 1.* *(47) It was redundant* *(65) It more or less displayed the same information as in show 1, but with the addition of images of the objects.*
Did not like the teaching method or concept used	7	*(93) …the only difference feeling like the distances being depicted with exact numbers instead of graphically.* *(94) As we move from one celestial body to another I was losing reference point. E.g. As we move from Moon to Sun, I was no longer seeing the Sun except imagining how far it should look.* *(115) Compared to the first show, this one was not as nice because it was more like counting the units instead moving outward and counting as you go.*
Segment was too short	4	*(67) The zoom out could be sped up.* *(76) This time around it became a bit played out, took too much time to move from one point to another and it made me a bit anxious.* *(83) …the actual timelapse could have been faster. It took a long time.*
Material was difficult or complicated	3	*(33) Too many information was being provided on a short period of time and there was not much time to absorb it, and get to appreciate it.* *(80) In comparison to the first show, it was slightly more difficult to get a true sense of scale* *(85) …it lacked detail that made the first more understandable as it was easy to lose track of objects and distance as a whole (even though it's shown in numbers)…*
Content was boring	2	*(98) Watching the value of the distance changing is like watching a loading screen* *(122) I fell asleep during the show…*
Student could not keep up with pace	1	*(33) Too many information was being provided on a short period of time and there was not much time to absorb it, and get to appreciate it.*
Content not relevant to course	1	*(56) … I still don't see how this contributed to the course other than reinforcing the fact that everything is extremely far apart in space.*
Student did not learn	1	*(95) …This was a complete waste of our time did not learn anything new.*
Presenter was not effective	1	*(122) … I recommend that for the next session [the course instructor] should take over*
Total Ideas	40	🟪 = key idea of ineffective educational experience 🟨 = key idea of bland experience

Table 6-13. Mid-level emergent categories of elements that detracted from student enjoyment of SPV2 Segment 2. These categories shared similarities labeled as high-level key ideas. Orange indicates emergent categories associated with the key idea of a bland experience. Pink indicates emergent categories associated with the key idea of an ineffective educational experience (see Table 6-15). Example student responses of the mid-level categories are also included along with how many student ideas fell under these categories.

As can be seen in the above tables, the total number of ideas is 113 from 75 students. About 65% (73/113) of the ideas expressed were positive while 35% (40/113) of the ideas expressed were interpreted as negative (or non-positive).

Similar to segment 1, the positive sentiments are again related to a wide range of different key ideas. A majority of positive comments (45/73) comprising 62% were specific issues related to learning (content, concept, relevancy, etc.). These were highlighted blue in the table. The remaining (28/73) comprising 38% of these comments were general positive comments about the experience including pleasing visual graphics, the show being interesting, and the feeling of moving. These were highlighted in green. Among the negative experience ideas, two categories emerged also similar to segment 1. The first category we interpreted as the student feeling disappointed or not particularly inspired by the segment. About 65% of negative ideas (26/40) were associated with this and were highlighted in orange in the table.

The second category again relates to the content of the educational experience. Here we once more have two subcategories. The first relates to the actual educational content including again the method of how the show teaches distance or the complexity or irrelevancy of the instructional material covered. The second subcategory relates to the delivery of this content in terms of pacing and the instructor. This category included 35% of negative ideas (14/40) and these were highlighted in pink in the table.

The following tables summarize the data and the points made in the discussions for show segments 1 and 2:

Segment 1	**Segment 2**	**Key idea**
85%	**62%**	Specific issues related to learning
15%	**38%**	General positive experience

Table 6-14. Key ideas as Percentage of Positive Ideas from student enjoyment responses taken from both SPV2 segments.

Segment 1	**Segment 2**	**Key idea**
58%	**65%**	Bland experience
42%	**35%**	Educational experience not effective

Table 6-15. Key ideas as Percentage of Negative Ideas from student enjoyment responses taken from both SPV2 segments.

Among positive key ideas, I saw a shift towards general positive experience from positive issues related to learning. Among negative key ideas, I saw a shift towards bland experience from key ideas indicating the educational experience was not effective.

In order to see how robust this categorizing of ideas is, I compare positive and negative [25]elements as percentages of ideas (Table 6-16) to the percentage of students who indicated they either enjoyed or did not enjoy segments 1 and 2 (Table 6-17). This essentially enabled another theoretical sampling instance of GTM for the study. Specifically, this compared how low-level data from two different question response types overlap at the higher-level.

Segment 1	**Segment 2**	**Ideas**
80%	**65%**	Positive
20%	**35%**	Negative

Table 6-16. Positive/Negative Ideas as Percentage of Total Ideas taken from both SPV2 segments.

Segment 1 matches up positive vs. negative idea proportions exactly with the number of students who selected whether they enjoyed or did not enjoy the segment. Segment 2 comes very close at about 4 percentage points off:

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[25] Positive elements are those that added to enjoyment while negative elements detracted from enjoyment.

Segment 1	Segment 2	Enjoyed?
80%	**61%**	Yes
20%	**39%**	No

Table 6-17. Percentages of students indicating whether they enjoyed or did not enjoy a segment of SPV2.

As the proportion of positive and negative key ideas significantly changed from Segment 1 to 2, I also express these key ideas as a percentage of total ideas (see Table 6-18). This is to compare how the key ideas relate among each other and therefore any resulting shifts between segments 1 and 2.

Segment 1	Segment 2	Key idea
68%	**40%**	Specific positive issues related to learning
12%	**25%**	General positive experience
12%	**23%**	Bland experience
8%	**12%**	Educational experience not effective

Table 6-18. Key ideas as a percentage of total ideas expressed by students regarding their enjoyment of both SPV2 segments.

Here there is a more complete picture of how ideas shift over the course of the show. There is a significant decrease of positive ideas associated with specific issues related to learning between segments 1 and 2 while the general positive experience and bland experience key ideas both double. The idea of the educational experience not being effective increases by about a quarter.

Content Reflection

In the second question, students were asked to tell a friend who missed the show what it was about. This was asked after each segment. I coded the responses with the initial instructional intent from section 5.1 as a guide, which I repeat here:

Give students a multi-perspective visualization that improves their sense of scale of the various celestial objects and distances that they encounter in introductory astronomy.

The coding came in the form of a rating from 0 to 3. As with SPV1, when responses were not clear, I would discuss with the PhAsER group. Controversial ratings were debated until 90% consensus was reached.

The minimum satisfactory description of the show would mention that it was about distances. There were more detailed responses that reflected concrete "takeaways" for the students that we decided to rate systematically. The next level of response would state that the show was about distances, but also includes an extra relevant detail. This detail fell into one of two categories. The first was about the specific objects involved such as the center of the milky way or Moon or specific distance measures such as AU or a "Voyager trip". The second extra detail was mentioning something specific about the method used to show distances, either through specifically mentioning how the scale changed with each object, the scale was logarithmic, or that "relative" scales were used. The top rating included both of these details in the description. A rating of 0 was included for if respondents did not give a show description that reflected the instructional intent.

A distinction was made between replying along the lines of "how far away objects in our galaxy are" which would be a 1 and "how far away the Earth is to the center of our galaxy" which is a 2. In this case even though the galaxy was mentioned as a specific object, it doesn't refer to the specific physical point that was referenced in the presentation which was the galaxy's center. Another distinction was made between “the distances of objects” which would be a 1 and “the relative distances of objects” which would be a 2. In the latter it is a direct referral to our specific method of demonstrating distances in that the show used the objects themselves and their distances to each other as units of measurement, so referring to this as using “relative” distances as opposed to simply “distances” deserved a rating one level higher.

This rating method was used for both segment responses regarding the content description. The results are presented in Table 6-19 & Table 6-20.

Description	n	Example Responses (seat #)	Rating	n (Rating)
Distances + method + specific objects/distances	35	*(21) Using known objects at various relatable distances form us to measure distance to another space object. Repeating this process over and over until we can quantifiably measure the distance to the centre of the Milky Way.* *(79) The show was about distances. It indicated how far several objects (like the centre of our galaxy) are from Cape Town. Different scales of distances were used (logarithmic scale)* *(87) Well they pretty much just showed us how far a few bodies were from Earth. The used units we'd understand (like 100x Moon distance or 10000 x Sun distance AU)*	3	35
Distances + method	21	*(53) It is about explaining the distance between various objects in our universe relative to one another* *(93) The show was centered around showing how far away certain things are from Earth and that with each object we looked at we could describe it by using the distance to the previous object we looked at.* *(104) The show aimed to convey visually the great size of space. By using log scales it makes this vast distances easier to comprehend.*	2	29
Distances + specific objects/distances	8	*(27) The show was about the visual interpretation of the locations (Cape Town) and also the distance of Sun, Moon, and Earth (Solar system)* *(85) The show was showing us how far certain objects in the universe are from cape town (it being the centre) from the Moon to the centre of the milky way galaxy (the supermassive blackhole)* *(111) It was about measuring the distances. We measured the distance to the Moon, to the Sun, alpha Centauri and to centre of milky way*	2	
About distances	10	*(41) It was about the scale of the distance between objects in our galaxy, showing how far away most of the stuff is.* *(101) It was about the distance between objects.* *(105) The distances of object in our galaxy.*	1	10
Blank	1	n/a	0	1
Total	75			

Table 6-19. Quality ratings of student indication of what SVP2 segment 1 was about. Colors correspond to assigned rating. A description of why the rating was assigned along with the number of responses receiving the reason and rating are also included.

Description	#	Example Responses (seat #)	Rating	# Ratings
Distances + method + specific objects/distances	18	*(18) The show was about demonstrating the relative distance between different object in our galaxy using various measurements (e.g., 1 AU or 1 Voyager distance)* *(37) It was showing the distance of objects away from the Earth. Each time it reached an object. The scale would change to now encompass the distance from Earth to that object E.g. Distance from Earth to the Sun = 1AU. Distance to Voyager 1800 AU* *(42) The show was the relative distance from Cape Town to the centre of the Milky while each time picking different scaling methods/references while using a graphical presentation*	3	18
Distances + method	23	*(40) The show once again illustrated the distance to various celestial bodies. The scale changes as we move further out.* *(114) The show was showing objects in our galaxy and the relative distances to those objects from Earth as the view is zoomed out to show our entire galaxy* *(125) The show was about the relative distances with Cape Town as a reference point. The show used objects to define units of measurements.*	2	37
Distances + specific objects/distances	14	*(27) I would tell my friend that he really missed a lot, like how far the Voyager 1 is to the Sun and also the show itself.* *(63) The show was about the distance of certain features and also showed how they look like. They showed us Moon, Sun, nearest star, Voyager, and our galaxy.* *(91) The show was about visualizing the distances of the Moon, Sun, Voyager I, and Proxima Centauri above Cape Town*	2	
About distances	12	*(54) Distance of various objects from Earth* *(61) The show was about viewing how further away are some objects beyond our sight* *(87) Same thing. Distances from Earth that's pretty much it*	1	12
Not related to distances	8	*(53) If watched the first one you didn't miss much.* *(98) You missed a loading screen. Although it was an education one.* *(101) The show was about the universe*	0	8
Total	75			

Table 6-20. Quality ratings of student indication of what SPV2 segment 2 was about. Colors correspond to assigned rating. A description of why the rating was assigned along with the number of responses receiving the reason and rating are also included.

I combine the quality ratings from both segments for comparison in Table 6-21.

Rating	Segment 1 quality	Segment 2 quality	Combined quality	Segment 1 combined quality	Segment 2 combined quality
3	47%	24%	High	86%	73%
2	39%	49%			
1	13%	16%	Low	14%	27%
0	1%	11%			

Table 6-21. Combined quality ratings for student indication of what segments 1 and 2 were about. Percentage is out of total responses.

The content description rating after Segment 1 shows a clear upward trend towards the maximum rating while the content descriptions for Segment 2 skews lower in quality.

Results from the questions asking which show they learned more from can be found in the Appendix C. My early analysis regarding results linked with seating position in the planetarium can also be found in the Appendix B. These were discarded for later investigations. From here I combined the results of SPV2 with the findings of SPV1 to undergo a broad analysis detailed later in the chapter.

6.2 Localized Model of Student Engagement

It was from the results of the student questionnaire data that I looked to answer Guiding Question #1:

How do students engage with a digital planetarium?

The two studies (SPV1 & SPV2) both involved the same planetarium facility and cohort of students in a university-level single-semester introductory astronomy course. In SPV1, 94 students were brought to the planetarium in the second week of their course and experienced a planetarium show planned and executed by the course instructor. This featured predominantly geocentric night-sky visuals and involved multiple topics related to the course component on the night sky. In SPV2, 75 of those 94 students[26] were brought back to the planetarium at week 11 near the end of the course. They experienced a planetarium show planned and executed by me and the PhAsER group that featured predominantly allocentric visuals of a demonstration of the astronomical distances involved with celestial objects encountered in the course. I reproduce compiled analytic results below for reference during this reflection.

In SPV1 the students were asked about their knowledge regarding a specific topic before and after while reflecting on their planetarium experience only after. In SPV2 students were asked about their experience following each of two segments. In both these cases the overall experience was found to be engaging and enjoyable experiences when students were asked to indicate in a "tick-a-box" manner whether they enjoyed the experience. SPV1 suggested this from 82% of students indicating the experience was very enjoyable, 15% enjoyable, and 3% neither enjoyable nor unenjoyable (see Table 6-1).

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[26] 19 fewer students took part in SPV2 than SPV1 as some students were absent or had dropped the course.

In SPV2, segment 1 received an enjoyable rating from 80% of students compared to 20% who did not enjoy it. However, in SPV2 segment 2, fewer students rated the experience as enjoyable with 61% indicating they enjoyed it with 39% indicating they did not (Table 6-22).

Segment 1	Segment 2	Enjoyed?
80%	**61%**	Yes
20%	**39%**	No

Table 6-22. Student indication of enjoyment from SPV2. Produced from combining Table 6-8 & Table 6-9.

Both planetarium visits can be considered as engaging experiences for students, however SPV2, with student probing over the course of the show, showed a decrease in enjoyment from segment 1 to segment 2. This I look at in more detail from the high-level ideas that emerged from student responses.

When I looked further at how students reflected on their favorite parts from SPV1, I initially found a distinct separation of ideas in the post-show related to the planetarium experience into key ideas of learning and novelty (Table 6-3). Considering that the students rated this as an overall engaging experience as judged by the tick-a-box ratings, students walked away with a vast majority (78%) of their ideas indicating educational content as the best part as opposed to 22% being ideas of general fun emotional or novelty content. This result was limited to that of a single snapshot at the end of the experience. Also, since this result was derived from a question on the students' favorite part of the experience, responses were purely based in "favorable" reasoning in that they revealed only what made the show good for the student.

SPV2 allowed me to further explore this notion by assessing student engagement at a higher resolution of the experience. Part of this came from including questions after each segment of the two shows, probing shifts in student experience as the overall show progressed. Particularly useful was the question of agreeing with whether the show segment was enjoyable or not with an accompanying explanation. This enabled the eliciting of negative feedback, something SPV1 did not enable because of its restrictive enquiry of what the "best part" was. Because I could tap into the negative domain as well in this analysis, 4 distinct key ideas emerged from the 2 segments (Table 6-18). These key ideas could then be directly grouped in whether they were positive or negative indications of the enjoyment of the experience (Table 6-23).

Segment 1	Segment 2	Key idea	Positivity	Segment 1	Segment 2
68%	**40%**	Specific positive issues related to learning	Positive	80%	65%
12%	**25%**	General positive experience	Positive		
12%	**23%**	Bland experience	Negative	20%	35%
8%	**12%**	Educational experience not effective	Negative		

Table 6-23. Key ideas from Table 6-18 regrouped as either positive or negative ideas regarding enjoyment of SPV2 segments.

I also compared percentages of positive versus negative ideas to the tick-a-box responses on whether students enjoyed the show or not to determine the degree that the emerged ideas reflected student choice on whether they enjoyed the segment (Table 6-24). The close correlation gives confidence that the key ideas emerging out of the data are a close reflection of student enjoyment of the experience. This can be identified as a form of theoretical sampling for improving investigation rigor.

Positivity	**Segment 1**	**Segment 2**
Positive Ideas	80%	65%
Negative Ideas	20%	35%
Students enjoyed	80%	61%
Students did not enjoy	20%	39%

Table 6-24. Combining Table 6-22 & Table 6-23 to check strength of key ideas reflecting enjoyment factor.

From segment 1 to segment 2 of SPV2, in which similar content was presented to students in different formats, there was a drastic decrease in positive elements specific to learning when considering their enjoyment. Table 6-23 shows how much of this came from a drastic decrease in the top expressed idea of positive issues related to learning that goes from 68% to 40%. Meanwhile, general positive experience and bland experience key ideas both doubled while the ineffective educational experience went up only slightly. The two key ideas that increased significantly, for either positive or negative reasons, both reflect ideas not specific to the learning experience. Thus, new Idea Themes emerged here that could be regrouped accordingly. These were the Idea Themes of **Teaching/Learning** and **Novelty/Entertainment** (Table 6-25). These corresponded very closely to the original key ideas of Novelty and Learning found in the SPV1 analysis on what students denoted was the Best Part of the show (see Table 6-3).

Segment 1	**Segment 2**	**Key idea**	**Idea Theme**	**Segment 1 Theme**	**Segment 2 Theme**
68%	**40%**	Specific positive issues related to learning	Teaching/Learning	**76%**	**52%**
8%	**12%**	Educational experience not effective	Teaching/Learning		
12%	**25%**	General positive experience	Novelty/Entertainment	**24%**	**48%**
12%	**23%**	Bland experience	Novelty/Entertainment		

Table 6-25. Regrouping key ideas from SPV2 enjoyment into Idea Themes of Teaching/Learning and Novelty/Entertainment. Color is arbitrarily assigned to identify the new themes.

When I grouped by these new Idea Themes, regarding student experience regarding enjoyment, segment 1 had 76% of ideas related to the educational experience as opposed to 24% related to novelty. In segment 2 the former drastically dropped down to 52% of expressed ideas with the latter increasing to 48%. There was a clear increase (doubling) in novelty elements tied to student enjoyment in both a negative and positive way, mostly at the expense of positive educational elements.

I interpreted these deviations in two different scenarios for students of negative and positive deviation. In the case of the negative deviation, explanations were dominated by key ideas of the segment being repetitive or tedious, indicating an element of boredom setting in. In the case of the positive deviation, there were top ideas of pleasing/stunning visuals or the up-close immersive nature of the segment. There was even a comment on the apparent feeling of moving making the experience enjoyable. This suggested added elements in the second segment that detracted from the learning experience. Segment 2 was indeed designed to be a more 3D/immersive experience, which appeared to introduce more elements of distraction or entertainment to students. Further specific examples can be seen later in Table 6-28 and Table 6-29.

I interpreted based on the responses that students in both studies were initially framing the planetarium visit as an extension of lecture with either the "best" or "enjoyable" elements being predominately educational and enabling learning. However, as interpreted from SPV2, as the show progressed, students would start to deviate away from this learning aspect. This deviation was either in a positive[27] or a negative[28] direction.

This can be reinforced by what was seen in the questions on content recollection. In SPV1 between the pre- and post-show questions on the celestial sphere there was a slight shift from High to Low quality (Table 6-7). And there was a more pronounced High to Low shift in SPV2 explanation quality when the students explained to a friend what the show was about (Table 6-21). Here there were other forms of "mental fatigue" in what amounts to students effectively repeating themselves with less thorough or enthusiastic detail.

I took note as well that this content-reflection question of SPV2 was open-ended, asking what the show was about, and compared its responses (Table 6-27) to the other, more open-ended content reflection of SPV1 that asks what students learned (Table 6-26). I saw a relatively straightforward connection that *a wide range of instructional intents guiding the content planning and development corresponded to a wide range of indicated learning outcomes by the students*. SPV1 had a large variation of recollected topics when students explained what they learned with 95% of the expressed ideas related to the instructor's stated intent for making use of the planetarium. For SPV2, when reflecting on what the show was about, nearly all ideas expressed by students in segment 1 (99%) were distance-demonstration related which corresponded to the instructor's intent while 89% did in segment 2. Appropriately*, a narrow focus of instructional intent corresponded to a narrow learning outcome*. This broadens the idea of students having a denser experience based on what is included in the intended, and correspondingly manifested, teaching content.

	Broad Category of ideas corresponding to Instructional Intent	**Relevant to instructional intent?**	**Relevancy**
47%	Visualize the night sky and celestial sphere in "3D"	Yes	**95%**
26%	Show a few of the main constellations and how they indicate cardinal directions	Yes	
13%	Show precession and debunk astrology	Yes	
9%	Show how the Sun "moves" at noon over the course of the year	Yes	
5%	Not corresponding to specific instructional intent	No	**5%**

Table 6-26. Open-ended content-reflection of students indicating what they learned from SPV1. Enhanced from Table 6-5 to include emergent concept of "relevancy".

Segment 1	**Segment 2**	**Broad Category of ideas corresponding to Instructional Intent**	**Relevant to instructional intent?**	**Segment 1 Relevancy**	**Segment 2 Relevancy**
99%	**89%**	Distance	Yes	**99%**	**89%**
1%	**11%**	Not corresponding to specific instructional intent	No	**1%**	**11%**

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[27] liking the new format or method or visual elements of it

[28] attention is lost as the show becomes tedious

Table 6-27. Open-ended content-reflection of students indicating what show was about from SPV2. Enhanced from Table 6-21 to include emergent concept of "relevancy".

Here I will point out that showing the segments of SPV2 in a different order to a separated cohort of students would have been worthwhile. For example, half the class could have been presented the segments in the order we conducted the show in while the other half was shown the reverse order. In this way I could better connect elements of bland experience to the style of the show versus the repetition. For example, if I observed an obvious symmetry of student engagement from both cohorts, I could possibly assume bland experience in rooted in the repetitive elements rather than the unique formats of the segments. This should be pursued in future studies and would be highly beneficial at improving theoretical saturation of the study.

