PROBING STUDENT ENGAGEMENT WITH SIZE AND DISTANCE IN INTRODUCTORY ASTRONOMY

Tshiamiso Neo Makwela

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Supervisor: Professor Saalih Allie

Co-Supervisors: Associate Professor Dale Taylor & Associate Professor Sarah Blyth

Abstract

Astronomy Education Research has shown that students have many challenges when it comes to understanding key concepts in Astronomy. Amongst these is a poor understanding of astronomical scales. Recently for example, both sizes and distances have been shown to present similar difficulties to students in both South Africa and Norway. It is difficult to attribute the findings simply to inadequate teaching due to the significant differences between the two countries with regard to language, culture, and the type of science teaching. It has, therefore, been suggested that since astronomical sizes and distances are beyond immediate human experience the explanation might in fact lie at a deeper cognitive level. The present thesis is aimed at exploring the link between astronomical sizes and distances as well as cognition.

Part I

The thesis focuses on investigating students' understanding of sizes and distances in astronomy. This was done by probing student notions of astronomical scales, using the size and distance questions from the Introductory Astronomy Questionnaire (IAQ), the instrument which led to the original findings noted previously. These questions were administered before and after a *specially* structured teaching intervention on sizes and distances. The results of this study in 2018 were found to be (a) in agreement with similar studies previously reported in South Africa and Norway, namely, that both sizes and distances in astronomy were poorly understood in both contexts and (b) that the teaching intervention was least effective for distances.

Based on the findings above, the focus of the thesis shifted to a more fine-grained investigation of how students conceived of distances, as they increased from "human scale" to "beyond human scale". The study was carried out using the Grounded Theory Method (GTM). Data were generated by prompting written explanations from introductory astronomy students on how they engaged with three distances two of which may be considered to be within human experience while the third lies beyond the realm of direct experience. The distances used were 7 metres, 100 Kilometres and the distance to the moon. The second distance was partly informed by the idea

that we often communicate large distances to each other in terms of time. In addition, the framing of the questions excluded the possibility of visual explanations.

The questions were administered to a cohort of introductory astronomy students at the University of Cape Town in 2019. A grounded analysis of the student responses was carried out to identify key ideas. The categories that emerged from the analysis showed clear evidence of students using different, unconnected types of explanations rather than simple extrapolations of one idea. A conceptual transition was identified relative to the body position of the respondents: body calibration and self-propelled body motion (or journeying). What was striking was that time was rarely mentioned explicitly.

The way in which students expressed themselves was assumed to be an expression of the way in which they were thinking about different distance domains and suggestive of the cognitive perspective offered by “Embodied Cognition”. Of particular interest was that non-static explanations were centered around the notion of a journey, and one of the key “thinking templates” in Embodied Cognition; the SOURCE-PATH-GOAL “Image Schema”.

Part II of the thesis summarizes key elements of Embodied Cognition that are pertinent to the present work and describes a pilot activity for teaching astronomical distances based on this account.

Part II

Theories of cognition can roughly be divided into two camps: those that assume that thinking is a “mentalese activity” involving symbolic manipulation. Most importantly, these symbolic elements are “amodal” in that they are not derived from the sensory modalities. On the other hand, Embodied Cognition assumes that these symbols arise from the sensory modalities, hence all thinking arises from bodily experience and its interactions with the environment in infancy. While there are several strands that feed into Embodied Cognition, of direct interest to the present work is that of Cognitive Linguistics and the notion of Conceptual Metaphor. In this view

metaphors are not regarded as (mere) linguistic devices but as conceptual expressions that reflect cognitive schematic structures that relate to the bodily infant experience. These cognitive schematic structures or “Image Schemas” arise from repeated bodily actions repeatedly activating particular neural networks and form the basic building blocks of all abstract thought. A fair amount of such Image Schemas (or “thinking templates”) have been identified of which the SOURCE-PATH-GOAL resonates most clearly with the data described earlier. This Image Schema comes about in infancy when a child learns that a toy on the far side of a room cannot be reached by grasping only but that moving the body from one place to another (crawling) is required. This is the basis of “Life is Journey or the Ph.D. Journey”, for example. Another aspect of Embodied Cognition holds that understanding involves a mental simulation using the cognitive resources that are activated at the time.