The desirable outcome of bringing a student to a planetarium should arguably be a positive experience for the student that is relevant to instructional intent. A degree of novelty to stimulate engagement can be included to aid in this goal and may even be necessary, but when it starts to detract from the positive learning experience, it is no longer useful. On top of this, the purpose of the planetarium visit should also be considered. There are unique affordances to the digital dome that cannot be recreated in the classroom or lecture hall. In considering SPV2, a deviation occurred over the course of the visit from a positive learning experience to either a negative experience of boredom or a positive experience of entertainment. Here I identified two quantifiable, semi-abstract domains of the planetarium visit in the context of a student being brought to the digital planetarium to learn. The first domain is how much **relevant engagement** or sense-making is taking place for the student. It was necessary to explicitly narrow down this domain because the student could leave the planetarium having "learned" something that was unintended by the instructor. I therefore considered this domain to be how much material *relevant* to the instructional intent the student is actively attending to and therefore engaging with. The other domain is **attentiveness**. This domain captures both *how many* things the student is aware of along with the *degree* to which they are attending to those things. I model here the experience as a two-dimensional spectrum regarding the two variables of learning and attentiveness (Figure 6-10). I refer to this as a localized model of student engagement in the planetarium, which addresses the Guiding Question #1.

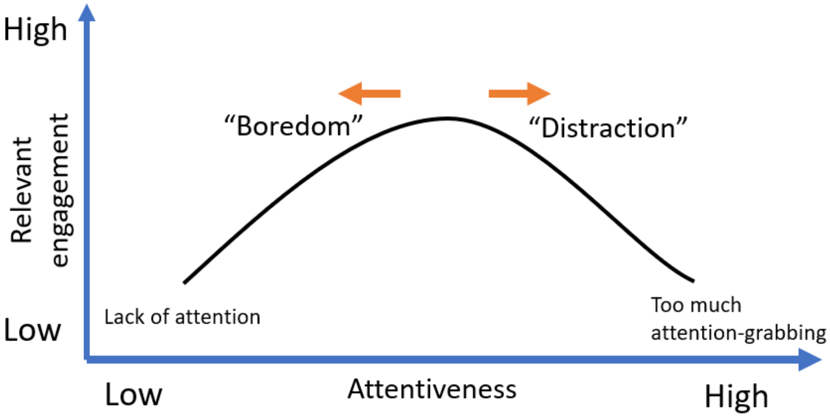

Figure 6-10. Localized model of student engagement that relates attentiveness to relevant engagement as suggested by our data. Students engage according to the above spectrum of low versus high "attentiveness". Low attentiveness was indicative of boredom with a lack of attention and high was indicative of distraction from too many things grabbing attention. Both extremes resulted in low student engagement with the relevant learning material of the planetarium experience. An "ideal middle" of student attentiveness seemed to maximize this relevant engagement.

Captured in this model are two deviations towards both the low and high attentiveness areas from a "goldilocks" zone of ideal attentiveness. The former takes place when there are not enough relevant elements to entice the student to pay attention to the relevant content. This also seems to occur in situations where the elements become repetitive for students. In Table 6-28 I produce explicit examples of this among students who expressed predominately positive ideas related to learning for segment 1 of SPV2 and then switched to predominantly negative ideas associated with novelty for segment 2. Meanwhile, the latter deviation of high attentiveness takes place when there were too many elements competing to entice the student to pay attention. In Table 6-29 I show examples of this when students went from predominantly positive learning ideas to positive ideas associated with novelty.

Seat #	Segment 1 Positive-Learning response	Segment 2 Negative-Novelty Response
40	*It makes the distances in space more relative by not baffling us with 10 to the nth power. The constantly changing scale helps.*	*It was too similar to the first show. Although it was presented better, it was repetitive.*
55	*I found the visual representation of distances to be useful in helping me contextualize the structure of the galaxy and solar system in terms of size and scale.*	*I found it to be too similar to the first and didn't offer a very different insight than caused me to view the topic in a different way.*
83	*It certainly does help to visualize how big the universe is even though one cannot fully comprehend the size. Different units do help in the visualisation*	*Although I prefer this method of showing distances more, the actual timelapse could have been faster. It took a long time.*
98	*I enjoyed it too. It's interesting to learn about the distances of stars and the centre of our galaxy on a relative scale.*	*Watching the value of the distance changing is like watching a loading screen*

Table 6-28. SPV2 student enjoyment responses transitioning between segments 1 and 2 from predominantly positive-learning to negative-novelty, indicating possible "loss of attentiveness" at detriment of relevant engagement.

Seat #	Segment 1 Positive-Learning response	Segment 2 Positive-Novelty Response
22	*The show gave a good model in which to visualize almost unfathomable distance. It made it easier to put things into perspective.*	*This show gave a more visual version of the first show which made it more engaging.*
72	*mind-blowing demonstration of the scale of space, very enjoyable and mind-opening (concept was good)*	*Very realistic, felt as if moving through space. Profound comprehension of scale of space.*
79	*The scaling of distance using various distances helped. The show was interesting as we could see the distances.*	*The show was interesting and fun to watch.*
107	*I enjoyed it because it put into perspective how far distances are in the universe and how insignificant and tiny our planet and solar system is in comparison to the rest of the Galaxy*	*I enjoyed the show because seeing how high different objects are above us and how the Earth got smaller till it disappeared was exciting and enjoyable.*

Table 6-29. SPV2 student enjoyment responses transitioning between segments 1 and 2 from predominantly positive-learning to positive-novelty, indicating possible "gain of attentiveness" at detriment of relevant engagement.

It was important to keep the attention domain more abstract in capturing both the quantity of things drawing attention along with the degree. For example, the student could be aware of the many elements of a very dense experience incorporating multiple visuals, text, sounds, and narration. Likewise, they could also be very heavily drawn to a single element like a bright model of a star appearing over their shoulders. In the case of the latter, the visual of the star may be relevant to the educational content, but it may be detracting from learning if it draws student attention from the broader components of the lesson.

What exactly do I mean by "drawing attention"? One can think of things that are primary, in-the-moment elements that students actively attend to. This can be content on the dome display, music or sounds coming over the speaker system, or the theatre setting with reclining chairs and whispering neighbors. There are also secondary things that can occupy the attention. The off-site planetarium visit, for example, requires sitting in an unfamiliar setting and taking transport off-campus to get there. It's also unclear over what sort of time-domain this localized model of student engagement would apply. It can be considered instantaneous in real-time throughout the planetarium experience or cumulative/average of the whole experience. The next localized model grounded in the observational data and the later synthesis address these issues.

6.3 Observational Data

By compiling the narratives from both SPV1 and SPV2, including the observations of the instructor's planning, the unstructured interview with the instructor, my own experiences as a show developer, the implementations of the shows, and the preconceptions I brought into the investigation, I analyzed the observational data. From these I picked out "aspects" of the planetarium that I identified as contributing to the experience of the student. Some of these things were also brought up by students in the questionnaires when reflecting on their enjoyment. Many of the compiled observations were also supplied by members of the PhAsER group.

This analysis involved putting different identified aspects of the planetarium experience onto sticky-notes and grouping them into higher categories. These were initially grouped by similarities found through coding and eventually categorized to higher and higher levels. From the iterative nature of coding inherent to GTM, the higher levels themselves I found could be revisited and populated by further low-level aspects identified in the data sources mentioned above. For example, I found that higher-level aspect groupings of "Visual" and "Auditory" could be combined into a "Sensory" aspect. However, this made me explore and consider other lower-level aspects related to sensory stimulation. This led to a whole new lower branch of "Spatial/Haptic" pertaining to even lower-level aspects of spatial awareness that would form part of the planetarium experience. This back-and-forth developed into another form of theoretical sampling in which new lower-level aspects could populate higher-level aspects that had already been established. Most of the coding was done by myself, but members of the PhAsER team would occasionally be on hand to assist when I found categorizing inconclusive.

Ultimately, these aspects tended to originate from four emergent primary sources: the show **content**, the **instructor**, the planetarium **environment**, and **external**. There were, however, a few 'cross-over' aspects that could be categorized from several of these sources. I present these as the compiled diagrams below, which are digital recreations of the sticky-note diagrams. It is important to note that these compiled diagrams of planetarium aspects are in no way exhaustive and there are many that I potentially left out. The point is to demonstrate the variety and form of inputs that accompany a student throughout their experience in the planetarium.

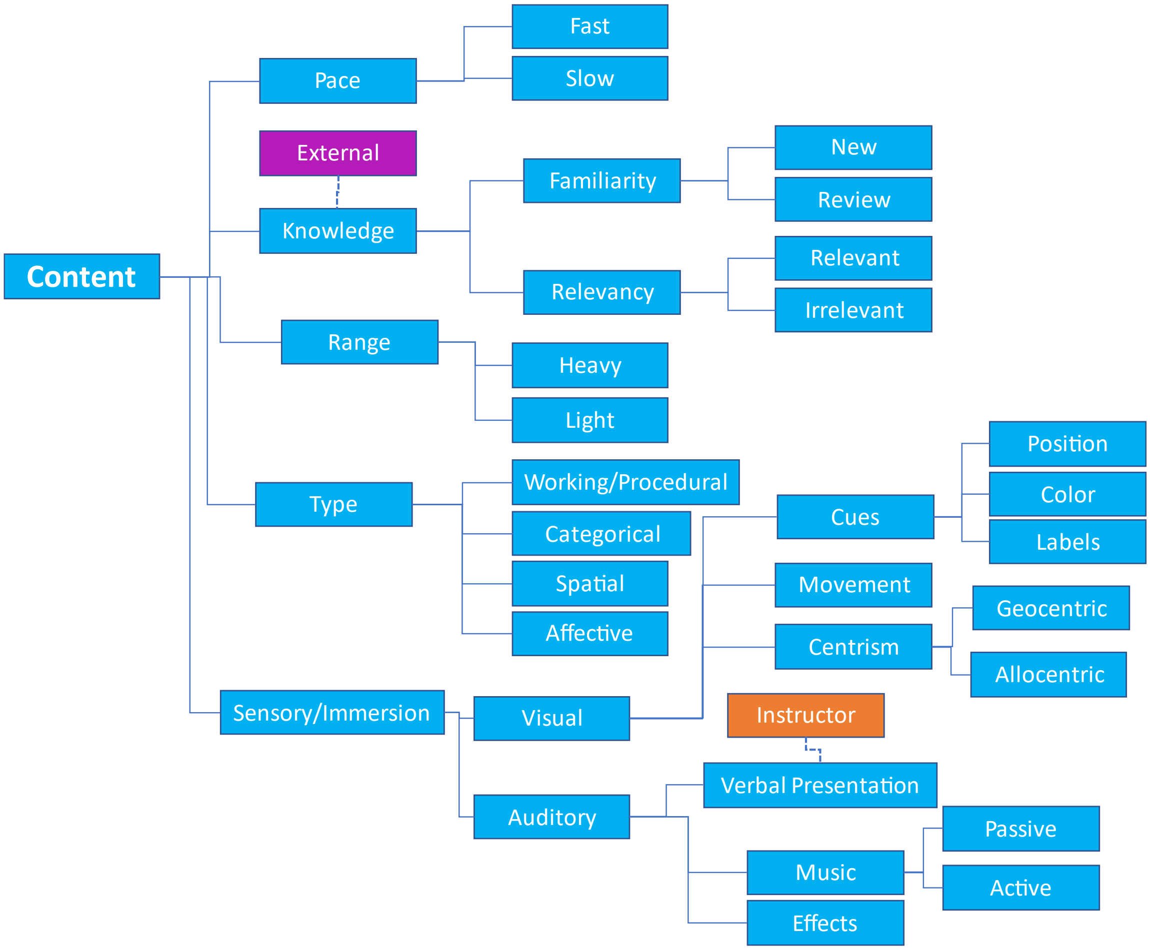

Figure 6-11. Planetarium aspects associated with the content of the presented planetarium show. Solid lines extend to more specififc elements of the aspects while dashed lines indicate "crossover" aspects from other sources.

The first category of planetarium aspects was that associated with the **content** of a planetarium show (Figure 6-11). This includes the material that goes into the planned presentation including the knowledge that is to be taught along with everything that supports this on the software side such as rendered visuals and sounds. Specific aspects of this category include the pace of the show, use of labels or music, the type and amount of subject matter being covered in the lesson as well as the relationship students have with it. A unique cross-over sub-category are the aspects associated with 'knowledge' which can have a lot of dependence on external influences linked to what students are bringing to the experience with them. What was notable with these aspects was their independence from the physical environment and therefore their portability; they can effectively be transplanted in different types of planetariums. The show that I designed for SPV2, for example, recreated many of the content aspects that were used in the Yu et al. (2017) distance study. Most of the aesthetic themes that Croft (2008a) named as essential, according to planetarium practitioners, falls under this category. This includes taking audiences on a journey, a slow and peaceful pace, music to fill the experience, and use of visual immersion.

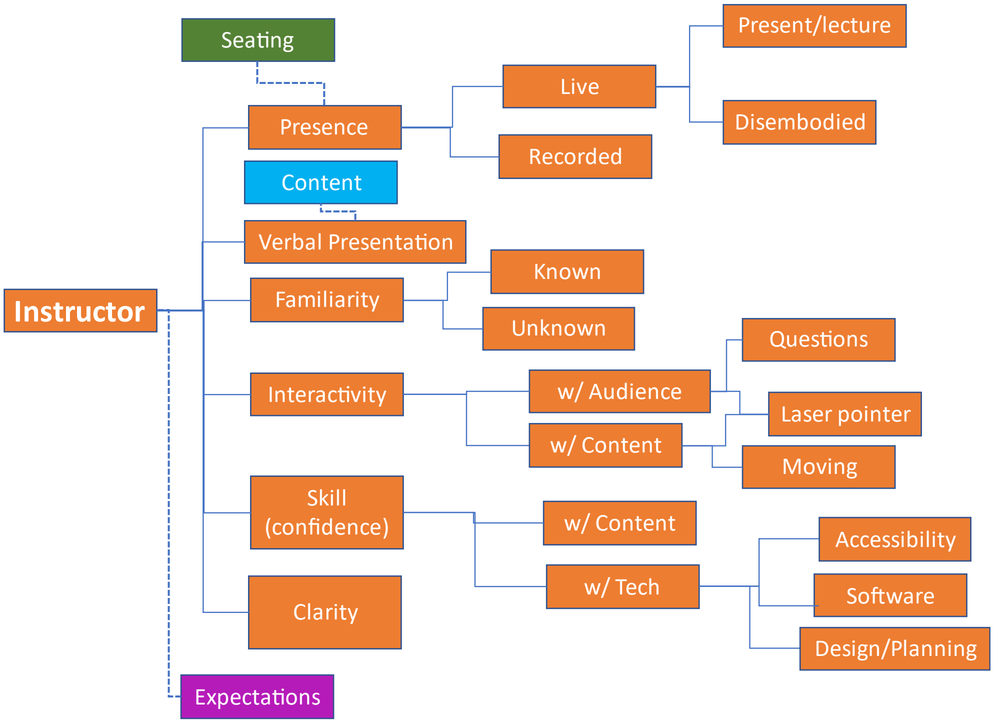

Figure 6-12. Planetarium aspects associated with the instructor presenting the planetarium show. Solid lines extend to more specififc elements of the aspects while dashed lines indicate "crossover" aspects from other sources.

Closely related to content was the **instructor**-based aspects (Figure 6-12). This includes how familiar students are with the instructor, the instructor's teaching style including interactivity, and whether they are visible in the theatre or not. In general, one could argue the input that the instructor provides to the experience is one that could be split between the other input categories. However, the critical influence that the instructor clearly plays in the experience buds their role off into a category in and of itself. What's important is seeing these aspects as originating from the knowledgeable person that leads the audience through a planetarium experience. Of course, the role of the instructor is one that can also be automated through a video playing, or even fragmented between multiple figures such as a speaker and operator as in SPV1. Dome-casting even enables broadcasting of planetarium visuals across planetariums (SubbaRao, 2018), giving opportunity for remote instruction on the dome. Croft (2008a) included a live presenter as an essential aesthetic theme for an effective planetarium show. Important cross-over subcategories include expectations, which the instructor can instill in students as external aspects. The visibility of the instructor is also a subcategory that can branch off from seating arrangement from environmental aspects, which is summarized next. A key difference between SPV1 and SPV2 were instructor-based aspects brought on by replacing the course instructor with myself. This introduced new associated aspects of non-familiarity on the part of the students as I was not a present figure in the general introductory astronomy course. I could in this sense be considered a stranger, which Ridky (1975) argued could be a direct contributor to the 'mystique effect'. I will discuss this later in section 10.2.

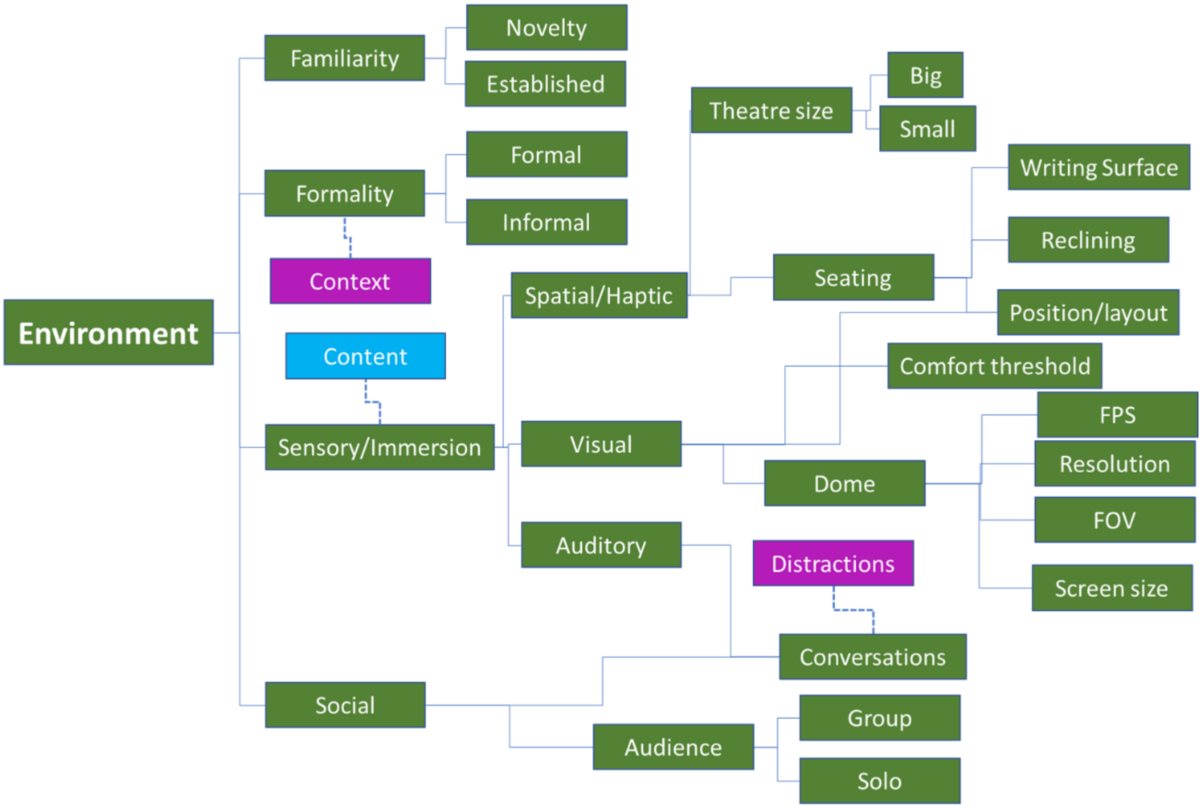

Figure 6-13. Planetarium aspects associated with the physical planetarium envrionment. Solid lines extend to more specififc elements of the aspects while dashed lines indicate "crossover" aspects from other sources.

As a facility with its own unique affordances, it became clear that the planetarium as an environment brings many aspects to the student experience. This introduces the aspects of the **environment** (Figure 6-13), which includes inputs from the physical planetarium space itself. These can include the type of dome, seating arrangement, things happening around the student such as conversations and squeaky chairs, the physical nature of the dome display, lighting, and speakers, as well as general familiarity with the space on the part of the student. This is distinct from aspects of content in that it considers physical features of the facility. Of course, there can be significant overlap, which is a reason that both categories include Sensory/Immersion subcategories. For example, a loud virtual big bang explosion on the dome would be an aspect of content while a door slamming in the theater would be an environmental aspect, though both could potentially draw student attention. This significant cross-over can be identified as a feature of the digital planetarium being an immersive technology, which as recalled from section 2.1.2, blurs the line between the physical and computer-mediated environment. Other notable cross-over subcategories include distractions, which could occur in the dome, but also from external sources such as stress about the course grade or pending traffic after the show. There is also the general context which frames the use of the environment according to external expectations and feelings about planetariums.

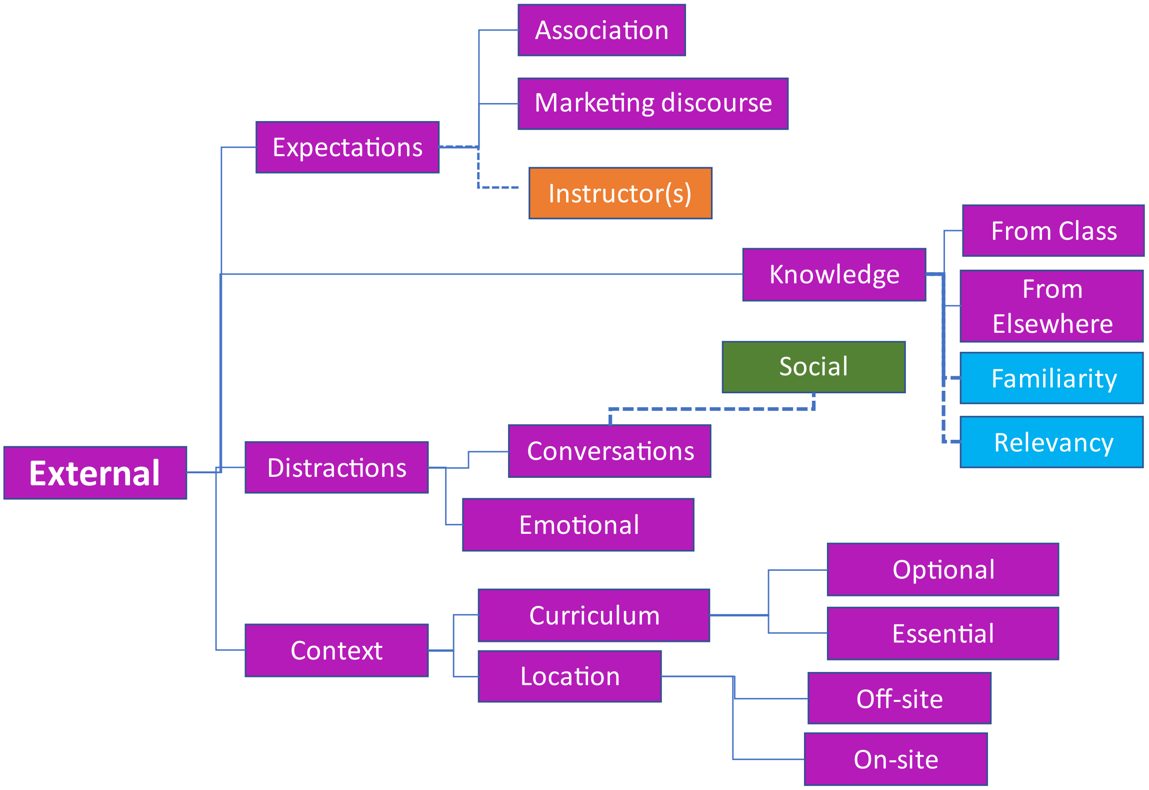

Figure 6-14. Planetarium apsects originating from external sources from 'outside the dome'. Solid lines extend to more specififc elements of the aspects while dashed lines indicate "crossover" aspects from other sources.

This brings the final category of aspects, which is **external** (Figure 6-14). External inputs include everything from the student's experience outside of the dome that is carried into the planetarium experience. This can range from general expectations from the idea of the planetarium or marketing discourse to the familiarity of the space and content shown. One important aspect witnessed in both of my studies was the conversation strains carried in from outside the dome. SPV1 had much talking and whispering among students throughout the show while SPV2 successfully broke this up through randomizing seating. It should be noted that although we incorporated a method to break up these conversations, I acknowledge that these conversations could very well be relevant to the instruction when students are helping each other understand what is happening.

6.4 Localized Model of Contextual Influence

It was from the results of the observational data that I looked to answer the Guiding Question #2:

What shapes the teaching and learning space in the planetarium?

The context of where the above localized model of student engagement takes place is essential to first acknowledge. The planetarium environment, for example, is anomalous to the typical routine for the student. During the two studies, the detailed description of events in the form of preliminary memos accompanying the PhAsER group's observations allowed me to take note of many aspects. Any of these aspects could have an influence on the planetarium experience for the student. These aspects take on many different forms and points of origin, but how exactly that happens I explored further. It is the nature of these aspects that led to me considering how students can interact with them, especially in the context of the "spectrum of attentiveness" of Figure 6-10. From here I set out on determining what sorts of things draw and compete for the attention of students in the planetarium. This, in the context of my findings, reflected the potential to contribute to, or detract from, learning in general. To consider these things, or **aspects** as I designated them formally, I needed to determine components of the planetarium experience that students attend to.

Aspects can take on many characteristics and forms, which makes looping them into a model a complicated one. How does the brightness of the dome affect a student's experience compared to a reclining chair? How does the familiarity of the facility compare to an unexpected slamming door in the back of the theatre? This seems to be an issue of comparing apples to oranges. To highlight this complexity and the accompanying abstraction, I first introduce a more complete, though not exhaustive, diagram of inputs for the digital planetarium experience (Figure 6-15). The diagram is collection of the identified high-level sources from the analysis in section 6.2. It reveals the complex web of interacting aspects that are potentially drawn from to produce the student experience in the digital planetarium. In other words, it accounts for the various aspects in the digital planetarium that shape the teaching and learning space. The reader must again acknowledge that this is not an exhaustive diagram, and instead serves to reveal both the primary sources and hierarchal nature involved in the various aspects.

This consolidated diagram I refer to as a localized model of the contextual influences contributing to the planetarium experience, which addresses the Guiding Question #2. The digital planetarium as an effective teaching and learning space is shaped by a potential range of interacting aspects. It is critically important to consider how these aspects can be influenced by an instructor throughout the curriculum design process. This idea I will park for later once I discuss how these aspects interact with the student experience, or more specifically, how my two localized models can be unified to find synthesis.

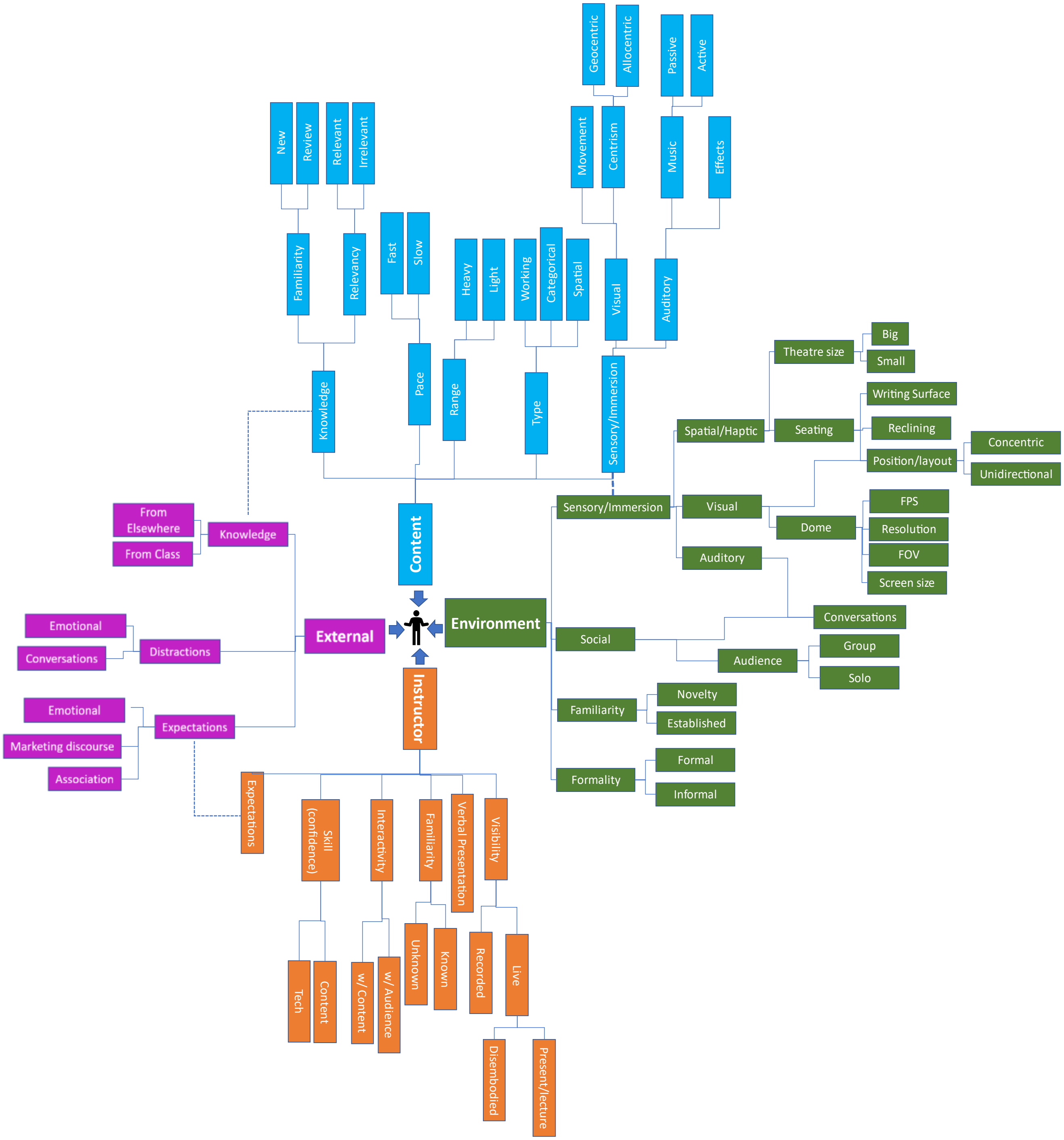

Figure 6-15. Complete, but not exhaustive, localized model of contextual Influence of compiled planetarium aspects under the high-level sources of Content, Environment, Instructor, and External. The complex web of interrelated aspects form the potential basis of a student's planetairum experience, represented by the figure at the center. Solid lines extend outward from higher-level, abstract aspects to lower-level, specific aspects. Dashed lines indicate examples of "crossover" aspects between sources.

6.5 Bringing the Two Grounded Theories Together

Each localized model can be regarded as addressing each manageable guiding question as posed in section 3.1. Thus, the localized model of student engagement links to the Guiding Question #1**, How do students engage with a digital planetarium?** It answers with the emergent spectrum of deviating attentiveness that was grounded in the data of the student responses of SPV1 and SPV2. Meanwhile, the localized model of contextual influence links to the Guiding Question #2, **What shapes the teaching and learning space in the planetarium?** It answers with the emergent complex web of digital planetarium aspects that form the basis of the student experience when they visit the planetarium.

Taken together, the two models can be considered as describing two dominant perspectives: one from the learner who has varying degrees of attentiveness based on aspects of the planetarium space and the other from that of curriculum design that harnesses many of these aspects to create a meaningful teaching experience. However, the broad goal underlying the investigation from section 3.1 remains:

Characterize the digital planetarium as a teaching and learning space.

From here I will describe the process and line of reasoning that led to addressing this goal in the form of a unified model.

One way to address the broad goal guiding the overall study is to develop a new model that will systematically guide curriculum development for the digital planetarium in the broadest sense. In the previous section, I proposed two localized models regarding the planetarium experience, one from the student attentiveness perspective and another from that of the contextual influence relevant to curriculum design. Thus, I suggest the starting point for such a model that broadly guides curriculum development is to synthesize these two low-level models into an overarching, unified model. This requires the consideration of some additional issues that fall into the broad area of cognitive theory.

For example, one issue is how the mind interacts with information in a given environment with variable stimuli. Specifically, what does the mind "attend" to, what sort of factors influence this, and how does this attention positively or negatively impact learning? This is especially important if the environment is out-of-the-ordinary or even brand new for students. And how are these aspects' contribution to attentiveness impacted by previous experience or knowledge of both the planetarium environment and the material being presented? Two additional factors are important to consider here, which emerged as recurrent concepts in the study: the intent of the instructor and expectations of the students. The former has a big influence on what is presented and what should be considered when determining a "successful" visit. The latter may prime the student on how they process the information being presented. One can think of this interaction in the form of a proposed unified model of planetarium instruction (Figure 6-16). Here, students enter the planetarium, they are faced with a complex combination of aspects of the planetarium, and an instructional outcome results in which the students walk away with something that they learned.

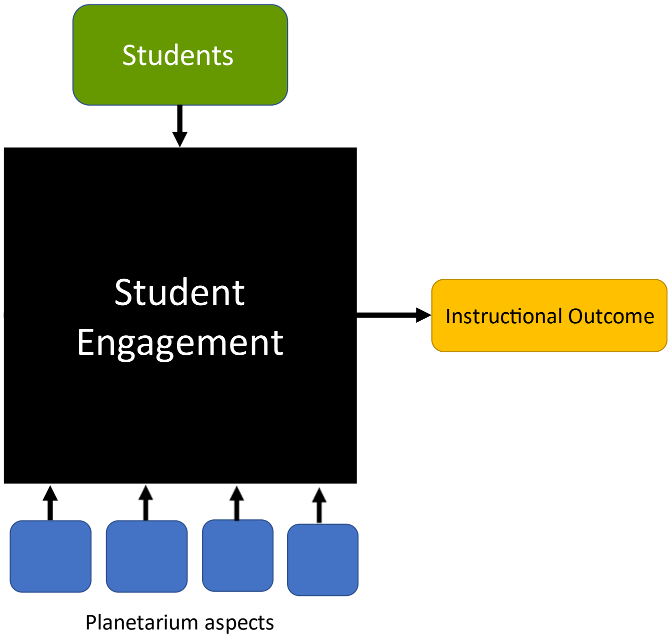

Figure 6-16. Proposed unified model of planetarium instruction. Students come to the digital planetarium to learn. Aspects of the digital planetarium experience corresponding to the localized model of contextual influence are introduced to the student to engage with. The student then engages based on the localized model of student engagement. An instructional outcome results.

The deviation from ideal attentiveness in my localized student engagement model suggested limitation. I needed a cognitive framework that explained how limited attention can limit learning. This must consider how things, both conducive and non-conducive to education, occupy limited attention. Meanwhile, this must also consider the attentional contribution of the variety, complexity and familiarity of the material being taught in addition to the teaching environment, as put forward by my contextual influence model. When considering learning and attention in the context of whether the material involved is contributing to or detracting from learning, a relevant cognitive model could construct a more robust grounded theory through theoretical coding. I therefore skimmed the literature and discussed several possible cognitive models with the PhAsER group. After meticulous discussion and debate, I decided, with the unanimous support of the group, that the model of Cognitive Load Theory (CGT) was the appropriate supplement. This supplement takes into account the limited Working Memory (WM) resources that are responsible for information that humans are actively attending to.

It was at this at this point in the study that a critical component of GTM, the "return to the literature" explained in Chapter 1, was necessary.

7 Return to the Literature: Theoretical Supplements

Here I introduce theoretical models in the field of cognitive research that are compatible with my later localized models, namely Working Memory and Cognitive Load Theory. I further apply them to refine my proposed unified model in the next chapter. This is a crucial late-stage phase of GTM in which a theoretical supplement is supplied to the localized models that were themselves fully grounded in the data analysis. This allows “theoretical coding” to provide the necessary external theory to generalize the localized models and establish the basis for a formal grounded theory, which I do in the next chapter.

7.1 Working Memory & Attention

If one assumes that the instructor’s goals in bringing students to the planetarium primarily depend on making a lasting impression on the students, it is appropriate to first consider long-term memory (LTM), specifically as defined in the original Atkinson–Shiffrin memory model (Atkinson & Shiffrin, 1968). LTM is the apparent infinite store where information is retained in the human mind as opposed to the temporary short-term, and sensory memories. What I wanted to know is how the instructor’s use of the planetarium interfaces with the LTM of the students throughout the experience. The next consideration was how the resulting LTM changes in the students potentially compare with the original instructional intent of making use of the planetarium in the first place. As Sweller (2005) put it, the primary goal of instruction should be to alter LTM and if LTM was not changed, then nothing was learned.

Although an important influence, the Atkinson & Shiffrin model is today considered outdated but was essential in leading to the models of working memory (WM). WM acts as an interface between LTM and human sensory-experience of reality as well as how people attentively deal with components of this experience in-the-moment. When I use the term WM, there are a few definitions in the field (Cowan, 2017). For my purposes, I consider the following definition of WM from Baddeley (2010):

“The system or systems that are assumed to be necessary in order to keep things in mind while performing complex tasks such as reasoning, comprehension and learning.”

What was particularly useful here with WM is that it allowed modeling how students attend to things throughout the planetarium experience and how that attention can lead to or detract from learning. For this I specifically considered the model that Baddeley and Hitch (1974) originally constructed from empirical evidence. In this model, the previously acknowledged ‘short-term’ memory from the Atkinson & Shiffrin model was replaced by WM that is separated out into a multi-component system of limited capacity. This included the attentional control system that Baddeley (1986) called the ‘central executive’ (CE) that selects which stimuli to attend to and which to suppress.

Baddeley described the CE as functioning in line with the attention model by Norman and Shallice (1986) with two functions of how attention is controlled. The first attentional function is automated and makes use of previously learned habits, such as driving a car. However, when this automation is not possible and new information enters the situation, the second function, the supervisory attentional system (SAS), takes over to make decisions and seek strategy for resolution. For example, if one is driving a car and a ball rolls onto the road, the SAS kicks in for the driver to consciously make a decision to put on the brakes.

This CE works with two dependent temporary stores of the visual-spatial sketchpad (VS) and phenomenological loop (PL). An important feature in the original model by Baddeley is this separation of different modes of temporary information storage. The VS processes visual and spatial information while the PL does the same for verbal & auditory information. With separate distinct stores, WM can process tasks simultaneously in the visual and auditory domain, but not within the same domains. For example, reading while listening to a conversation is difficult as these tasks both use the PL. However, navigating while listening to directions is a lot more manageable because the former uses the VS, and the latter is confined to the PL.

To be processed in WM and eventually learned, information must first gain the attention from the CE, but the limited capacity of the WM components means things can become overwhelming. Anything that draws attention for the mind to become conscious of has the potential to fill a portion of working memory. So, the question is how can humans improve their ability to attend to and work with information involved in complex tasks? There was a crucial later addition to the model (Baddeley, 2000) of another capacity-limited component. This was the ‘episodic buffer’ (EB), under control of the central executive from which it was split off. This EB manipulates and binds together information from the other subsystems (including LTM) into coherent pieces or ‘episodes’ that can then be interfaced with LTM in feeding in and retrieving information. This interface with LTM is the key to dealing with the complex tasks mentioned above. The binding feature of the EB pulls pieces of information together into condensed chunks that allows complex information to fit into the limited capacity of working memory with the aid of LTM. For this, I also needed to recognize the form of schemas that knowledge takes in LTM that allows this chunking. What was particularly useful here was both how EB contributes to LTM through learning and how LTM influences attentive processes and processing of complex information through WM.

7.2 Chunking & Schema Construction

The binding role of the EB by the CE ties in with the essential use of LTM in processing information in WM. There is a general consensus that WM consists of slots that hold ‘chunks’ of information that enter working memory once they draw the user’s attention. These can then either be lost if not rehearsed or processed into long-term memory (Miller, 1956) usually within the temporal limit of maximum 20 seconds (Peterson & Peterson, 1959). The number of these slots tends to be limited to 3 to 5 in terms of capacity (Cowan, 2010). Chunks that take up these slots have different levels of complexity depending on what is already familiar to the person (i.e., what is already present in LTM). This familiarity comes from schemas. Baddeley et al. (2020) acknowledged these schemas referring to the original findings from Bartlett (1995) and describing them with the definition from Gilboa and Marlatte (2017) as “superordinate knowledge structures that reflect abstracted commonalities across multiple experiences, exerting powerful influences over how events are perceived, interpreted, and remembered.”

These large cognitive structures in LTM allow multiple familiar elements to be condensed into single ones in WM (Sweller, 2005) while also allowing the ignoring of irrelevant information or details (Sweller et al., 1998). According to Baddeley et al. (2020), schemas are important because they enable people to draw meaning as they receive information. This happens by filling in gaps of information, applying generalizations and stereotypes to situations, allowing recognition of objects and being flexible to adapt by having new things added to them or allowing their own structure to be modified.

As an example of schemas impacting WM processing, one can consider a hypothetical student beginning a course on introductory physics. They may be shown the equation for Newton's second law $F = ma$ during their first lecture and proceed to process 1) an equality, 2) a concept of force, 3) a concept of mass, and 4) a concept of acceleration as four separate chunks that fill up four slots in their EB of WM. However, over time as the student becomes more skilled and familiar with the individual concepts and their relation, the equation $F = ma$ itself can be stored in LTM as part of a schema that includes Newton's second law among other similar concepts. When later presented with an example problem of two identical objects receiving different magnitudes of force and asking to calculate acceleration, these can be identified as subcomponents that belong to that previously stored schema. What would have in the past occupied potentially four slots in WM due to unfamiliarity would now only occupy one or two, saving the other slots for further details in the problem such as how many objects, presence of outside forces, whether the objects are identical, etc. If the student is introduced to such a problem immediately after learning about $F = ma$, they would not be able to condense all the information into manageable chunks and it would be too difficult to solve. Learning allows the student to construct schemas in LTM that in turn allows identification of attended information as components of chunks and therefore work with them more effectively in the limited-capacity WM.

There are also recognized 'automated' schemas that don't require any space in WM via attention to process, which is different to chunked information that may still need to be consciously processed (Sweller, 2005). An example is the advanced skill of reading. Automated schemas in LTM combine letters into recognizable words, meaning the letter no longer requires individual conscious awareness when one is making their way through reading sentences. Becoming an expert with a topic essentially amounts to learning by building schemas that allow chunking of processes into more manageable pieces or automating them to bypass WM entirely (Kotovsky et al., 1985). Either way, complex processes and the information involved become more manageable with experience through building of these schemas in LTM. Constructing schemas can be adding information to old schemas or fully rearranging them (Baddeley et al., 2020).

With many potential experience aspects involved in a planetarium visit for students, I identified that many of these aspects can influence the recollection of schemas from larger familiar schemas in LTM that were previously established from multiple external sources. Sweller (1988) pointed to the work of Groot (1966) that found chess grandmasters were better able to reproduce chess board configurations than novices. Chase and Simon (1973) clarified this advantage only occurs when the configurations were based on real games. This suggested expert skill over novices lie not in an increased ability to search for good moves with a more capable WM, but via the ability to tap into a denser library of encountered board configurations in their LTM along with the appropriate moves for such configurations. The pieces on the chess board exist as configurations and associated moves which are categorized as schemas in LTM. A novice lacks these schemas and must use more slots of WM to determine the right move to make.

Marcus et al. (1996) explained the concept of *understanding* itself through schema building and the LTM-WM interfance. Simply put, if all the critical pieces of new information cannot occupy WM at the same time, then that information cannot be understood. A student must undergo schema construction through learning so that these elements can eventually fit into WM simulataneously as organized chunks. After this is accomplished, the student can be considered to have gained an understanding of the new information. This leaves an itterative process of sorts. In order to learn, students must make changes to organized structures called schemas in LTM memory so that future information can be processed to make even further changes to LTM schemas to then process even more complex tasks. Meanwhile, changes to these LTM schemas can only occur via manipulation via a spatially and temporaly limited WM that is filled with information the student is attending to from both LTM and sensory input. Again, such limitations can be overcome from the chunking and automation enabled by previously learned schemas.