In order to see if activating the SPG / Journey “thinking template” prior to engaging with the teaching material would help in comprehending astronomical distances a two-part teaching activity (A and B) was developed around the notion of a journey. Part A was presented to the students as ‘Journey to the observable edge of the UNIVERSE along UNIVERSity avenue” and required students to walk the length of the campus in a structured manner that is described in detail in the thesis. Part B, engagement with the teaching material, was carried out immediately afterwards in the Main Hall of the University. Thus, the thinking behind the two-part activity, piloted in 2020 just prior to Covid related lockdown, was that “journey” cognitive resources would be activated by the experience and would therefore be used in engaging with the teaching material regarding astronomical distances. Student evaluations were gathered in order to probe how students had engaged with the activity, including if any of the resources associated with journeying were expressed. A post-test ranking task showed that while results were mixed relative to previous studies overall there was a marked improvement for the present cohort.

In summary the work shows clearly that there were two different modes of thinking about distances (i) based on counting and (2) based on the notion of the journey/journey-ing. Results were interpreted as the activation of schema described by embodied cognition. The difficulty that students experienced with astronomical distances was attributed to the lack of activating the Source-Path-Goal schema. In order to see whether there was a way to activate the Source-Path-Goal schema, an activity involving students walking was designed. The outcomes from the activity, indicated promising results with regard to student engagement with astronomical distance.

Declaration

I Tshiamiso Neo Makwela, hereby declare that this research thesis is my own unaided work. It is presented in fulfillment of the degree of Doctor of Philosophy at the Department of Astronomy, University of Cape Town. It has not been submitted for any other degree or examination in any other university, nor has it been prepared under the guidance or with the assistance of any other body or organization or person outside the University of Cape Town.

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10 June 2022

Dedication

To My Mom,

Mpule Louisa Makwela,

For all your sacrifices, your prayers, your love, guidance, and support.

I thank you greatly.

I love you.

KE SETLHOGO SA DITLOU!!

KE MOTHO WA GA MAKWELA GO LEMA TLOU.
BAMO THATA LEOPENG
LEOPE KE WELA DIFOFU LE BABA MATLHO BALE WELA
KE SETLOGOLO SA MALESELA MOKGOBOKWANE

RE NTSHA GO JA LEGOKGO DINGWE DI FULA MOTLHAKOLA
KE MOTHO WABO MATJIANE, WABO MATEMA WA LEEPE
LE BA MAKGOFE MAIMELA

KE MOTHO WABO MOTOPI WA DIPULA TSA DINALEDI
WA BO MOSHIBUDI MABALANE MAGAKGALA
MODIKELA A SENA WABOO BARENG MPHEPHE WA LAPISA
MOTHO O KGONA KE SA GAGWE

O BONA KE TSHWERE ENG, KEISITSE DIATLA KWA MOGARO
KE RWELE SOROTWANA SA KORONG MO TLHOGONG.

TLOU WEE!!

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Thank you, Almighty God for Your wisdom and strength that carried me, throughout this journey, 2 Corinthians 12:9-10.

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A note on the style of thesis

Please take note of the following style in the structure of the thesis

1 I often use the pronoun ‘we’, which refers to the first author of the thesis. This is because the thesis was first reported as short proceedings papers, with me and my supervisors as authors. (These journal papers are still in the process of being submitted for publication).

2 There is a brief literature review focusing on AER in Chapter 2 and another literature review focusing on the theoretical framework in Chapter 5.