Effective teaching thus becomes the construction of schemas in LTM while working with current limitations of WM. It was therefore worthwhile for me to consider how, with a limited WM, optimizing its content for the greatest gain in schema construction is what instructors want to achieve in the planetarium. For this I introduced the model of Cognitive Load Theory (CLT). CLT identifies different types of load pertaining to the inherent complexity of a topic and how the information of the topic is presented to a student, whether in a way that is contributing to or detracting from constructing schemas in LTM.

7.3 Cognitive Load Theory

It was especially useful to draw on the work of Sweller (1988) and the later Sweller et al. (2019) regarding Cognitive Load Theory (CLT). In the context of information being processed in WM, CLT introduces a construct of 'cognitive load' as the resultant combined mental effort and mental load due to the limited resources of WM (Paas & Van Merriënboer, 1994). This is modeled in three major components: the intrinsic complexity of the information, known as "intrinsic load"; the manner in which the information is presented, known as "extraneous load"; and the resources that are left in order to learn through building schemas, known as "germane load".

Intrinsic load cannot be manipulated by instruction as its level is inherent to the complexity of the information being presented. This complexity comes from both the nature of the information along with how familiar the person processing the information is with it. Therefore, this load can only be manipulated through either changing the material or the familiarity of the person processing it. Sweller (1988) initially described this inherent complexity as the level of "element interactivity" inherent to the given material. These elements are things that need to be learned and their interactivity refers to how many of them need to be held in WM simultaneously, as opposed to being able to serially learn them in isolation. This may sound familiar as element interactivity is a direct result of previous schemas stored in LTM and the ability of the EB to chunk these elements. With familiarity of material, what would be multiple interacting elements for somebody inexperienced, they can be reduced to a single element for an expert. In the example of the last section with Newton's second law, the equation $F = ma$ would initially have many interacting elements and would therefore present a high intrinsic load for novices. Meanwhile, experts could treat it as a single element with low element interactivity and therefore low contribution to intrinsic load.

Extraneous Load results from how the presentation of information manifests. This can be altered through the design of the instruction. More recently, Sweller (2010) has associated element interactivity with extraneous load as well in that a large number of interacting elements not productive to learning leads to a high extraneous load. Intrinsic and extraneous loads stack as total cognitive load, of which a maximum limit exists due to limited WM. What results is high extraneous load becomes an issue when intrinsic load is already high through high element interactivity. The limited resources of WM in this case are used up and learning cannot take place. What follows then is the consideration of what must be optimized to allow for learning.

Germane load is the load required in schema construction and automation (Sweller, 2005). In other words, this load is dedicated to dealing with the content of intrinsic load through learning. What this means is that when less WM resources are needed to deal with extraneous load, the more can be used to construct schemas in LTM in order to process the content in intrinsic load. From Sweller et al. (1998), this germane load was also additive in that the stated goal in instructional design was to reduce extraneous load to replace it with germane load. However, this was revisited later (Sweller, 2010; Sweller et al., 2019) in considering germane load as not an independent source of load by itself but rather a designation applied to the WM resources left available to deal with the intrinsic load's interacting elements.

The goal of instruction is then as follows. Given material with an intrinsic load caused by the inherent interacting elements resulting from complexity and student experience, extraneous load tied to the manner of instruction must be minimized in order to maximize the germane load required to deal with the intrinsic load through schema construction. This extraneous load is caused by its own interacting elements as a result of both complexity and student experience. Optimizing space for germane load can be accomplished by analyzing the element interactivity of the intrinsic and extraneous loads prior to instruction and making adjustments to instruction. Such instruction must direct attention away from elements that contribute to extraneous load and towards schema-building tasks.

It is important to consider sources of this extraneous load from the planetarium. A more recent model by Choi et al. (2014) put special attention on the learning environment itself and its contribution to cognitive load, adapting an earlier model by Paas and Van Merriënboer (1994). He suggested cognitive, physiological, and affective effects of the environment on the student, which Sweller et al. (2019) designated as uncertainty, stress and emotions respectively, compete with processes in WM that are relevant to the task, thus increasing extraneous load. The planetarium environment no doubt holds aspects specifically relevant to these domains.

8 Discussion

In this chapter I continue the development of the unified model initially proposed at the end of chapter 6. With this model, the initial research goal of the investigation can be addressed by characterizing the digital planetarium as a teaching and learning space. It was clear from the discussion so far that the planetarium environment is a complex teaching and learning space. Any endeavor to make use of it has two complimentary aspects: that of the designer and that of the recipient. While the designer, in this case the instructor, has a fair amount of control of the space, there are a number of factors that are beyond the control of the instructor. The most important factor in this case is the response of the recipient, in this case the student. In order to structure this space so that it becomes a meaningful experience for the student centered around learning, several factors must be taken into account. These range from seemingly mundane issues, such as seating, to cognitive issues that affect the degree to which students create meaning from moment to moment.

I initially proposed a broad model of planetarium instruction that models student engagement at an appropriate level in order to inform the effectiveness of curriculum design (Figure 6-16). Here I show how I continue to build up my broad model using the theoretical supplement from chapter 7. This broad model was initially based in a potential synthesis of the localized model of student engagement that emerged from the emergent key ideas of student responses along with a localized model of contextual influence that emerged from the complexity of planetarium aspects I identified and documented from planetarium visit observations. The question of how this complex web of inputs contributes to the planetarium experience of a student through drawing their attention has a more focused scope when I bring in the cognitive theory explored in the previous chapter.

I will first center on the student in the planetarium and make the argument that their experience is an appropriate case of working memory (WM) and schema construction. This leads to WM being compatible and applicable to the emerging model in Figure 6-16. With this established, I then consider the use of the planetarium through the guidance of Cognitive Load Theory. Specifically, I look at how instruction should consider the limited WM resources of students through identifying the interactive elements inherent to various planetarium aspects. I then broaden the scope of the model to the perspective of curriculum design in the planetarium. This introduces the various degrees of influence the instructor, as curriculum designer, has on the many aspects of the planetarium. I also consider how that influence is incorporated into the instruction that is planned and administered with a preconceived instructional intent.

8.1 Student Engagement from a WM Perspective

Students are brought to the planetarium to be shown material as a supplement to the course curriculum. While at the planetarium they experience content that they must interact with in some way with the purpose that they then leave the planetarium having learned something. From the previous section, I can reduce the process of learning down to making changes to a student's LTM in the form of constructing schemas. These changes to schemas I will now refer to as the Instructional Outcome extracted from the Figure 6-16 model as that is what students walk away with following the planetarium instruction. This must take place via the WM of students as they perceive information and attend to it with the process of their Central Executive. WM has limited capacity but can also deal with complex information through previously learned schemas held in LTM. This takes place via chunking information into smaller elements with the Episodic Buffer or automating some information processing entirely. The CE of the student has two functions of attention. The first is simply automated attention. The second is active attention with the supervisory attentional system (SAS) when novel information or something unfamiliar must be consciously attended to when automation is not possible. Students are thus faced with the information they are presented with in the planetarium, which they then attend to or suppress with their limited capacity WM. For my purposes here, I will focus on the following key elements: 1) the supervisory attention system, 2) the (limited) span of four slots 3) long term memory and 4) the episodic buffer that brings it all together. [29]

Here I apply WM "under the hood" to my previously proposed unified model of planetarium instruction (Figure 8-1). The planetarium aspects present information to the student that the students must attend to with their limited WM. The instructional outcome takes the form of schema construction in LTM resulting from how WM attended to these aspects and interfaced with LTM. Interfacing takes place via chunking and automation in the EB according to the student's previously stored schemas in LTM. This simple yet insightful model based on Baddeley et al. (2020)'s functional description of WM gives an indication both of why students can have a variety of aspects that they reflect on following the planetarium experience and why certain aspects can draw their attention over others. If something draws their attention based on the SAS of the CE, that is what will occupy the limited storage of WM.

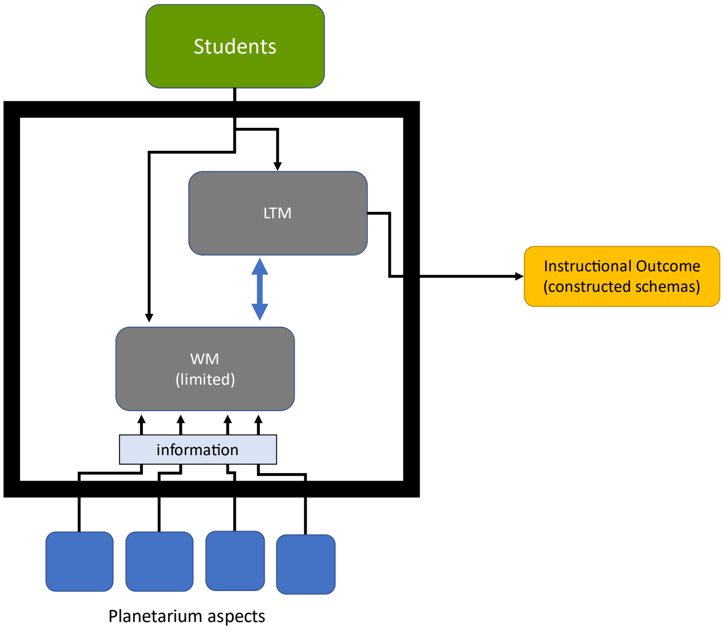

Figure 8-1. Confirming the compatibility of my proposed unified model of planetarium instruction in Figure 6-16 with Baddeley's WM model. The student engages with the different planetarium aspects as information that competes for the their limited WM. This determines what new LTM schemas are constructed from the experience, which make up the Instructional Outcome. This confirms WM, and therefore CLT, can be used for theoretical coding to expand the unified model.

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[29] It is not necessary here to distinguish between modes of storage such as auditory and visual information, although these could also play an important role which we reference later (see chapter 9).

Students arrive at the planetarium with their previously constructed schemas in LTM that may feature multiple aspects of the planetarium experience. This could be schemas containing concepts of the learning material, such as the celestial sphere, which would be relevant if the student is expected to attend to a presentation corresponding to a review of the celestial sphere. Students could also have schemas in LTM that contain features of the planetarium environment itself. If a student has never been to the planetarium, it is most likely that many novel features present in the space may be unfamiliar, leading to more slots of their WM being occupied. In this case aspects of the planetarium itself would potentially have high element interactivity. While high attentiveness to a particular task is relatively easy to explain based on salient input, low attentiveness is a much more complex phenomenon. There are many reasons for lack/loss of attention other than simply boredom or distraction from an off-task salient input. I consider the attentional control of the students here in that the Central Executive can either be automated or invoke the SAS to pay attention when directed or presented with novel information.

8.2 Using Cognitive Load Theory

With the argument made that student engagement can be modeled with WM, I can apply the concepts of both schema construction and element interactivity. With that I can justifiably invoke the framework of cognitive load.

A student has limited WM resources that must be considered when they are faced with processing information in the planetarium. The element interactivity of this information, based on its inherent complexity and the student’s previous experience in the form of schemas in LTM, is the deciding factor in whether the information can be processed to learn and construct further schemas. The use of these limited resources can be taken up by intrinsic load caused by the material of the instruction, or extraneous load, caused by the manner in which the material is taught. Any available WM resources not used up by the combined intrinsic and extraneous load can be used to construct LTM schemas, or allow germane load, which is the desired instructional outcome. In other words, the level of attention, the total of which can be considered a combination of on-task and off-task, can be described by CLT in terms of a combination of intrinsic, extraneous, and germane load.

The planetarium as a potentially unfamiliar environment is more likely to have aspects that presents information to students that cause a high extraneous load. It is possible that this is not an issue if the material being taught is itself composed of few interacting elements, causing a low intrinsic load. Here a high extraneous load from elements of the unfamiliar environment will still have WM resources left over for germane load so that schemas relevant to instructional intent can be constructed in LTM. However, if both intrinsic and extraneous load were high due to a planetarium experience being composed of high element interactivity, from either instruction material or the manner in which it is presented, learning cannot take place and the instructional outcome may be unproductive.

A scenario of high intrinsic load can come from students being presented with an unfamiliar topic. This may be a non-issue if students are already familiar with the planetarium. In this case the aspects of the experience would contribute little extra information and leave sufficient WM resources to construct schemas for the unfamiliar topic. The students effectively learn in this case because the high intrinsic load along with the low extraneous load of the familiar planetarium was low enough for sufficient germane load to tend to the content of the intrinsic load. Conversely, if students have never been to a planetarium, simple or more familiar material, such as a topic review, should be taught. In this way a low intrinsic load is paired with the high extraneous load that the unfamiliar planetarium aspects will bring.

Anything taking up limited WM resources that is not relevant to the material should be considered as causing unnecessary extraneous load. In my localized model of student engagement from section 6.2, I can now recognize that decreased learning from either a high or low level of “attentiveness” as a high level of extraneous load that is preventing learning. In the case of “high attentiveness”, other things are drawing attention away to cause the increase. In the case of “low attentiveness”, the relevant aspects of the show are not drawing attention enough. Concerning the latter, Kalyuga et al. (2012) used cognitive load in the context of low learning for experts of a topic to explain what is described as the “expert-reversal” effect. This is the phenomenon of diminishing and eventually reversing returns of instruction that may be initially effective for novices, but ineffective and even detrimental to experts. Specifically, as people become more experienced with information, the same form of instruction was found to diminish and eventually reverse in effectiveness to become detrimental to the expert’s understanding of the situation at hand. He explained the phenomenon as those with sophisticated schemas related to a topic are forced to cross-reference the unnecessary low-level details of the lesson, thus causing the use of additional, unnecessary cognitive resources and thus causing higher extraneous load.

I explained the case of a student learning through interaction with planetarium aspects through the scope of cognitive load. The question now arises on what an instructor’s role is, specifically in the context of making the decision to visit the planetarium with their students and the curriculum design that follows. Students brought to the planetarium have a two-way system of 1) bottom-up processes through their senses and attention that occupy the limited capacity working memory and 2) the top-down processes of LTM schemas either condensing that information into manageable chunks or bypassing WM through automation while deciding where to direct attention. It is not just the quantity and variety of information from planetarium aspects that potentially fills the capacity of WM, but also how familiar the student already is with those aspects to condense them into those chunks. This completes the model by considering it from a perspective of curriculum design.

8.3 Proposed Model for Curriculum Design in the Planetarium

When considering my localized model of contextual influence from Figure 6-15 regarding the aspects contributing to the planetarium experience for students, the complexity was immediately clear. This complexity is important to acknowledge when the planetarium is being used by an instructor with specific instructional intents, as there is the potential for these aspects to either reinforce or detract from these intents. In this way, the digital planetarium can be truly employed as a complement to a curriculum, contributing with its unique benefits if its weaknesses are diminished. Of course, what constitutes a benefit and what constitutes a weakness would vary based on the context of the planetarium’s role in complementing the curriculum; any potential model must provide the flexibility to identify these so a planetarium experience could be planned, implemented, and assessed accordingly.

From the arguments in the previous section, I now consider these aspects through their contribution to cognitive load. However, this itself is not immediately useful as these aspects can originate from a variety of sources with a variety of influences from the instructor planning the visit. Here I set out on how to categorize such variety into a workable model from the instructional design perspective. Such a model must consider both the instructor’s intent and the influence they have on aspects of the planetarium experience, all the while incorporating the constraints imposed by the student which I proved can be modeled by CLT.

First, I consider the overall context of the visit. The planetarium can be used to supplement a lecture series through either single or multiple visits or the planetarium itself can act as a prime venue for a lecture. Within this context, I consider the users involved in the experience. There is the common case of an instructor taking their students to the planetarium, but I also acknowledge the individual operating the planetarium facility. Furthermore, there is the potential to have a developer if a show was designed beforehand. With this in mind, I establish the category of **instructor**, who can be multiple people in the form of the course convener, the operator of the planetarium, the designer of the show, tutorial instructors assisting, etc. Opposite the instructor there are the **students**, which is the audience that the instructor aims to teach.

Next, I consider the intention of the instructor. What do they wish to get out of the planetarium experience? What should the student understand differently after leaving the planetarium? This I label the **instructional intent**, a recurring concept identified throughout the investigation's analysis. Borrowing from the previous emerging model of instruction (Figure 8-1), I can also classify this as the *desired* instructional outcome of constructed schemas from the planetarium experience. It is with instructional intent where one can initially assess intrinsic load based on student experience as it directly states what the material of instruction will be.

The digital planetarium is chosen as a facility to visit because of certain features and capabilities it possesses that the classroom or lecture hall lacks. My model should account for this by identifying these features as **primary (or essential) aspects** to the experience. From the instructional intent, it is important to then identify these primary aspects of the planetarium that are useful or even necessary to fulfill it. These can be specific components of the planetarium environment, such as the full dome, or the software capabilities of rendering scenes and visuals. From CLT terminology, I consider primary aspects of the planetarium as things that are specifically targeted for their ability to reduce extraneous load for a given instructional intent. These primary aspects "open up" the planetarium for the instructor's consideration as a teaching and learning space.

Outside of these primary aspects, I consider everything else that contributes to the experience. These are aspects that, though not directly linked to the rationale of making use of the space, do have important contributions to cognitive load. I categorize these based on how much influence the instructor has on them. Deciding to play music during the show, for example, can be influenced, but may not be a primary aspect that the instructor decided to use the planetarium for. I label these aspects under reasonable control of the instructor that are not central to the decision to use the planetarium as **secondary (or supplementary) aspects** of the planetarium experience. Seating assignments, font size on labels, the script of the instructor, and the pacing of the show are examples of secondary aspects that the instructor has reasonable influence over.

The remaining aspects are **tertiary (or independent) aspects**. These are components of the planetarium experience that are not considered reasons for making use of the planetarium and are out of the instructor's reasonable control. This includes, for example, the location of the planetarium, especially relative to the main learning setting if the experience involves a visit. This could also include organization of the facility such as whether it is part of a museum, a room at a university, or even portable. The physical aspects of the planetarium are also key. This includes the size of the planetarium, seating arrangement, whether its analog or digital, and other general notes on the status: Are the projectors and speakers operating correctly? Do the software visuals lag? Is there ambient noise such as the fans required for inflatable planetariums?

These aspects of the experience and their relation to the instructional intent and outcome require compatibility with the student engagement I modeled previously. The result is the **Model for Developing Instruction in the Planetarium (MCDiP)** in Figure 8-2.

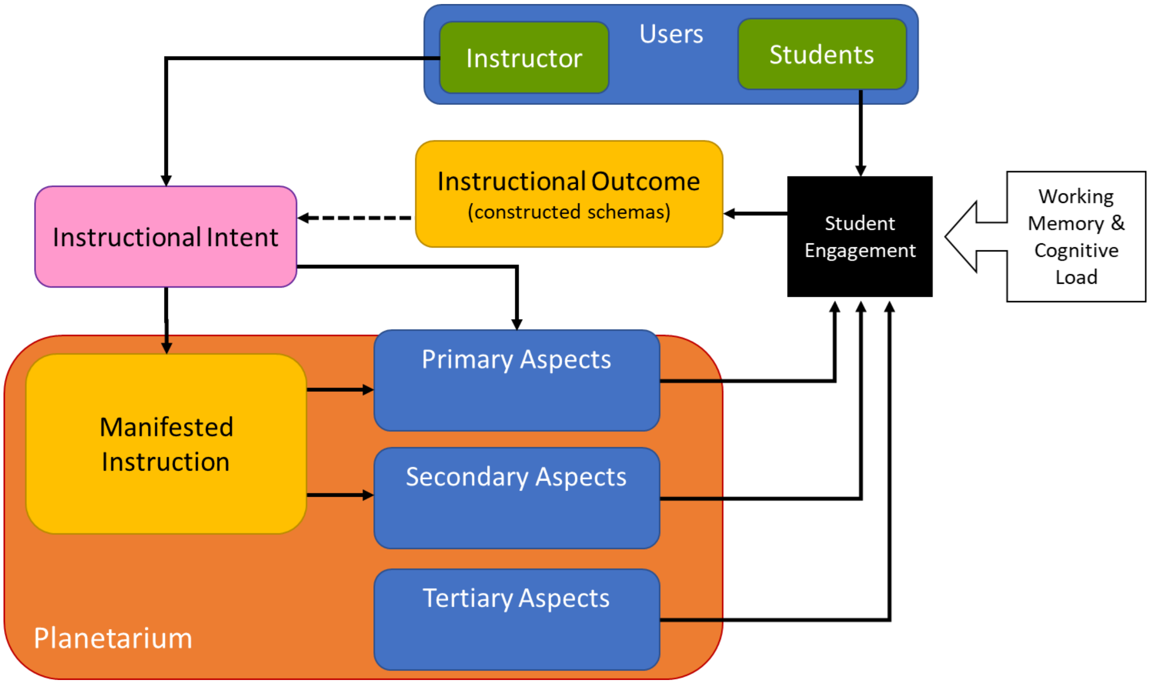

Figure 8-2. Expanding my proposed unified model of planetarium instruction from Figure 6-16 to create the Model for Curriculum Design in the Planetarium (MCDiP). Users come to the planetarium as the Instructor and Student. The Instructor has an Instructional Intent in the form of potential schema they desire students to construct in their Long Term Memory (LTM) after the experience. This Instructional Intent results in a Manifested Instruction that takes place in the planetarium. The planetarium experience itself is composed of Primary, Secondary, and Tertiary Aspects. Primary Aspects are pieces of the experience that the Instructor specifically wants to make use of the planetarium for. Secondary Aspects are the remaining pieces of the experience that the Instructor has reasonable control over while Tertiary Aspects are outside reasonable control. Primary and Secondary Aspects result from the Manifested Instruction. These Aspects compete at varying degrees for student's attention by engaging with the student's limited Working Memory. The result are the constructed schemas written into the student's LTM, which can be compared to Instructional Intent to assess the success of the teaching and learning experience. Meanwhile, aspects of the planetarium experience can be systematically categorized both by the instructor's influence (Primary, Secondary, or Tertiary) and what type of potential Cognitive Load (Intrinsic, Extraneous or Germane) they impose on the student.