3 Chapter 3, 4, and 6 are structured in the form of journal papers and may contain some repetition.

Acronyms

SA: South Africa

IAQ: Introductory Astronomy Questionnaire

AQUED: Astronomy Questionnaire: Understanding Engagement of Distance

AAAS: American Association for the Advancement of Science

TSPCK: Topic Specific Pedagogical Content Knowledge

PMQ: Physics Measurement Questionnaire

GTM: Grounded Theory Method

IS: Image Schema

SPG: Source-Path-Goal

SALT: Southern African Large Telescope

SARAO: South African Radio Astronomy Observatory

SKA: Square Kilometre Array

Chapter 1: Thesis Introduction

Summary of chapter

This chapter gives an overview introduction of the research study focusing on probing students' engagement with sizes and distances in introductory astronomy. In this chapter, the context of the study is provided by centering the role of astronomy in South Africa as well as where the field fits in the school curriculum. The rationale of the study is also included, to provide not only reasons for, but the importance of this current study. This is followed by the research questions that the thesis aims at addressing. A brief section on the methods of research and the analysis of the data is provided later. The chapter concludes by giving an overview of each chapter in the thesis.

1.1 Introduction: State of Astronomy in SA, school curricula

South Africa (SA) has chosen Astronomy as one of its flagship sciences, exploiting the geographical advantage of the southern skies. South Africa is also one of the countries at the forefront of world-class astronomy development and science. As such, astronomy is one of the key research areas in SA and the development of it across all the wavelengths has been a focus of government policies. The Southern African Large Telescope (SALT) and the Square Kilometre Array (SKA/SARAO) are well-known examples of telescopes dealing with some of these wavebands (multi-wavelength astronomy White paper). Since these developments and research are situated in this field, it requires that we develop capacity from all communities across the country (SA) and continent (Africa).

However, in the South African school curriculum, astronomy is not well covered. It is taught as part of Natural Science subject between grades 4 to grade 9 and as part of geography grade 10 (National Curriculum and Assessment Policy Statement, *CAPS*). Thereafter, students who would like to become astronomers/ astrophysicists enroll for a Bachelor of Science Degree (BSc) at a higher institution of learning (University) then study astronomy. Other students pursue a Bachelor of Education (B. Ed) to become science teachers, in which astronomy modules form part of their tertiary education. In other words, there is about a three-year gap in high school where science students (National Curriculum and Assessment Policy Statement, *CAPS*) do not learn any astronomy within the current school curriculum. Although, students are encouraged to use some of this astronomy knowledge in their other school subjects, such as physics, which poses a challenge when the teacher's astronomy knowledge is limited.

In addition, astronomy is one of the sciences which people find to be of interest, although professional astronomy is not well understood amongst the general population. Often first-generation, non-traditional university students are attracted to the field by its romanticism and the intrigue factor or by the promise of a career. Most of the students enrolling for an introductory astronomy course are drawn by the awe and wonder factor which the night sky fully elicits, but then, students often struggle to comprehend basic astronomical concepts (Ball, 2018; APS Physics).

Moreover, studying to become an astronomer involves mastering a lot of physics and mathematics in the first instance. These are then coupled with astronomy concepts which on the surface appear beguilingly simple but are hard to fully understand. For example, students seem to struggle with (a) the translate or apply their basic mathematical and physics knowledge to an astrophysics problem; b) to connect the different topics taught within the course (introductory astronomy and second year astronomy, which are admittedly quite broad courses) into a single story. The students to struggle to put together what they learn about stellar physics with what they learn when they study galaxies (which are made of stars and in which what they learn about stars become a component to understand the more complex system); they seem to be more prone to learning by separating the topics instead of trying to connect them.

Therefore, as part of initiatives to construct a curriculum that allows meaningful participation for all, an astronomy educational research program was established to identify student difficulties. This educational research was and continues to be carried out at the University of Cape Town (UCT). This is done in an introductory astronomy course. Thus, identifying student difficulties through research enables us to feed the insights gained into the development of an appropriate curriculum.