The initially proposed unified model of planetarium instruction from Figure 6-16 is fitted nicely into MCDiP in considering an input of aspects and a resulting **instructional outcome**, which is the resultant schema construction in LTM for the student. This outcome can then be compared to instructional intent to assess the planetarium's use as an effective teaching and learning space. To put it bluntly, if this instructional outcome reflects the instructional intent, then the visit to the planetarium was a success! MCDiP also clearly indicates how the instructional intent has a direct connection to primary aspects in "opening up" the use of the planetarium. Without primary aspects, there is no justification to employ the planetarium as an effective teaching and learning space. I also included here an element of **manifested instruction** to refer to the final administration of instruction that we see has an input to

Primary and Secondary aspects, but Tertiary Aspects remain independent. I also draw parallels here of MCDiP with curriculum theory (Van den Akker, 2004), namely that Instructional Intent, Manifested Instruction, and Instructional Outcome map appropriately with Intended, Implemented, and Attained curriculum.

There are thus two ways to classify planetarium aspects according to MCDiP. The first, originating from the low-level student model, is how those aspects impact cognitive load. If they contribute to a high extraneous cognitive load, any high intrinsic load originating in the content of instructional intent would lead to a high total cognitive load, thus hindering germane load and learning. Such classification comes from identifying the background and experience of the students and their familiarity and/or knowledge of these different aspects along with instructional intents. The second way to classify planetarium aspects is from the curriculum development perspective. Given an instructional intent, some aspects are specifically chosen as reasons to visit the planetarium to fulfill this intent, which are labeled as primary. Others are then categorized by what sort of influence the instructor has on them. Aspects with reasonable influence I label as secondary and the remaining independent aspects I label as tertiary.

MCDiP initially began as its own substantive grounded theory from the synthesis of two localized pragmatic models, themselves being substantive grounded theories. Through the theoretical supplement of WM and CLT, MCDiP takes on a more generalized use for instructors making use of the digital planetarium in a formal learning environment. MCDiP thus sets the basis for a formal grounded theory that addresses the initial broad goal by characterizing the digital planetarium as an effective teaching and learning space.

9 Implications for Instruction in the Planetarium

Here I take a look at the implications of the MCDiP. Particularly, I consider the model's use as a tool to systematically design curriculum in the digital planetarium for formal education and to probe the resulting curriculum's effectiveness. The task of an instructor essentially becomes assessing the situation guided by MCDiP, even prior to making the decision to visit the planetarium with their students. Recall from CLT that the goal in instruction should be to maximize germane cognitive load that allows schema construction dealing with the intrinsic load that we have tied directly to instructional intent. Assessment should therefore involve several considerations.

The starting point should be considering the value of visiting the planetarium. This is particularly important with the planetarium as a teaching tool because it is often a time and resource investment for a curriculum to incorporate it. This can be assessed by first identifying primary aspects of the planetarium facility that minimize the extraneous load of students for certain instructional intents present in the curriculum. Recall that these primary aspects are considered unique to the planetarium that cannot be found with other facilities or tools that may be more accessible or implementable. It thus becomes a possibility that avoiding the planetarium completely may be a consideration for a course convener. My observational findings of the inaccessibility of the software and resources in planning a show only reinforce this notion. Basically, the planetarium should have a good reason for visiting it.

The instructor should also decide what material to teach in the planetarium. In other words, they must identify the instructional intent and the intrinsic load of its content. This may involve a pre-assessment of a few evident planetarium aspects and their contribution to extraneous load as well as the present experience of the students. For example, surveying if students have been to the planetarium previously could be a quick method of engaging a familiarity aspect. If these aspects are composed of many interacting elements, then it would be difficult to teach a new or complex topic with high element interactivity. A simpler or familiar topic would be best in this case. Preference should of course be given to topics for which primary aspects of the planetarium can be identified that minimize extraneous load.

Perhaps the most difficult thing for the instructor to consider is how to plan and administer an effective planetarium show for students. This is due to the potential complexity. It is here where an instructor must assess, given an instructional intent with an intrinsic load along with the constraint of tertiary aspects of the planetarium, how primary and secondary aspects can be configured to both minimize element interactivity that causes extraneous load and emphasize aspects that encourage germane load. This is not a straightforward process and, in many cases, may even involve trial-and-error. For example, following a trial planetarium visit, instructional outcome can be compared to instructional intent with instructional intent, as well as primary, and secondary aspects adjusted accordingly for a future visit. It would be advisable to start simple and introduce planetarium aspects systematically, such as withholding music or limiting the number of topics and adding them in later.

The above considerations may be visited non-linearly as well. For example, an instructor might decide on topics to teach in the planetarium and the primary aspects that are suitable for these topics, satisfying the first two considerations above. However, when looking at the third consideration and identifying the details of an effective show that minimizes extraneous load, the intrinsic load might just be too high. The first consideration would then need to be revisited to drop or add a topic to accommodate the situation. Or maybe after not identifying primary aspects for topics to see if the planetarium is worth visiting in the second consideration, the first consideration should be revisited to seek out instructional intents in the curriculum that do have such aspects.

It may sometimes be unclear whether identified aspects lead to high extraneous load, and it may even be subjective in some cases based on different students. In SPV2, for example, there was certainly no unanimous consensus of the resulting audience experience. Some thought segments were too long, some thought the same segments too short. This subjective experience is complex. When an audience of multiple to many students is involved, it becomes a potentially cumbersome task and even an issue of "overfitting" if too much detail is considered and accommodated for. The MCDiP assessment process would probably need to be scaled in a case of balancing where the most general gains can be made with the least assessment. For example, a quick "raising hands" survey of whether students have been to the planetarium already might be practical for a large cohort of students. If there are only a few students, more personal-level questions such as their sensitivity to loud noises or motion sickness may be asked.

Of course, there is the possibility of aiding this entire process by preemptively constructing schemas prior to visiting the planetarium that would reduce the extraneous load of certain tertiary aspects that cannot be adjusted during the visit. This could of course take the form of an orientation session as Ridky (1975) recommended, but also building schemas in the classroom that would reduce element interactivity for extraneous load. For example, the lecturer could use similar imagery[30] in lecture slides, notes and handouts as that used in the planetarium. This could be easily done with screen-grabbing software on the planetarium system and then pasting onto PowerPoint slides. It could also be made explicit how the planetarium will look different than lecture visuals. For example, the instructor could explain the transition from the external representation of the celestial sphere to the internal. The celestial sphere in lectures prior to SPV1 predominately showed the celestial sphere from the "outside", which we saw in all drawings from the questionnaire that this is how the celestial sphere was generally considered by the students. The lecturer also showed representations of the celestial sphere using *Stellarium* in lecture, but it may be worthwhile to show a diagram of how in the planetarium the students will be shifting their perspective to sitting inside the celestial sphere. This could prevent the necessary extraneous load for students at the beginning of the planetarium experience as schemas are reconstructed to recognize how the celestial sphere looks from the inside.

Overall, the MCDiP points to the necessity of multiple visits if the full benefit of the planetarium is to be realized. These must be visits that focus on related topics over several sessions. The first visit would serve as a means of gaining familiarity with the presentation of topics in the environment. The second or subsequent visits would be conducted with more confidence that students possess in their LTM more elements of the subject matter together with the context of the planetarium and its associated aspects. As familiarity with the planetarium space is gained over time, more complicated and unfamiliar topics can be introduced in a scaffolding manner. This is assuming the planetarium already begins as an unfamiliar environment for students, which is a safe assumption for most students.

An assessment through MCDiP can also lead to identifying conflicting aspects of the planetarium experience. This is especially important if it turns out that primary aspects associated with topics of instructional intent are conflicting by stacking extraneous load when they are introduced together either through complexity or invoking conflicting schemas. Recall the situation with the instructor in SPV1

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[30] font, colors, images, etc.

including topics from the course curriculum in the instructional intent alongside showing the students how the planetarium is a “nice place to go”. This was risky as there may be aspects an instructor wanted to show that reinforces the facility as “nice” but then might make it harder for the student to activate the relevant schemas for other instructional intents that are of higher priority. This could lead to high extraneous load and prevent satisfactory schema construction. It may be better to leave the “nice place to go” instructional intent for a preliminary orientation session and drop it in future visits to prevent conflicting primary aspects.

Other ideas for reducing extraneous load include keeping the visual content on the dome minimal and the essential use of a laser pointer to direct attention to reduce the extraneous load of the immersive dome. Fisher et al. (2014) found that decorated classrooms with diagrams and charts have a detrimental effect on learning for students, and a stack of visual stimuli in the digital planetarium can be analogous to this. The planetarium’s dome may provide a way to show information in a way that is less cognitively demanding in one context but could easily be counterproductive if an instructor is not directing the student attention to the relevant visual. For example, the critically important image of the Sun rising at the back of the dome could be missed while students attend to the prominent galactic center overhead, anticipation of a familiar song being played in the background, or even the reclining seat.

I previously invoked the expert-reversal effect as an empirical effect that fits with CLT and could be applied to a tedious experience for students as found in SPV2. From Sweller et al. (1998) and more recent updates to the CLT model (Sweller et al., 2019), there are a collection of more of these learning effects from empirical findings named and explained/modeled using CLT. It would be worthwhile to adapt some of these to instructional design in the digital planetarium with MCDiP. In this way, instead of simply looking at instruction in the planetarium and considering it from a CLT framework, researchers can also strengthen the model through considering empirical findings from the framework and applying it to other potential scenarios. A small collection of relevant effects is named here.

The Split-attention and redundancy effects may help with the storyboarding and planning of a show’s content. The split-attention effect finds that when multiple, separate components must be considered and integrated together to find a solution, the process leads to high cognitive load and hurts learning. This is avoided by integrating the information initially in presentation of the problem. Tarmizi and Sweller (1988) used the example of a geometry diagram with angles labeled in a figure with measurements listed under the figure as leading to the split-attention effect. Students fared better when the angle measurements were integrated directly into the figure. The similar redundancy effect from the work of Chandler and Sweller (1991) was found in the situation when there were multiple components presented that could be understood in isolation and did not require integration. In this case integrating added components that were unnecessary yet difficult to ignore increased extraneous load. Both these effects can be used to better choose and integrate the visuals of a planetarium presentation with the given software of the dome and decide how a script would complement them. For example, the split-attention effect could guide how an instructor can balance between use of the sweet-spot and periphery imagery on the dome. With the redundancy effect, when demonstrating the distance to Voyager 1 in SPV2, a visual of all the orbits of the planets was used when I could have just used Earth or Pluto alone. Each individual orbit would provide a reference point for scale of an orbiting planet of the solar system but together they would be redundant and increase extraneous load for understanding how far Voyager 1 has traveled.

The modality effect initially discovered by Mousavi et al. (1995) takes into account the different modes of WM storage modeled by Baddeley such as the auditory information of the phenomenological loop and the visual/spatial information of the visuospatial sketchpad. The implications with this are the ability to effectively increase WM limitations by presenting information that is processed in the different components of WM, thus reducing extraneous load and facilitating learning. The distance circles used in segment 1 of SPV2 can possibly be visual information processed as spatial information that could be processed separately from the auditory information of the instructor's voice. The distance counter in segment 2, by contrast, could occupy the same auditory information processing as the instructor's voice, thus increasing extraneous load. This effect really speaks to the power of including CLT in MCDiP. Its basis in the low-level WM model allows us to occasionally "peek under the hood" to finely examine and tune how planetarium aspects are contributing to student engagement.

The transient information effect from Leahy and Sweller (2011) identifies the cognitive load of information like spoken words and animations that is presented to students but disappears within seconds. As opposed to non-transient information, students may need to hold transient information in WM for later processing, increasing extraneous load and hindering learning. Two effects to get around this are the self-pacing effect (Mayer & Chandler, 2001) that found students having control over pacing leads to learning benefits, and the segmentation effect (Spanjers et al., 2011) that found animations in segmented pieces with pauses in between was better for novice learners but not for experts. This is critical with the planetarium setting as information is often presented in a "show" format. The self-pacing effect can probably be adapted with a high-skill operator that can easily go back to portions of the show if students want a section repeated. I also take note how our own distance show from SPV2 did incorporate pauses in between objects, which is a major difference to the original Powers of Ten video that has a constant zooming animation. Such a difference is important in the potentially high-extraneous load environment of the planetarium as opposed to watching the original video on a flat screen in the lecture.

There are a few more of these effects and new ones are being introduced in the literature as CLT is applied to more empirical results in education research. It would be worthwhile to further apply these effects in the specific context of planetarium teaching in order to enrich MCDiP.

The limits of the single digital planetarium also revealed the lack of information and documentation on the various planetarium software. Efforts should be made, in a similar spirit to Faherty et al. (2019), to consider the interoperability of this software, specifically for educational use. This could also be centered around the opensource *WorldWideTelescope* and *OpenSpace* projects. In the design-phase of SPV2, the lack of resources, both for knowledge and content, for developing a digital planetarium show for IPDD proved to be a barrier to me in understanding the facility's capabilities. It is highly likely that this would be an issue for most educators wishing to introduce the planetarium into their curriculum with MCDiP. A compiled resource of effective digital planetarium use should also include guides and other resources contributed by the community that would include pre-made content[31] that can be transferred between planetariums, commented on and rated using the MCDiP as a guide. This would prevent the need to "reinvent the wheel" for educators while also giving them confidence that the

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[31] Pre-made content could include assets like the circle distance grids or scripts like the camera movement for the distance show in SPV2.

aspects they are implementing have been tested for effectiveness by the planetarium education community.

Overall, MCDiP should serve as a guide for instructors considering using the digital planetarium to complement their formal curriculum. This can lead to productive assessment on whether the planetarium should be used, what should be taught, and how it should be taught. The latter is more complex, but the ongoing development of CLT as a theoretical supplement to MCDiP promises an increasing opportunity to manage this complexity.

10 Investigation Rigor

I decided from the start of the investigation to toe the line of the pragmatic flavor of GTM in the constructivist tradition. As mentioned back in the introduction, this extended to assessing the validity or quality of the derived grounded theory. In the words of Bryant (2017), “the products of GTM- oriented research should be judged not in terms of correspondence to reality but with regard to whether they are useful in serving certain purposes and practices”. This means that a critical look at the investigation should primarily assess the utility of the emergent grounded theory. In the context of this thesis, this means critically assessing MCDiP itself. I therefore take a look at what I call the “rigor” of the investigation by assessing how well its resulting abstraction at different stages fits lower-level data.

According to the GTM, a primary method of judging the quality of the investigation is assessing theoretical saturation. This is when introducing low-level data directly to established abstraction, a process called theoretical sampling, no longer introduces new categories and concepts but rather reinforces previous ones. Although theoretical saturation is not something that can simply be claimed as achieved or not, efforts can be made to assess it. With that being said, I first consider instances of identified instances of theoretical sampling that took place throughout the study. This demonstrates the sensitivity I afforded throughout the study to addressing this key component of GTM. I then apply the final product of the study, MCDiP, to a few scenarios and situations from my own planetarium visits as well as previous planetarium studies. This is a way to demonstrate how well low-level data fits into the final concepts of the model, reflecting the final theoretical saturation. Of course, there can be a bit of a contradiction if I claim this using the data from which the model emerged, specifically from SPV1 and SPV2. I therefore also apply the model to empirical results from two other studies in planetarium education research.

I must remind the reader that I do not consider MCDiP to be a full formal grounded theory, but rather setting the basis for one. It started as a substantive grounded theory based on a use case in a formal education environment. With that in mind, it is critical that the model undergoes further rigorous testing in order to prove its quality with more data. I give examples in this chapter of how MCDiP can be applied, but it will be up to further empirical studies to graduate MCDiP to a true formal grounded theory. I go into more detail on such future research in Chapter 11.

10.1 Identifying Theoretical Sampling

One instance of theoretical sampling that took place was in the student questionnaire analysis as a result of the high number of students taking part in the study. The addition of student questionnaire responses throughout the iterative coding process enabled coding to be done on subsets of the responses and then expanded to the wider set. This varied between response sets, but sometimes I started with, for example, a subset of 20 responses that I would code over several iterations and start to form categories from. This made the process more manageable than considering the full 94 respondents at once. It also allowed me to assess as the coding process proceeded that my refinement, condensing, and culling of previous codes and categories was making progress. This became apparent as new subsets added would have codes assigned pertaining to previous ones. This happened within the PhAsER group as well where we would discuss and debate these assignments if disagreement arose until 90% consensus was achieved. The high sample size of questionnaire respondents was enabling later subsets of the responses to undergo theoretical sampling.

Another instance of theoretical sampling was in the coding of observational data. As I mentioned in section 6.2, as higher-level aspects were identified, I could seek out lower-level aspects within the observational data and preconceptions. This back-and-forth produced entire branches of planetarium aspects that may have gone unnoticed otherwise. The necessary top-down populating of what became the localized model of contextual influence was a form of theoretical sampling. It found new aspects via the high-level categories that emerged from common themes in other low-level aspects.

There was also theoretical sampling across the data types. For example, in the coding process of the questionnaire data in SPV1 where students explained what they learned, mid-level emergent categories were found to correspond to the intention of the instructor, found previously in observational data. The intention of the instructor was then organized as Instructional Intent, which was a high-level concept. This concept formed a key part of the localized model of student engagement, where it determined what productive engagement was. It also was an important aspect in the localized model of contextual influence. The emerging concept of *instructional intent* ended up becoming a key component of MCDiP.

Finally, splitting the investigation between phases of SPV1 and SPV2 also allowed for instances of theoretical sampling. The questionnaire data collected from the two visits were coded separately. Despite this, and despite the questionnaires asking different forms of questions, the SPV2 analysis uncovered similar key ideas but at a finer resolution. Specifically, it also placed student ideas into learning and novelty, but in positive and negative flavors. A key reason for this resolution improvement came from expanding the questionnaire scope to enable the students to highlight their negative ideas regarding the experience. Deciding to administer the questionnaire after each component also broke down the change in these key ideas over the temporal span of the SPV2 show. These changes enabled the key identification of how student ideas of learning and novelty diverged into positive and negative varieties that changed with time. Furthermore, my decision to capture planetarium aspects not previously present in SPV1 by including digital capabilities in SPV2 made use of early identification (see section 4.3) of the planetarium environment and content being important components. Although not revealing high theoretical saturation at the time, this informing of SPV2 show and instrument design choices based on SPV1 did reveal the progress of a GTM investigation. SPV2 essentially formed a session of moderate theoretical sampling in response to the more open nature of the SPV1 data collection and analysis.

10.2 Further Evidence of Model

I continue here by explicitly applying low-level data and results from the investigation itself into the final MCDiP. This is followed by a similar look at applying MCDiP to two other studies of planetarium education research. This serves to assess how well theoretical saturation was achieved, though a more thorough look at improving this is discussed in chapter 11.

10.2.1 Student Planetarium Visits

Here I use my documentation from our observations of SPV1 and SPV2 to find empirical areas where MCDiP applies. I first identify in Table 10-1 concrete examples of MCDiP from SPV1. These examples are not an exhaustive list.

MCDiP Component	**Corresponding low-level data from SPV1**
Instructional Intent	Visualize the night sky and celestial sphere in "3D"; Show how the Sun "moves" at noon over the course of the year; Show a few of the main constellations and how they indicate cardinal directions; Show precession and debunk astrology; Advertise the planetarium as "a nice place to go"
Primary Aspects	Using the fulldome to wrap visuals of the celestial sphere around the students to put students inside the celestial sphere; telescope montage video used as entertaining advert
Secondary Aspects	Adding music and telescope-montage video to the show, including different locations demonstrate celestial sphere at different latitudes, showing telescope montage video at the beginning, etc.
Tertiary Aspects	Planetarium is off-site, 140 seats; students chat to each other; limitations of *DMSM* software

Table 10-1. Identifying MCDiP components from SPV1.

I then consider some explanations of what we observed. For example, when I look at the instructional intent from SPV1, I identify here possible conflicts that emerge from the resulting primary aspects. In student responses regarding the best part of the experience, 10% of ideas explicitly point to the *Relentless Nights* video as the best part. The video was included as a primary aspect to compliment the instructional intent of advertising the planetarium as a "nice place". This may be in line with a portion of the instructional intent, but here a consideration of priority in instructional intent may need to have been considered. When students were reflecting on the schemas that they constructed from the show, a sizeable portion referred to this short entertaining portion from the beginning.

Another observation was that the instructor already considered part of our model when they indicated in the post-show interview that she would not bring brand-new content into the planetarium. This shows an indirect and valid understanding of the importance of considering intrinsic load when potentially facing a high extraneous load environment. The Likert-scale ratings from students where 78% indicated the overall content was easy also reflects the nature of the instructional intent having few interacting elements as review material from lecture.

The choice to incorporate "relaxing" music as a secondary aspect is also worth examining. I consider from Yu (2020) the various findings of music used in movies and planetariums. For example, Boltz et al. (1991) found that music can affect audience through better recollection of scenes when the mood of the music played concurrently was appropriate for that scene. Interestingly, if music that was not appropriate for the mood of the scene was played before the scene instead of during, then recollection of that scene was better. The researchers invoked schema theory in their own interpretation by suggesting audience members have their expectations violated in such a case. Yu also included experimental evidence of familiar music distracting students from learning material and instrumental music being preferred for a learning environment. Invoked strategically, I interpret this with CLT to suggest complementing and violating expectations through background music can guide students in paying attention to planetarium aspects that encourage germane load. I conclude in general that unobtrusive, unfamiliar music is better. If the music does indeed have a relaxing effect on the student, it may be beneficial at reducing extraneous load according to the environmental effects from (Choi et al.) mentioned in section 7.3 as well as cueing students when and where to pay attention. Lehmann and Seufert (2017) found constant background music to interfere with learning comprehension, suggesting that music in general must be strategically employed if it is to minimize extraneous load.

Other specific examples from students indicating situations of high extraneous load were students, including the comfortable chairs and the feeling of the room moving as their best parts of the show. The former could be considered a tertiary aspect while the latter is a secondary aspect that originated in the decision during the show planning phase to "fly" instead of "jump" between night-sky locations.

I next investigate MCDiP components of SPV2 in Table 10-2.

MCDiP Component	**Corresponding low-level data from SPV2**
Instructional Intent	Give students a multi-perspective visualization that improves their sense of scale of the various celestial objects and distances that they encounter in introductory astronomy.
Primary Aspects	Software can show multiple perspectives using virtual camera; Dome allows objects to "come into view"
Secondary Aspects	Speed of the camera movement; which celestial objects to show and what distances to use; font color and style on labels; randomizing seating; second entrance prevented seeing of distance exhibit
Tertiary Aspects	Second visit by students to offsite location, distance exhibit, limitations of Dark Matter software & resources

Table 10-2. Identifying MCDiP components from SPV2.

I consider that this was the second visit for students and as such a few aspects of the planetarium environment that may have had high element interactivity in the first visit would have less. This warranted the justification of raising the difficulty or complexity of the instructional intent. However, the two segments of the show ended up being so similar that 50% of negative ideas emerging from the second segment being its repetitions to segment 1. I interpret this from WM in seeing this as the Central Executive of students not attending to a situation that they are automating. In the design phase, I could have probably included additional visual cues as secondary aspects to encourage the SAS of the students to engage and pay attention while still maintaining the "different perspectives" primary aspects that the planetarium software provides for our instructional intent. Previously I had classified this as a "lack of attention", but I can also reevaluate with CLT. As I brought up in section 8.3 previously, the expert-reversal effect seems to be a great explanation to apply here. I consider the students as having constructed schemas from the first segment and are therefore considered more "expert" in the topic for the second segment. Forcing these students to revisit details and have them cross-reference to their LTM schemas becomes tedious from the high extraneous load.

I also take note of a few students mentioning the presenter, both in contributing and detracting from their enjoyment. As mentioned in chapter 9, familiarity with the planetarium instructor can indeed have an impact on extraneous load by introducing more interacting elements to student experience of the instruction.

Taking on the curriculum designer role for this visit was particularly insightful for me in identifying tertiary aspects that an instructor could commonly be faced with (see section 5.1.3). The *DSDM* software I was required to use at IPDD, for example, had severe limitations. This was a combination of the software being proprietary, the availability of resources regarding its use, and our own skill levels with using it. It was also challenging to identify primary aspects of the planetarium complementary to my instructional intent of a distance demonstration. I tried to incorporate the immersive display in having celestial objects appear "over the shoulder" of students as they came into view in the second segment.

However, this could have also contributed to the multiple cases of positive novelty experience detracting from positive educational experience. In general, the immersive dome of the digital planetarium seems to still be a clearly valid primary aspect for lessons involving geo-centric visuals while its role as a primary aspect for allocentric visuals can be regarded as a frontier. In fact, the case can be made that the primary aspects in SPV2 were not strong enough to warrant a visit to the planetarium. This is reflected in a response by one student that said it was a "waste of time" to come to the planetarium following the show. The primary aspect that rationalized use of the planetarium (and therefore a visit) could have been challenged because alternate software and forms of media could be found that would allow the same demonstration on distances to be shown in class.

Considering the astronomical distance topic itself, it would be worthwhile carrying out a detailed investigation of the aspects involved in the study of Yu et al. (2017) to apply MCDiP more closely. In that study, the astronomical distance demonstration show led to an advantage with planetarium students over lecture hall students in terms of long-term retention, suggesting manageable cognitive load and valid primary aspects of the planetarium. There was also a critical difference between the student cohorts in the Yu et al. study and that of my study in that the students in the former were tasked with visiting the planetarium and classroom a single time while students in the former had two planetarium visits split between SPV1 and SPV2. This could have important implications especially regarding the expert-reversal effect, which may be dampened if students visiting a single time are given less chance to feel that they are repeating an experience.

10.2.2 Explaining the 'Mystique Effect'

It is useful to apply CLT to the previous work of Ridky (1975) who found a key difference in how students are introduced to the planetarium and its impact on learning. At the time of the experiment there were numerous studies being published that did not show an advantage of using the planetarium over a classroom to teach astronomy, and in some cases was worse. He hypothesized that a lack of an orientation session could be related to the ineffectiveness of the planetarium.

Through informal discussions, planetarium professionals would indicate the importance of one or multiple orientation sessions in a planetarium prior to using it to host meaningful lessons. Ridky refers to this as overcoming a "mystique effect" for students. In the day before students were given instruction in the planetarium, one experimental group was brought to the planetarium for an orientation session. This session was meant to familiarize them with both the construction and operation of the planetarium. Three main items were discussed which included the purpose of the dome-shaped ceiling, the operation of the projection system as well as the lighting system.

The group that underwent an orientation session had displayed a clear improvement over the group that went straight to instruction. Ridky pointed out how the study did not attempt to isolate the exact causes but suggests familiarity with the instructor could be one of the causes among several. He also concluded that the mystique effect can be overcome by instructor's scheduling an orientation session prior to instruction, or several visits should be conducted before objectives are taught. Rosemergy (1967) indicated the usual practice for instructors at the time to visit the planetarium only once when teaching their class astronomy. Ridky referred to this as a probable cause for the lack of evidence in the planetarium's advantage as a teaching space.

With MCDiP, I identify an unfamiliar planetarium environment as holding aspects with high element interactivity for students that is reduced following an orientation session. Familiarity with these aspects can be a major difference in the extraneous load they cause as we have discussed. This is especially important given that the digital planetarium introduces even more aspects to the environment while Ridky's study was in an analog planetarium. An instructor can introduce a series of secondary aspects in the form of an orientation session similar to the one conducted by Ridky in order to reduce element interactivity and extraneous load for the students in the planetarium.

10.2.3 Immersive Dome as Primary Aspect

There are studies where there was a clear advantage in teaching astronomy topics in the digital planetarium (see section 2.3.2). I interpret from this that, under certain conditions with certain topics, the planetarium can be a better facility of instruction to construct schemas in LTM and therefore can present information in ways that encouraged germane cognitive load. According to MCDiP, there are instructional intents for which valid primary aspects of the planetarium are proven to exist.

Yu et al. (2015) carried out a study in which students who were taught about seasonal change in astronomy showed better long-term retention of the material when instructed in the planetarium compared to a flatscreen in the classroom. Yu explained how the demonstration of seasons from the simulation of the Sun changing position in the sky throughout the year can be shown in the full dome of a digital planetarium without the need to adjust the position of the sky on the screen. However, to show the same simulation on a flatscreen with a limited FOV, the camera of the scene must pan around to show different parts of the sky at different times. The latter requires students to "reconstruct" in their limited WM where the Sun is or how the virtual camera is oriented in the virtual scene. The dome in this scenario had a single clear ability that cannot be mimicked by tools in lecture using a projector or other flatscreen. The immersive dome reduced extraneous load in how it presented the Sun's position over the year and left students with enough WM resources for germane load to construct schemas in LTM. The students watching the flatscreen had a higher extraneous load that prevented germane load and thus failed to construct schemas, leaving the planetarium group with an advantage in recalling the information months later. From this situation, I suggest that when an instructional intent involves teaching how the Sun's position changes throughout the year with the changing of seasons, the immersive dome of the planetarium would be a valid primary aspect. Recall that SPV1 carried a similar instructional intent and primary aspect for the Sun's movements.

In the end, MCDiP was developed as the basis of a formal grounded theory with reasonable theoretical saturation. This was assessed not only in the final model's ability to explain low-level data, but also in the recurring cases of theoretical sampling that took place throughout the investigation. There are, however, limits to MCDiP that could not be addressed within the scope of this thesis. I consider these in the next chapter along with suggesting future studies that can directly address them.

11 Limitations & Future Research

As with any implementation of GTM, there is often room for more theoretical sampling. In the case of my study, this can include more visits, more planetarium variations, more researchers involved in the coding process and more investigative instances of educational or immersive technology. This would essentially improve the theoretical saturation of the model. Grounded theories can also be improved with further theoretical coding through the inclusion of additional theoretical supplements, similar to how elements of WM and CLT were added in this investigation. While the present MCDiP takes into account multiple issues related to curriculum design in the digital planetarium, there are a number of areas that could still be investigated with findings incorporated into a more robust model. In general, MCDiP should be considered a skeleton that must be populated with the necessary substance to make it a full formal grounded theory. In Chapter 10, I assessed the quality of the investigation by directly considering the utility and theoretical saturation of MCDiP. However, it remains worthwhile to consider the limitations of the investigation itself and future research that can address these limitations.

An obvious limitation was the amount of data that went into producing MCDiP. This would be an issue with any application of GTM, as it is never straightforward to decide if theoretical saturation has been achieved or not. However, there is no doubt that MCDiP would have benefited if one more follow-up visit had been conducted with a new cohort of students the next year. The questionnaire instrument can also be rewritten to include higher resolutions of planetarium show experience. For example, the questionnaire from SPV2 included only two options of how much the student enjoyed the show. Initially this question was intended to elicit a qualitative response regarding the student experience on their enjoyment. However, as seen in the final analysis, the student's tick-a-box response ended up becoming a good measure against the coding of positive and negative responses. The higher resolution of the SPV2 questionnaire between negative and positive showed benefits that perhaps a higher resolution Likert-scale response would improve upon. Similarly, pursuing follow-up interviews with students to gain additional insight on key responses could have also improved the quality of the investigation.

The same criticism of limited data can be said regarding the further inclusion of multiple planetariums and other instructors. This reveals issues of the initial scope I limited the investigation based on the available use case being observed. Specifically, I considered a planetarium's use in a formal education environment at a university over a semester. Previously I had explained the multifaceted role of the planetarium. This included not just the role we observed it being used for, but also informal education, outreach, entertainment, and even for research. The informal education and outreach uses are of particular interest as that is arguably the main use case for digital planetariums, especially those housed as extensions to museums.

Furthermore, a critical feature of the digital planetarium is its ability to display a range of things outside the field of astronomy. However, the investigation was limited to its use in the subject scope of astronomy. MCDiP therefore emerges through the analysis of data within this narrow band of use, when the facility itself is capable of much more. I therefore cannot assume that the model easily or even appropriately extends to these other use cases. This limited scope also limited my localized model of contextual influence, upon which MCDiP relies. I acknowledged previously that the diagram did not function as an exhaustive documentation of all aspects of the digital planetarium experience. Instead, it was purposed to reveal the higher-level sources of the experience. However, populating MCDiP with a catalog of known and tested aspects would improve the utility of the model immensely. This would come from investigating other planetariums and other use cases, initially in the context of formal education, but possibly outside as well.

To address these limitations of saturation, I propose that studies looking at the different aspects of the digital planetarium and their educational impact on students do so in a way that allows application of the identified concepts and components of MCDiP. This would also be aided by a standardized reporting of planetarium details in all studies on planetarium education research. This can include information such as planetarium size, type of software, and the location of the facility relative to the students' center of learning. At a minimum, this should lead to a compiled resource for planetarium instructors of primary aspects and the instructional intents for which they are found to reduce the extraneous load. For example, I could make convincing arguments from Yu et al. (2015) that if you want to teach how the seasons and the movement of the Sun are related, the immersive full dome display of the planetarium is a suitable primary aspect to teach the topic. Another example comes from Price et al. (2015) who used CLT to assess 3D stereoscopic display use on the dome. The use of 3D on the dome was found to have better long-term information retention compared to traditional 2D display when teaching about galaxy formation, shape, and modeling. They specifically pointed out how stereoscopy provides spatial elements to cue depth that decrease extraneous load, allowing the information to be easier remembered and recalled. From such a study I would categorize the use of a 3D display as a proper primary aspect for the instructional intent of galactic morphology.

An expanded MCDiP can be adapted to other immersive technologies and their uses outside astronomy as well. I consider other immersive technologies used in science education. Frederiksen et al. (2020) for example found empirically that medical students experience high extraneous load from high element interactivity when learning about surgery in immersive VR. The 3D interactivity of VR could be a primary aspect for certain instructional intents about medical surgery. The inclusion of the primary aspects category in MCDiP remains key to identifying advantages that a novel technology has over traditional media for a given intention.

An extension of MCDiP might also be to apply it to a user learning how to operate the planetarium for any use. This would more directly borrow from the many aspects that MCDiP is already designed to consider. These could be applied to astronomers exploring the digital planetarium as a visualization tool for their research, such as Marchetti and Jarrett (2018). The investigation only considered the digital planetarium, but I also suggest extending MCDiP to other immersive technologies used for scientific research. VR, for example, is also currently being explored as an alternative method of visualizing and interacting with big data in astronomy (Jarrett et al., 2021). Similar to the digital planetarium, many claims, hype, and marketing discourse surround VR. Very similar issues come in such as new users of the technology experiencing a high extraneous load. This could be detrimental for researchers wanting to learn something new about their data yet are unfamiliar with VR use. This could also negatively impact the developers trying to expand their user base. Identifying primary aspects of the technology associated with "Research Intent" with the data[32] could be a sensible extension to MCDiP that aids introducing new immersive technology for use in scientific workflows.

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[32] analogous to MCDiP's Instructional Intent

There is also the potential of looking more closely at how cognitive load is directly impacted in the planetarium. This can better refine the theoretical coding for MCDiP. Sweller et al. (2019) highlighted ways in which to measure cognitive load directly, including a subjective rating system originally constructed by Paas (1992). More recent studies (Leppink et al., 2014) looked at a notable instrument that is being explored to distinguish between different levels of cognitive load that is experienced by students. Sweller also referred to possible physiological measures that can be used to assess total cognitive load in a given instance such as eye movement and measured brain activity. This could be incorporated with our own systematic method of plotting student response to seating position in the planetarium, which I excluded from my analysis but describe in Appendix B.

There is also the limitation of the incorporated theoretical supplements of WM and CLT. This can be addressed through wider instances of theoretical coding from alternative theoretical supplements for MCDiP. For example, there is little doubt that the work of Eriksson et al. (2017) is potentially supplementary to the present work. An extended model should be developed that combines the insights based on social semiotics with the present model that grounds engagement cognitively but does not detail the nature of engagement with different representational forms. For example, “noticing” in the Eriksson model resonates with “attentiveness” in the present model and what is noticed seems to be related to accessible schemas in LTM. The data of Erikson indicated a novice-expert divide as would be expected but also indicated that physics experts incorrectly “notice” certain features. The MCDiP model would explain this in terms of activation of schemas from LTM, similar to the Sweller (1988) discussion of chess grandmasters versus novices in section 7.2. Thus, for the physics novice, there would not be a schema to draw on or, at best, a poorly developed schema. In the case of a non-astronomy expert, a random, well-developed schema would be activated by the attention-grabbing feature, but it would not be the appropriate schema for the context in question.

12 Conclusion

12.1 Summary

Astronomy as a discipline has a rich history of consistently incorporating state-of-the-art technology, both for research and as well as education purposes. We see examples of this today with the exploitation of immersive technologies, such as virtual reality, curved screens, and the digital planetarium. Incorporating any new technology into an educational curriculum should be handled with care and objectivity. This is especially important when such technology has hype or nostalgia attached to it. In this thesis I set out to investigate the use of the digital planetarium as part of an introductory astronomy curriculum by following the broad line of inquiry:

Characterize the digital planetarium as a teaching and learning space.

This goal was considered through adopting the Grounded Theory Method (GTM). As a unique approach to qualitative-based research, it was necessary to start off with a thorough look at the methodology behind GTM. I also included explanations of the resulting traditional structure that resulted from implementation of the methodology.

The next step was to give an overview of the preconceptions that I entered the investigation with. For this I first took a brief look at the century-old history of planetariums. Particular emphasis was placed on their modern adaptation to the digital age, including the broadening of capabilities and variations in style. I next considered the rich background of using planetariums as a space for instruction. I included a look at previous planetarium education studies with the mixed results regarding the facility's effective use in astronomy education. Additionally, I summarized the modern marketing discourse along with other considerations tied to the facilities from the affective domain.

From here I gave an overview of the study design. This started with the initial broad inquiry mentioned above that emerged from discussion guided by my preconceptions. To better organize the investigation, the broad inquiry was deconstructed into two manageable guiding questions:

Guiding Question #1 (GQ1):
How do students engage with a digital planetarium?

Guiding Question #2 (GQ2):
What shapes the teaching and learning space in the planetarium?

These questions formed the basis of the investigation's two lines of data collection: student responses and observational data. I provided the setting from which this data would be drawn by giving background information on the Iziko Planetarium & Digital Dome and the UCT introductory astronomy course that made use of it. This included the consideration of ethics that went into the investigation.

Data collection was organized along two temporal phases of the investigation corresponding to the two planetarium visits undergone by students of the introductory astronomy course. These were labeled Student Planetarium Visits 1 and 2 (SPV1 & SPV2). The data collection chapters also included bits and pieces of analysis and discussion to properly document the constant comparison of GTM. For SPV1, in which the introductory astronomy students were taught by the course instructor, multiple visits were first conducted during which we as the research group familiarized ourselves with the IPDD and its use as a presentational and educational space. This included introductions by planetarium staff and the use of the facility as part of a curriculum for a cohort of introductory astronomy students over the course of two visits. Observations included documentation and discussion on notable features of the facility along with the behavior of its users. For the visit itself, I designed and administered a student questionnaire with the PhAsER group to probe how students responded to the general planetarium experience as well as the educational content. This included a student reflection on what they felt they learned along with their understanding of a research focus topic of the celestial sphere. This particular visit was then followed up by an interview with the instructor regarding the observed processes. Early findings indicated that the digital planetarium was a complex learning space with elements of both entertainment and learning and that a simple before/after understanding probe did not provide deeply informative insight for such complexity. This was carried over to the design of SPV2.

The second Student Planetarium Visit (SPV2) differed from the first in that the planetarium show content was specifically designed by the researchers and the questionnaire had been modified based on the results of the first visit. This allowed me to document and analyze the design process from the perspective of the instructor. From the experience of SPV1, I established a list of considerations to help in this design process. The first was how I plan, design, and conduct a planetarium experience that maximizes a narrowly focused educational goal. The second was how I constrain the experience to that of a predominantly educational environment while probing the effectiveness. The third was how I include unique digital capabilities of the planetarium in a manner relevant to the course curriculum. For this I chose the topic of demonstrating the various distances of the celestial objects covered in the course. The show was then storyboarded, developed, and trialed using the same *DigitalSky-Dark Mater* software as the IPDD. The show for SPV2 was administered and documented along with the modified student questionnaire. For this I probed how students felt about the show and how they engaged with the educational content.

Final data analysis was then reviewed in which the iterative approach of GTM produced abstraction though higher-level categories and concepts. For the student questionnaire data, this was done with the help of *NVivo* software. Responses based on experience were coded as emergent key ideas while responses related to topic understanding were coded based on quality. Observational data was organized on sticky notes under common themes and eventually high-level sources of aspects of the digital planetarium experience.

I then took a broad look at the findings compiled from both studies. Whereas from SPV1 I saw a separation of key ideas from students indicating elements of entertainment and learning in the planetarium, SPV2 indicated both positive and negative associated with learning and non-learning elements. This was found to have a divergence over the course of the two-segment show from predominantly a positive experience of learning to both positive and negative experiences of non-learning. In addition, a narrower focus in show content led to a narrower variety in content reflection by students in SPV2 compared to SPV1. From these results, as a key step in the GTM approach, I was able to develop a localized model of student engagement, which answered GQ1. This model suggested student attentiveness was a key parameter. This parameter lay on a spectrum with low and high levels leading to learning deficiency while there existed an optimal level of attentiveness with maximal learning. From the observational data, the combination of digital planetarium aspect sources suggested the planetarium experience involved a complex collection of aspects. This I named my localized model of contextual influence that answered GQ2. I then proposed unifying these localized models to answer the broad guiding inquiry of the investigation. For this I suggested the explanatory power of broader cognitive models, namely Working Memory, Cognitive Load Theory, and the concept of schema construction that relates the two.

This brought me to Working Memory, Schema construction, and Cognitive Load Theory, of which I gave an overview in addition to explanations on how they are connected. In the frame of GTM, this was the necessary “return to literature” that provided a necessary theoretical supplement to reinforce my proposed model.

I then applied these cognitive models to the proposed unified model through a process of theoretical coding. This was done by first modeling the low-level student engagement with working memory to explain how varying levels of attention lead to schema construction in long term memory and how previous experience makes this possible. I then explained how the student engagement model allowed me to apply cognitive load theory for assessing how students interact with various aspects of the digital planetarium. This led to identifying the planetarium as a learning space with many aspects that can contribute to both extraneous and germane cognitive load for students. With the acceptance of working memory and cognitive load theory as a valid framework for student engagement, I then constructed a higher-level Model for Curriculum Design in the Planetarium (MCDiP). This model considered the instructor’s influence of planetarium aspects and how they relate to the instructor’s intended teaching outcome. By establishing this basis for a formal grounded theory, I effectively addressed my initial broad goal on characterizing the digital planetarium as a teaching and learning space. The resulting model demonstrates that the facility can function as an effective teaching and learning space through systematic categorization of the various interacting aspects that form the experience. This categorization takes place on the side of teaching through the instructor’s influence and the side of learning through student engagement as cognitive load.

I then highlighted implications of the model for instructors intending to incorporate the planetarium into a curriculum. This included assessing the reason for visiting, what should be chosen as teaching topics, and how the experience should be set up to maximize learning gains. Also, in order to test the rigor of the investigation through the resulting model’s utility, I considered the level of theoretical saturation of the investigation. I did this through first considering the various instances of theoretical sampling that took place throughout the investigation in which low-level data was introduced to previous higher-level categories and concepts. This was followed by applying the final model itself back to my own study results in addition to past studies on instruction in the planetarium. I ended by considering the limitations to the investigation and resulting model and how future research can enrich it. The process of the investigation is summarized in Figure 12-1 on the next page.