1.2 Rationale of the study

The topic of scales in astronomy (celestial sizes and distances), has not been fully explored in Astronomy education research (AER) studies. Piaget (1967) was one of the early researchers who investigated children's spatial abilities, although since then, the notions of sizes and distance in astronomy, have not been well researched in AER. It is therefore difficult to draw clear generalizations and conclusions about student knowledge (prior knowledge as well as school knowledge) and understanding with regard to these aspects. In many instances, sizes and distances in astronomy have been part of big studies which focused on other concepts and aspects of astronomy such as seasons, eclipses, phases of the moon, as well as flat earth. In this study, we investigated students' understanding of conceptions and ideas concerning celestial objects' sizes and distances. Furthermore, Lelliott and Rollnick (2010), identified astronomical sizes and distances as a fundamental big idea in astronomy education, which forms the basis of understanding other astronomical phenomena.

The research studies which covered aspects of astronomical scales and size report that students have no basic understanding of large scales. For example, some students struggle to identify that stars are bigger than planets, even after instruction (Sadler, 1998). Studies by Sadler (1998), Agan (2004), and Cin (2007), included a focus on distances of stars. In these studies, it was found that some students struggle to answer the questions pertaining to astronomical distances correctly, this was the question students were asked in the study by Agan (2004) 'What are the distances to stars? If the Earth were 1 inch in diameter, how far away would the Sun/nearest star be?'. More so, Agan (2004) further stated that although high school students were able to speak of "great distances" between stars, they were unable to connect this to astronomical scale models. Hence, Bakas and Mikropoulos (2003) contend that the comprehension of large scales in astronomy is almost meaningless to students, and they are just too abstract thus not understood. However, Sharp (1996) argued that children were capable of grasping complex abstract concepts. Lelliott and Rollnick (2010), therefore, further argued that the area of size and scale in astronomy is under-researched, and further research within this big idea is recommended.

The existing literature on astronomical scales and size is limited, making it difficult to compare the results and findings between the research studies. The reasons that contribute to the difficulty in comparison are linked; to the different research methods used in the studies; the framing of questions for data collection and the samples of the studies are also different as well as the main aim of their studies. As such, these difficulties contribute towards the lack of standardization of research instruments, and probing and analysing this aspect have remained a challenge for researchers to fully explore the extent of student difficulties.

The study conducted by Rajpaul et al., (2014) using the Introductory Astronomy Questionnaire-IAQ, showed that astronomical sizes and distances are poorly understood. The study further indicated that an understanding of astronomical sizes and distances is also seemed to show to be a predictor of student overall performance/achievement in the introductory course. Meaning that some of the students who understand these concepts perform better in the subject than students who do not grasp these fundamental concepts. Thus, they are gate-keeping concepts that open up the richness of astronomical knowledge to students. Thereafter, the IAQ was translated into Norwegian and administered to middle school students as well as science pre-service teachers (Lindstrom et al., 2016; Rajpaul et al., 2018). The results pertaining to astronomical sizes and distances were as poorly answered in the original IAQ (Rajpaul et al., 2014). A full account of these studies is given in Chapter 2.

The current study is important in astronomy education research (AER) because it addresses the issues of astronomical scales as well as the cognitive difficulties that are related to this. These cognitive issues are often overlooked in Physics, Mathematics, and Astronomy. This study also enabled us to standardize the way in which astronomical sizes and distances are probed and analysed in AER. Hence, offering comparable research findings. In terms of broader goals, this study links well with the aims of transformation and inclusion in science fields, as the experimental work in this study focuses on the students and uses students' knowledge to develop their understanding of new concepts.

One of the ways in which this study uses the experimental findings is seen in chapter six where we used the findings coupled with an explanatory framework to develop a teaching intervention. This teaching intervention is named "a Journey through the UNIVERSE along UNIVERSity Avenue". In our daily lives, we use the metaphor "journey" to describe abstract concepts such as 'career, carrying out a research study (i.e., Ph.D.), recovery'. This metaphor is not just a linguistic tool, it is a conceptual metaphor that is based and built through our recurrent sensory motor experiences. The journey conceptual metaphor was identified in students written responses, when probed on their engagement with distance.