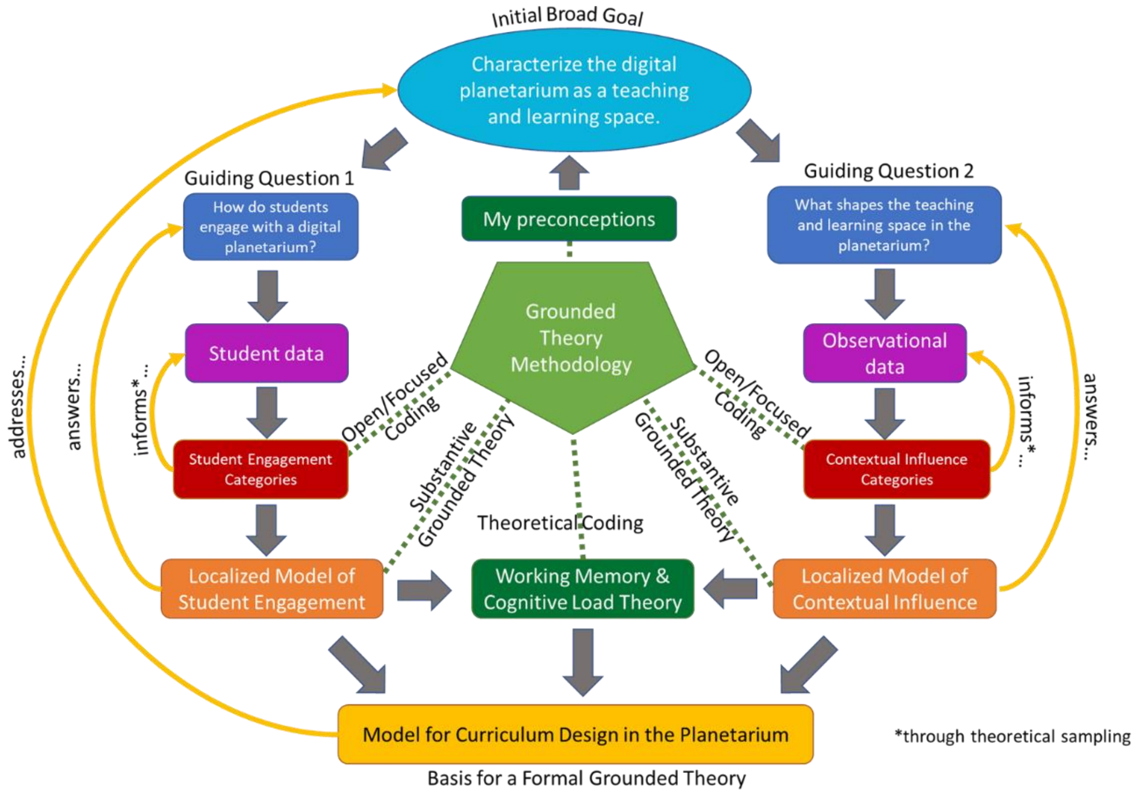

Figure 12-1. Updated schematic diagram from Figure 3-1 of investigation pertaining to this thesis with annotations. The two types of data corresponding to the two manageable guiding questions GQ1 & GQ2 each produced high-level concepts composed of abstract categories through the iterative coding process. The first revealed how students engage with the digital planetarium experience that included emergant categories and key-ideas along with ratings of content reflection. These were encapsulated in the localized model of student engagement that answers GQ1. The second revealed the various hierarchal aspects of the digital planetarium experience culminating in four high-level sources. These were encapsulated in the localized model of contextual influence that answers GQ2. These localized models, or substantive grounded theories, were then combined using theoretical coding from the theoretical suplement of WM and CLT to produce the final Model for Curriculum Design in the Planetarium. The final model serves as the basis for a formal grounded theory that characterizes the teaching and learning space of the digital planetarium.

12.2 Key Findings

My key findings in characterizing the digital planetarium as a teaching and learning space arise through my resulting grounded theories. Students engage with the digital planetarium according to my localized model of student engagement. This classifies the digital planetarium experience as a spectrum of student attentiveness in which an ideal level results in maximum engagement with the relevant components of the presented instruction. Furthermore, my localized model of contextual influence considers what shapes the digital planetarium as a teaching and learning space. Aspects from content-, environment-, instructor-, and external -based sources form the building blocks of the student experience in the planetarium. These two localized models form the core of my final unified model, the Model for Curriculum Design in the Planetarium (MCDiP), reproduced below in Figure 12-2. This shows how the modern digital planetarium may afford teaching opportunities beyond those possible with traditional means of instruction; however, to structure the planetarium as an effective teaching and learning space, many aspects must be taken into account during curriculum design. Overall, there is a complex interaction of both cognitive and environmental factors that plays a significant role with regard to the educational outcomes. Specifically, the digital planetarium experience produces unique aspects that have varying effects on the cognitive load of students. MCDiP serves as a research-based guide for how to proceed with effective instructional development. In addition, the model serves as a powerful foundation for incorporating further dimensions that may come about as a result of future research carried out by the planetarium educational community.

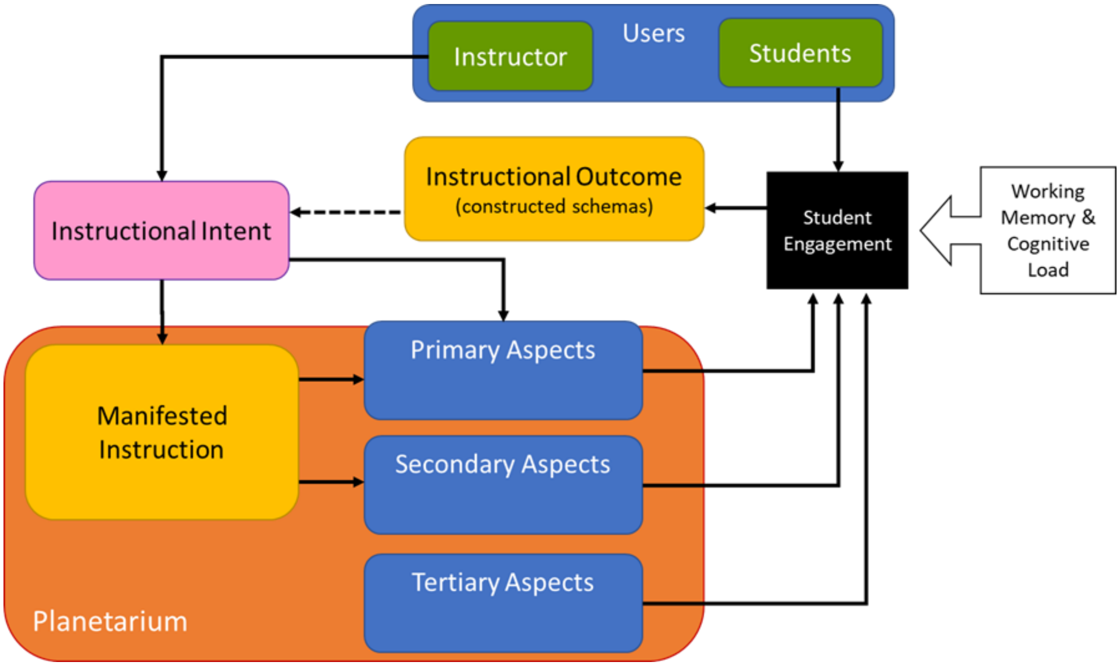

Figure 12-2. The Model for Developing Instruction in the Planetarium (MCDiP) is the final product resulting from the GTM investigation that characterizes the digital planetarium as a teaching and learning space.

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Appendix

A. Observational Data Coding

Observations were made throughout the study in the form of a thick description of events. These were done primarily by the author with additions made by the rest of the PhAsER team. From these personal and collaborator observations, we collected and categorized into a table based on similar emerging categories. Note that this was done manually and not with the aid of software like NVivo.

Observations were made, documented then categorized using the categorization phase of the GTM approach.

The results are presented here for SPV1:

Observations	Category
• Visualize the night sky and celestial sphere in "3D" • Show how the Sun "moves" at noon over the course of the year • Show a few of the main constellations and how they indicate cardinal directions • Show precession and debunk astrology • Advertise the planetarium as "a nice place to go"	**<u>Purposes of the show planned out-of-dome</u>** Instructor had a clear intended use for the planetarium
• 89 students • Everybody entered from main public entrance • Students chose own seating – quick but conversations were persistent • All seats not the same; some parts of dome obscured • No desk facility – limits certain interactions • Indirect lighting not ideal for writing • Instructor would not want to teach this material for the first time in the planetarium Instructor notices more students answer out loud in planetarium, meaning "that they were following"	**<u>Planetarium logistics & seating</u>** Notes about administering the planetarium show and questionnaire
• 35-minute presentation • topics ○ Planetarium as a tool; researchers use for data visualization; ability to visualize data in 3-Dimensions ○ Dubstep montage of Hawaiian telescopes ○ Components of celestial sphere at different locations ○ Changing height of Sun with ○ "have some fun" in zodiac/precession section • Run by operator, spoken by operator and lecturer	**<u>Content Presented in-dome</u>** What was shown to students as manifested instruction

• Interactive with students; asking questions • Instructor notes in planning that some of the detail is “exhaustive”, “but shouldn’t take long” • Phaser team felt number of topics was high	
• Relaxing video game music • Exit signs and emergency protocol • Instructor perception o “teaching prac[tical] not a show” o “it’s a bit harsh just hearing a voice” o Students more engaged than lecture • Sounds of astonishment when stars moved quickly • Conversations among students • Squeaky chairs	**<u>Atmosphere/vibe in-dome</u>** Noticeable affective elements of the experience
• Diurnal motion shown in lecture on a flat screen using Stellarium; instructor says in the planetarium “it’s better in 3D” • In lecture content preview o “learning about the celestial sphere” o “looking at how the height/alt of the Sun changes over the course of the year” Session would “hopefully… help [them] be able to visualize in 3D a little bit better what we are doing with the celestial sphere because it is a tricky section**,** and we try to attack it from all angles”.	**<u>Out-of-dome influences on students</u>** Things that were “carried in” to the planetarium experience from external influences
• Questionnaire to assess how students felt about show and what was learned o Likert-scale “tick-a-box” o peer-to-peer explanation framing • No desks: writing surfaces to be provided • Questionnaire passed out and collected by hand; chaotic • 10 minutes given for pre-show questionnaire • 15 minute post-show questionnaire Instructor impatience over questionnaire time dedication	**<u>Conduciveness of Environment to Formal Responses from Students</u>** Notes on how friendly the planetarium environment is to conducting studies
• Geocentric constraint to show (not “leaving” Earth) • Language used by users o “Fly” and “leap”. “Know how to drive” referred to in the pre-show o “we are currently sitting in Cape Town” o “teleporting” between locations o “who feels like a trip to New York City?”. o Diurnal mechanism at work; rotation of Earth on axis o “we” to indicate both Sun and the planetarium users	**<u>Immersion</u>** Ways in which the immersive characteristics of the planetarium experience stood out

○ “our” tour ○ “this beautiful 3D dome” ○ “puts you physically in [the celestial sphere] to see what’s going on” - instructor in interview Instructor sits in separate setting as students during show	
• Laser pointer used by instructor • Instructor not visible, behind the students; disembodied voice Instructor asked questions from students and received out-loud responses	**Interaction students / lecturer in-dome** Ways in which the students interacted with the lecturer

While we were conducting our observations throughout the study, we started taking note how distinctive emerging roles were being occupied by the various people involved. These included:

Presenter- person who interacts with the audience through speaking and explaining the content on the dome

Developer/Planner- person who “puts the show together” before it takes place through highlighting the goals and deciding how to accomplish those goals in the dome

Operator- person assigned to the controls of the planetarium

Audience- person that the planetarium show is presented to

Observer- person that watches and documents the use of the planetarium and people involved (unique for a study context)

We list here an assessment of the various identified people involved in the study and their roles as users of the planetarium.

User	**Role(s)**	**Tasks**
Course instructor	Developer/planner	- List intentions for instruction - Run through written outline of show
	Presenter	- Majority of audible instruction to accompany dome visuals
Tutorial instructor	Developer/planner	- Constrain instructor’s intention - Offer suggestions based on knowledge of system
	Operator	- Control the planetarium software
	Presenter	- Welcome students - Housekeeping (exits) - Constellations & telescope video

Student	Audience	- Sit in planetarium theatre and watch dome presentation - Occasionally answer out-loud questions from instructor as group
Researcher	Audience	- Sit in planetarium theatre and watch dome presentation
	Observer	- Watch and document process of planetarium use - Administer probing instrument to audience

Similar to the SPV1, we gathered the observations and interactions carried out by the PhAsER group and categorized them. The results from SPV2 are presented here:

Observations	Category
• Give a sense of the scale of our universe ○ 2 segments (“2D” and “3D”)	**Purposes of the show planned out-of-dome** Instructional intent of the designer of the show
• No music • Single topic • Randomized, separated seating • Allocentric	**Changes from first show** Lessons learned from SPV1 that informed SPV2
• Lack of documentation for development ○ Scripting API ○ General usage instructions of software • Virtually no community resources for software • Proprietary software ○ Special use case that we had access to “development environment” • Seeing what audience sees ○ Developing on different tool (cobra display) ○ Trial show on dome revealed variation of visuals ○ Operator’s seating is separated from audience; different perspective of dome	**Accessibility/Usability of tool** Notes on experience as a show designer using DSDM software
• Quiet, no speaking • Occasional laughter • Occasional sighing, yawning • Student afterward upset about content and effort to come to planetarium	**Student interaction** How the students visibly and audibly interacted with the show content during the experience

- Students uninformed of content until show itself - "we are going to take a look at the various range of relative distances we encounter in astronomy" said at beginning - Students were kept away from museum exhibits related to content	**Priming/influences** Noted ways in which students were influenced from external factors taking place outside the dome
- 75 students - Everybody entered from secondary public entrance - Students assigned seating – slow - Some seats blocked on peripheries due to obscured visuals found in trial show	**Logistics** Notes about administering the planetarium show and questionnaire

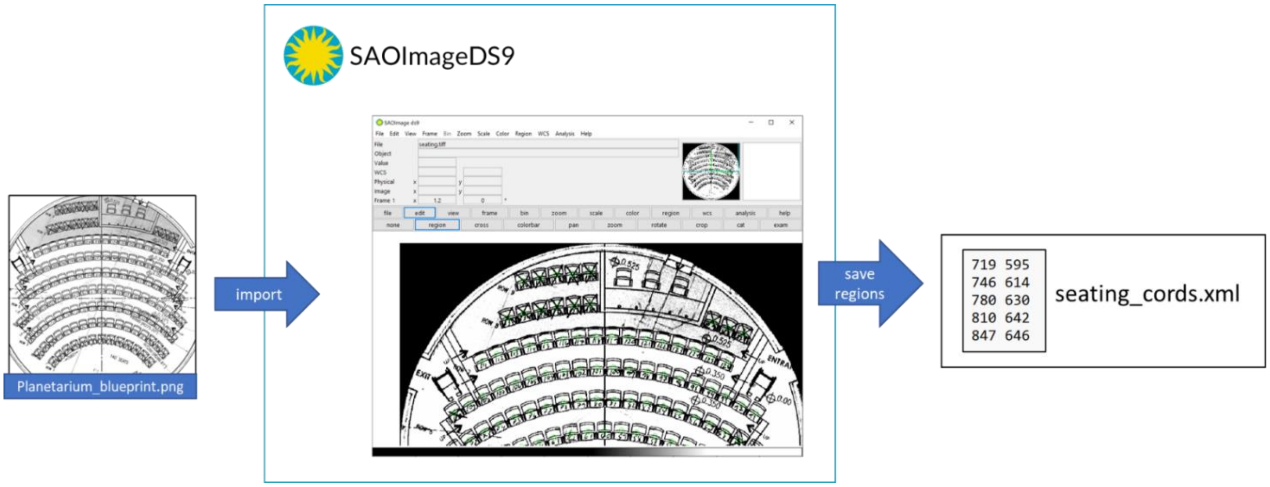
Similar to SPV1, we list here an assessment of the various identified people involved in the study and their roles as users of the planetarium for SPV2:

User	Role(s)	Tasks
Researcher	Developer/planner	- List intentions for instruction - Run through written outline of show
	Presenter	- Majority of audible instruction to accompany dome visuals
	Operator	
	Audience	- Sit in planetarium theatre and watch trial dome presentation
	Observer	- Watch and document process of planetarium use - Administer probing instrument to audience
Student	Audience	- Sit in planetarium theatre and watch dome presentation - Occasionally answer out-loud questions from instructor as group
Course Instructor	Audience	

B. Seating Analysis for SPV2

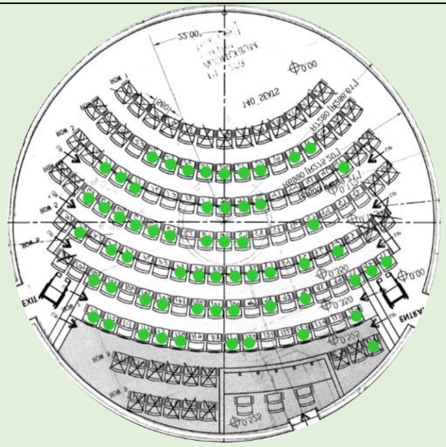
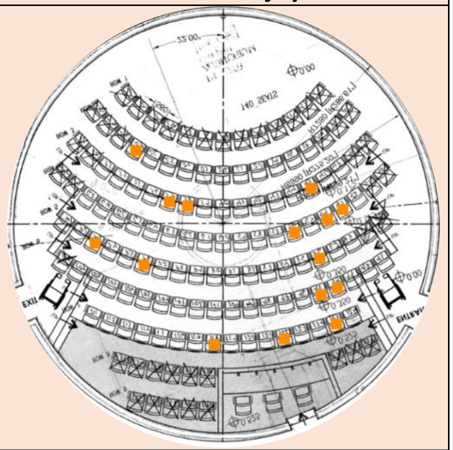
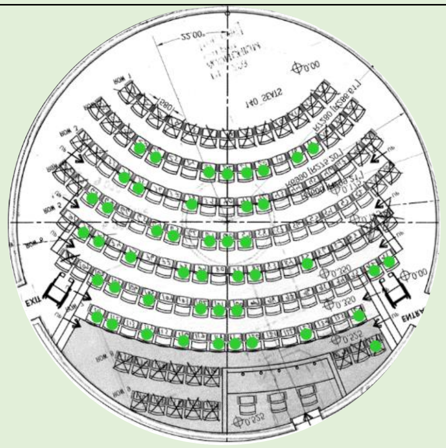
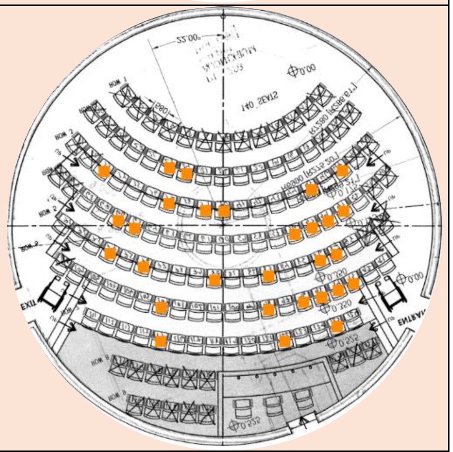
For each respondent, the seating position in the planetarium theatre was recorded. Another benefit of applying cases to the responses was the seat number attribute allowed further analysis based on seating position. As NVivo does not have robust 2D plotting capabilities, I decided to export the data for use in other software.

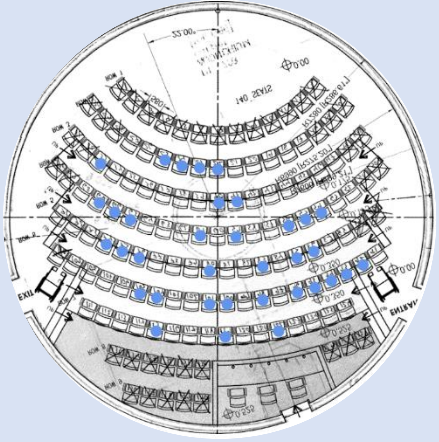
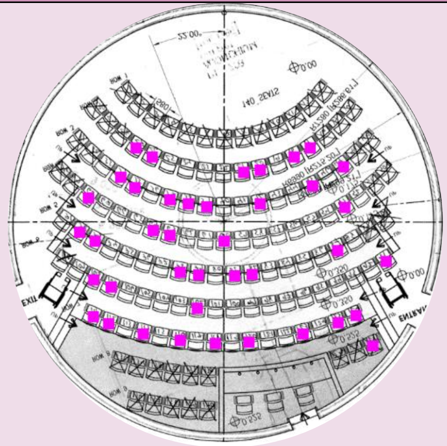
From NVivo I had response attributes (show preference, enjoy/did not enjoy, etc.) and qualitative coding mapped to seat number. I wanted to used python and the matplotlib library to visually represent these responses, so we first needed to convert seat number to 2D pixel coordinates on the seating chart image. A quick way of doing this ended up being by using the Regions tool in the DS9 software often used by astronomers. In DS9 we imported a .png image of the seating chart, manually created point regions on all the numbered seats, and exported the regions as a spreadsheet.



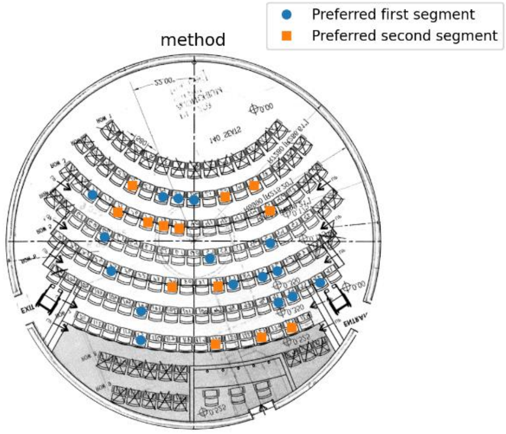
719	595
746	614
780	630
810	642
847	646

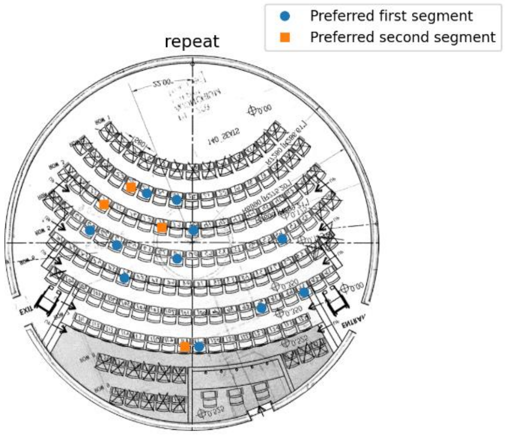
With the seating coordinate spreadsheet, I now had a mapping of response coding to position in the planetarium via the seat # attribute from NVivo. With the pandas and matplotlib libraries of Python, I could then plot the response coding over an image of our planetarium seating chart. This could be done with A/B responses as shown here:

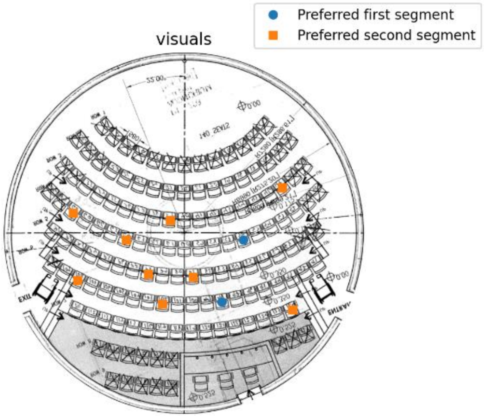
	Enjoyed	Did not enjoy
Segment 1		
Segment 2		

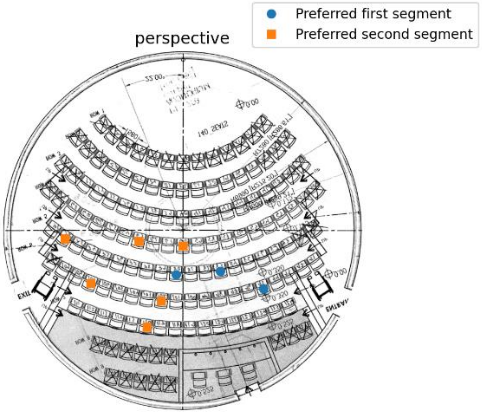
	Learned more from Segment 1	Learned more from Segment 2
Seating positions		

As well as seating chart plotting based on qualitative coding, as shown in the following example with segment preference:









There doesn’t seem to be much emerging pattern associated with seating position and enjoyment or segment preference. One thing that does seem to show itself is the pairs or even groups of students that answer the same. It is also interesting to note how nearly all the students sitting at the ends of the rows prefer the second segment of the show, although none of them commented on the viewing angle or difficulty in seeing the content in their explanations.

C. Perception of Learning Comparison

The final question asked of students had them reflect on which of the two show segments they learned more from. The question required selecting whether the student agreed with somebody who felt they learned more from the first segment or with somebody who felt they learned more from the segment. They were then tasked with explaining their decision.

We first tallied up the indicated preference of which segment they agreed they learned more from. Of this, 47% (35/75) chose segment 1 and the remaining 53% (40/75) chose segment 2.

Similar to the grounded theory approach used previously, we coded explanation responses into ideas and then categorized them whether these ideas indicated a segment had a perceived positive or negative impact on the student's learning experience. Similar to the section on Enjoyment, these ideas were coded independently of whether the student indicated their segment preference, but the idea could be guided by the preference. So, for example, a positive idea about segment 1 could come out of an explanation where the student indicated they learned more from segment 2 if they explicitly referred to a positive learning idea of segment 1 while an ambiguous idea could be categorized based on the segment preference.

The following tables indicate the ideas that emerged. The first two tables were grouped as positive and negative learning ideas of segment 1 and the second two tables were grouped as positive and negative learning ideas of segment 2:

Segment 1:

Positive Element	#	**Example Responses (Seat#)**
Preferred grids	15	*(5) The grids shown in the first half of the show made is easier to put the distances into perspective…* *(11) In the first half the use of the grid made me recognize the distances easily…* *(52) The circles used were giving a better reference view rather than just seeing magnitude of distance.*
Benefit of being first	9	*(8) In the first show I was still excited of what I was going to learn…* *(11) …my mind was still fresh to concentrate much on the presentation.* *(18) Because it was the first one I saw.*
Perspective used	3	*(26) …It really helped to graphically grasp the enormity of space with a view from above the plane…* *(42) It's much easier and better to get a sense of scale when you observe the entire system from an outsider's perspective as opposed to viewing it from within the system.* *(45) Seeing things on a scale is a better learning experience for me then experiencing the distance in first person and not seeing the reference point.*
Engaging visuals	2	*(54) At first it was fascinating and enjoyable to be able to observe the distances from Earth (above CT) to the centre of our galaxy…* *(55) …show A was more visually stimulating.*
Recalling what was learned from	2	*(31) …show 1 included the distance from CT to the centre of the galaxy.* *(38) … the first half kind of showed that to measure the distance*

segment		*between two astronomical objects we can use the distance of objects or features found on Earth for reference/as reference to show how far objects are from each other.*
Total	31	

Negative Element	#	**Example Responses (Seat#)**
Uses only approximation of distances	4	*(13) In the second half show you tend to learn more. It doesn't give us approximate how far something is relative to CT as in the first half…* *(20) The second half consisted of actual values whereas the first half didn't….* *(70) …the first half only gave me an approximation of the distances.*
Segment was confusing	3	*(10) The first show was short and confusing than the second show…* *(63) …I had an idea on what we were doing, unlike in the first show* *(68) Because at first didn't understand what it was about…*
Log scale used	2	*(27) …the first show just used a logarithmic scale to show distances, without actually showing the object in question.* *(41) The second show was better as there was no logarithmic scale and you could understand the scale better…*
Too short	1	*(10) The first show was short…*
Not engaging	1	*(12) In the first half of show I wasn't concentrating that much as the show proceeded..*
Dislikes circle grid	1	*(15) …Random concentric circles don't really hit home the same way a big number does.*
Total	12	

Segment 2:

Positive Element	#	**Example Responses (Seat#)**
Preferred numbers or counter	14	*(2) … the counting up of the units was more helpful than the lines that forced you to estimate the distance.* *(15) … it was easier to digest in number form…* *(72) …show B showed how the distance was increasing one unit at a time instead of using log scale…*
Seeing visual representations of celestial objects	10	*(29) On the second half of the show we got to see the real image of these objects which helps us to understand them more….* *(34) …show 2's visual representations felt like they made a bigger impact on me with regards to size and how the objects looked, etc.* *(62) B was having pictures of the objects (i.e. Earth, Moon, Sun, Voyager, Proxima, milky way)…*
Perspective used	8	*(35) More life-like, felt as if actually travelling through space therefore greater comprehension of (representation of) sheer size of the galaxy and the distance between bodies in space.* *(53) Easier to gauge distances with grid system but having the objects show up in 3D perspective in the second was nice…*

		(58) You can visualize better as you move through and not over. You can also see the distance change as you move from one object to the next. This give a better understanding of distances and the units used.
Visuals kept student engaged	7	*(14) I enjoyed the visuals of show B making it more engaging so I concentrated more for its duration.* *(40) The second show seemed more interesting and drew all my attention and it helped visualize the distances better…* *(74) The second show had amazing visuals of the Earth, Moon, the Sun, Voyager, Proxima, and milky way. The way the second show was presented actually helped with visualising.*
Recalling what was learned from segment	7	*(49) The second half showed distance of the observed objects (Moon, Sun, Voyager 1 & Proxima Centauri) from above my current location which is CT.* *(64) Because in show B they explained how far is to the Sun above CT using different units. They also showed us how far is Proxima.* *(65) The second show better helped gauge the relative distance to objects in the galaxy.*
Acted as review	5	*(6) The 2nd half just solidified what we learned in the first half.* *(12) In the first half of show I wasn't concentrating that much as the show proceeded. In the second half I concentrated and got the main point of the show.* *(68) Because at first didn't understand what it was about. But the second time I got the chance to see what it was about looking to the things I missed at first…*
Clearer or less cluttered	5	*(2) I feel that I learned more from the second half of the show because I believe that the presentation was clearer and that by zooming out with nothing else in the field of view allowed for a better conceptualization of distance between objects….* *(10) The first show was short and confusing than the second show. The second was able to show takes us to the Moon, Sun, and galaxy, and also it was clearly explaining how far the v1 is from Earth* *(48) There weren't as many graphical lines or planes. That made it easier to notice the distance.*
Slower	2	*(4) Slower pacing, resulting in more time being focused on each space object….* *(16) The numbers were shown more clearly and less faster than in show A…*
Total	58	

Negative Element	#	**Example Responses (Seat#)**
Repetitive or redundant	7	*(23) After seeing info in show 1, show 2 became redundant.* *(33) The second show was extremely repetitive and the content was already covered in the first show.* *(51) Show 2 felt like a repeat of the info that I had just learned from show 1…*
Use of exact	5	*(24) The first half of the show showed radii when representing*

numbers		*distances which I found to be more insightful when comparing scales as opposed to just seeing the value of the distance.* *(47) …Show B made use of exact numbers, which doesn't help with visualising these distances.* *(66) Because we counted the unit distances as we moved outward [in 1st segment] as opposed to a bunch of numbers increasing in the 2nd show…*
Boring or lost interest	4	*(50) …I lost interest…* *(54) …on the second one it became boring.* *(60) I fell asleep during the second show.*
Total	16	

A total of 117 ideas emerged out of the student explanations. Of these ideas, nearly three quarters (76%) were positive ideas of the shows and the remaining quarter were negative ideas. Of note was an obvious asymmetry where half of the ideas were positive ideas concerning segment 2 while only a quarter were positive ideas of segment 1, so segment 2 had almost twice the positive ideas associated with it.

Ideas	**Segment 1**	**Segment 2**	
Positive	26%	50%	76%
Negative	10%	14%	24%
	36%	64%	

The following is a summary of the tick-a-box responses regarding show preference related to perceived learning:

	Learned more from Segment 1	**Learned more from Segment 2**	**Total**
Respondents	35	40	75
Percentage	47%	53%	

D. Investigation Preamble

The IPDD is part and parcel of the UCT Visualisation Lab (VisLab). My thesis project was set to be based in physics/astronomy education research (PhAsER), however with a background in astronomical instrumentation, game design and 3D modeling, I was also drawn to the UCT VisLab and their mission of big data visualization. Exploring state-of-the-art technologies in how they can transform methods in research seemed a natural compliment to looking at the role of new technology in education. This was especially true considering that the digital planetarium was already actively being used by a researcher in the astronomy department as part of their introductory astronomy course curriculum.

At the same time as familiarizing myself with methods employed by members of the PhAsER group and the field at large, I was also given access to the VisLab and planetarium. This was a critical few weeks that led to the establishment of my second role as a data visualization developer with UCT Astronomy and IDIA, primarily with the digital planetarium and VR projects of the VisLab. This role emerged from two situations:

1) I would routinely visit the planetarium on the reserved Monday slot, where the facility grants exclusive access to researchers as part of agreements established by the parties responsible for the digital upgrade. Here I would observe the two main astronomer users (Prof. Jarrett & Dr. Marchetti) interact with the software while also asking questions and familiarizing myself with the system.

   On one occasion a visitor, Dr du Toit from the Neuro Research Group (NRG) at Stellenbosch, was working with Prof. Jarrett. They were using the planetarium to display volumetric (3D) renderings of images taken of mouse cerebellum tissue (Ntsapi et al., 2019). The data format of the Dark Matter (DM) planetarium software was revealed to be quite strict in that in order to import a volumetric cube, for example, it was required to be in a DirectDraw Surface (DDS) proprietary container file format (Microsoft, 2018) which is essentially a file containing a stack of images. This DDS stack of images is taken in by DM and displayed as a stack with a finite thickness that can be adjusted at the user interface (UI), making the stack appear as a 3D object.

   Prof. Jarrett tasked me with recreating the same data format that Dr. du Toit was able to ingest into the system. With the knowledge that Dr. du Toit used layers in the opensource software Gimp to export as a DDS, I performed a simple exploratory experiment to get a 3D object into DM. Using the 3D rendering software Blender, I took a 3D mesh model of a bunny that I had created for fun a year before, placed it in a scene with a plane that acted as a mask that subtracted all by a “slice” of the rabbit. I then placed a virtual camera in the scene perpendicular to the plane and recorded a series of images with the plane mask moving through the bunny mesh model. In Gimp, I could then stack these images as a set of layers and export as a DDS file. When we saw that this worked with the planetarium, I concluded an early scenario of exploratory research. I observed a new tech that researchers are not used to and connected it to a data file format that the tech is not directly compatible with through a series of conversions.
2) The VR project in the VisLab was in an early proof-of-concept stage in which a single data set could be rendered in a scene that the user could then adjust the location, size and rotation of using the VR controllers. Up until that point, a direct scientific use had not been implemented. The VisLab developer, Dr. Angus Comrie, had based this proof-of-concept on the Unreal Engine

> middleware, which was a similar system to Unity, a game engine that I had hobby experience with. As this VR project was of potential interest to me, I spent a few weeks learning the basics of Unreal Engine. On one particular day, Dr. Comrie was traveling and Prof. Jarrett asked if I could urgently enhance the VR software by adding the ability to display multiple data sets.
>
> Using my recently acquired skillset with Unreal, I was able to clone the object in the game "scene" that was rendering the first data set and instruct the second object to load a second set. This resulted in numerous crashes and errors that needed to be addressed as the software up to that point was not designed for multiple data sets, but we ended up successfully implementing the change. This concluded another scenario for a role I was to take up in the VisLab as a developer for the VR software guided by the requests of and discussions with users of the software.

So it is with this dual role as an astronomy education researcher and data visualization developer for a PhD project that influenced the general bifurcation of my project into two strands. The first strand was looking at the planetarium's use as an educational instrument (Planetarium for Education, P4E) and the second was looking at virtual reality as a tool of research (Virtual Reality for Research, VR4R), both within the astronomy department at UCT.

It is important to highlight this background role as this project is not simply an astronomy education researcher exploring the use of technology in astronomy from a position of naivety, but on the contrary, from a position of active development and privileged access of the technology being explored. These strands would invoke knowledge and skill from both of my roles, though not necessarily in equal amounts. Likewise, the strands themselves tended to be rather complementary to each other with knowledge in one potentially influencing ability in the other.

E. SPV1 Interview Questions

Why did you take your students to the planetarium?

Why did you specifically choose the celestial sphere as a topic for the planetarium?

What specific aspects make the planetarium a more suitable venue for a lecture?

What specific aspects make the planetarium not so suitable for a lecture?

Is there anything that you wanted to do at the planetarium that you could not?

Is there anything you remember that went wrong during the planetarium visit?

What do you think your students learned at the planetarium?

Is there anything you do with your students to prepare them for the planetarium visit?

How did you follow up with the planetarium visit in lecture?

Are there certain things you notice from the students to indicate the effectiveness of the planetarium visit?

F. Script for SPV2 Distance Show

UCT PhAsER Cosmic Distance AQUIP show *script*

>Setup, high quality Earth, and close up of Earth, all behind 0% scene visibility

Good afternoon and welcome once again to the Iziko Planetarium.

Today we are going to take a look at the various range of relative distances we encounter in astronomy.

You will be presented with two shows, about ten minutes each with a 3 minute questionnaire to follow each one.

With that, let's begin the presentation.

>Fade onto view of Earth over South Africa

Here is Earth.

If you don't recognize the view, this is looking straight at Cape Town, from about 1 Earth radius above.

>Fade into view the orbits of ISS and HST

I will show you the orbits for the International Space Station and Hubble Space Telescope for reference.

Now we will use the radius of Earth as a unit of measure in constructing a distance grid.

>Fade in Earth radius grid

We will leave this in as we take a look at the distance to the Moon.

With every magnitude of 10, we will use those as our new units on our grid.

Here is the Moon. A little more than **60** Earth radii from Cape Town.

>Fade out Earth radius grid. Fade in Moon distance grid.

We can now use the distance between Cape Town and the Moon as a unit of distance to show how far the Sun is from Cape Town.

As before, every power of ten, we focus on that as our new distance unit.

Here we see that the Sun sits almost **400** Earth-Moon separations from Cape Town. We can now use the Earth-Sun separation distance as a new unit. Does anybody remember what this is called? The Astronomical Unit, or AU.

>Fade out Moon grid. Fade in AU grid

I would like to use this as our distance unit now to show you the distance from Cape Town to the Voyager 1 spacecraft, the furthest human made object from us. It sits about 145 AU above Cape Town.

I will put up the trail of Voyager 1, but also include the orbits of the planets of our solar system. Don't worry, I will put Pluto's orbit as well… for another comparison.

Voyager sits at the edge of the Heliosphere, the solar system's atmosphere. We can use its distance to once again, define a new unit of distance of 1 Voyager distance.

>Fade out AU grid. Fade in Voyager grid

With this unit, we will show the distance between Cape Town and Proxima Centauri, the nearest star to the solar system, at about 1800 Voyager distances. At this point I will turn on Orion, a familiar constellation of stars, for reference.

If you divert your attention to the bottom, you can see the Alpha Centauri system consisting of three stars appear as one bright dot, almost 2000 Voyager distances from Cape Town. Among those is the closest to us, Proxima Centauri, a little red dwarf about 1/8th the mass of our Sun.

>Fade out Voyager grid. Fade in Proxima grid

Let's take the distance between Proxima and Cape Town as the final unit of distance as we take a look at the distance to the core of our galaxy, the Milky Way, about 6000 Proxima distances away.

As mentioned before, we have the Milky Way fully in view, and can count about 4,5,6000 Proxima Centauri distances above Cape Town to the super massive black hole at the center.

>Fade out Scene

And this concludes the first show.

Under your seat you will find two papers. Can you please grab the top one, titles **Show 1** and fill in your student number with the handy writing pad and pen we've provided.

Now I will be presenting two questions for you. Here is the first.

___

You have 90 seconds to write down your responses.

Okay, please wrap up your responses. The second question is as follows,

___

Again, you have 90 seconds.

And when you are finished, please place the questionnaire under your chair. And we can begin the next show.

Here we are once again viewing Cape Town from 1 Earth radii above. We will now take another look at the distance to the Moon. First I will put up a distance measurement for reference. Here we will use 1 Earth radius as our unit of distance.

>Fade in Earth radii script

The Moon sits about **60** Earth radii above Cape Town.

With the Moon in view, we can set a new unit of distance of 1 Moon distance from Cape Town.

>Fade out Earth radii script. Fade in Moon distance script

We can then take a look at how far the Sun is from Cape Town, which we will see comes to about **400** Moon distances.

Once again, here is our Sun.

Our new unit of measure will now be the distance between Cape Town and the Sun, or 1 AU.

>Fade out Moon distance script. Fade in AU script.

Now I will show you the distance that the Voyager1 spacecraft, the furthest human made object from Earth, sits from Cape Town. In the meantime I will bring up the planet orbits for reference. I will also include Pluto once more, so nobody gets upset.

Voyager sits about 145 AU (or Sun Earth distances) above cape town.

Can anybody spot the Voyager craft? Remember, it is the size of a car. Keep your eyes peeled. There it is. The Voyager spacecraft is currently at the Heliopause according to its measurements, the layer where the solar wind is stopped by the interstellar medium.

We will now use one Voyager 1 distance as our unit of distance.

>Fade out AU script. Fade in Voyager script.

Once again, we can now show the distance to the closest star, Proxima Centauri, about 1800 Voyager distances above Cape Town.

I will make visible the Orion constellation for reference.

…(long time goes by)

Here is Proxima Centauri, our Red Dwarf neighbor. Proxima is actually part of a triple star system with Alpha Centauri A and B, but Proxima is the closest to Cape Town.

>Fade out Voyager script. Fade in Proxima script.

We set our final unit of distance as one Proxima Centauri distance, and take a look from a few thousand of these distances away, back toward Cape Town, with now the Milky Way in view with its center, home to the Sagittarius super massive black hole.

Here we will end the second show.

>Fade to black

You may now take the second sheet of paper titled **Show 2**. I will now give you the first question to answer for this sheet.

____

You have 90 seconds to respond.

I will now read the second question.

____

Again, please take 90 seconds to record your responses.

Finally, if you can flip over the paper to the side labeled **Shows 1 & 2**. I will now read question 3 for this side.

____

You have 90 seconds for this question.

When you are finished. Please leave the two sheets, writing board, and pen on your seat.

Thank you very much for your participation. I hope you enjoyed the show

G. PhAsER Consent Form

DEPARTMENT OF ASTRONOMY

UNIVERSITY OF CAPE TOWN
PRIVATE BAG X3
RONDEBOSCH 7701
SOUTH AFRICA

Informed Voluntary Consent to Participate in Research Study

PhAsER Group Education and Curriculum Development Studies

Background

In order to improve the quality of teaching and learning in Astronomy and Physics research projects are undertaken by the Physics and Astronomy Education Research (PhAsER) Group in order to understand how students engage with aspects of the curriculum. This includes both conceptual and perceptual issues.

Procedures: During this study, you will be asked to fill out a questionnaire.

Risks: There are no potentially harmful risks related to your participation in these studies.

Confidentiality: All information collected in this study will be kept private in that you will not be identified by name. Confidentiality and anonymity will be maintained as the data are analysed without reference to any particular student. *You will never be identified to the lecturer during the course. You are requested to fill in your student number on the information page in the event that the researcher(s) are able to contact you in order to clarify or expand on your responses. However, this page is detached prior to any analysis and only identified with the unique response set number in the event that a clarification is felt to be necessary. Further*

What signing this form means:

By signing this consent form, you agree to participate in this research study. The aim, procedures to be used, as well as the potential risks and benefits of your participation have been explained verbally to you in detail, using this form. Refusal to participate in or withdrawal from this study at any time will have no effect on you in any way. You are free to contact me, to ask questions or request further information, at any time during this research.

Disclaimer/Withdrawal: Your participation is completely voluntary; you may refuse to participate, and you may withdraw at any time without having to state a reason and without any prejudice or penalty against you. Should you choose to withdraw we commits not to use any of the information you have provided without your signed consent. Note that the researcher may also withdraw you from the study at any time.

I agree to participate in this research (tick one box) ☐ Yes ☐ No _________ (Initials)

Name of Participant	Signature of Participant	Date

PHASER RESEARCHERS
Saalih Allie,
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Alexander Sivitilli