1.3 Research problem

Astronomy is one of the most intriguing sciences of nature, as we all have the luxury of the night sky, and in the Southern Hemisphere the best view of the Milky Way galaxy. The problem is that many people fail to fully conceptualize the vastness of the night sky and the universe at large. This makes it difficult, especially for students who are interested in astronomy as a career, (for example, astronomers, aspiring teachers, and amateur astronomers at large). This difficulty poses a challenge as students are unable to make sense of/ understand other fundamental concepts in astronomy. As stated, astronomical scales and sizes are a big idea in astronomy. Without a full understanding of this big idea, students' overall performance may be poor. However, teaching these concepts is not an easy task as well, and many interventions have been put in place, but none have shown substantial improvement in student understanding. As a result, the purpose of the study was to probe the extent of student difficulties as well as to characterize the nature of difficulty and find ways to overcome them.

1.4 Research questions

The study aimed to probe student engagement with aspects of astronomical magnitudes, especially distances. In an attempt to understand these aspects, the following guiding research questions were asked, to help us shape our study:

1. To what extent do introductory astronomy students have difficulty with astronomical distances?
2. How do students think about distances?
3. How do we theorize about the different thinking modes from guiding research question 2?
4. To what extent does an activity based on activating the JOURNEY 'Source-Path-Goal' schema in Embodied Cognition address student difficulties with astronomical distance?

1.5 Research design

The current study explores the issue of astronomical sizes and distances by fundamentally understanding student conceptions, which we probe in different ways. We try to understand student conceptions by probing the notions of the sizes and distances of celestial objects, through a ranking task first (See chapter 3) and then a written response questionnaire later (See Chapter 4). As a starting point, we looked at the existing trends in literature and confirmed whether the issues persist with a different group of students using only the size and distance ranking questions of the IAQ. The IAQ (focus on Size and Distance) was used in order to be able to standardize how these aspects are probed to be able to compare the study with previous studies that have used the IAQ (Rajpaul et al., 2014; Rajpaul et al., 2018).

We then further probe astronomical distances, as Agan (2014) argued about the inability of students to relate "great distances" between stars and astronomical scale models. In probing students' notion of distances, a written response questionnaire was used. A grounded theory method was used to analyze student responses and we took note of the emergent descriptive categories. These categories provided us with low level theory with regard to student thinking about the concept of distance. Furthermore, this low-level emergent theory seemed to be coherent with a theory of cognition that is specifically offered by embodied cognition (Lakoff & Johnson, 1980).

Using the findings and results from probing student distances, we then developed a theory-based practical activity, focusing on distances in astronomy. This TBA (Theory-Based Activity) will be integrated into the introductory astronomy curriculum as an intervention exercise that will assist students with understanding astronomical distances.

1.5.1 Research Instruments

There are two main research instruments that were developed and used to collect data in this study: (1) Introductory Astronomy Questionnaire (focus on size and distance ranking)- IAQ_SD and (2) Astronomy Questionnaire: Understanding Engagement of Distance- AQUED. The original IAQ consisted of 9 questions which were aiming at probing broader aspects of the introductory astronomy course, especially in a South African context (Rajpaul et al., 2014). Due to the nature of our study, we chose only the size and distance ranking questions to use for data collection. We modified these questions (see details in Chapter 3), thus renamed the IAQ to IAQ_SD (Size and Distance). The IAQ_SD focused on the ranking of sizes and distances of celestial objects as well as a short 'explain to a friend' question, which required the participants (students) to provide a written explanation. The IAQ_SD ranking tasks provided us with quantitative data, which was analysed to identify patterns in student understanding, so as to be able to draw a conclusion and thus generalize the trends within the astronomy education population. The long explanation question (with a particular audience) of the IAQ_SD provided us with qualitative data, which provided insights into student ideas about celestial objects. The IAQ_SD was administered as a pre-test and a post-test with an instructional intervention between the two. The main reason for administering the questionnaire in this format was to look at how students' ideas change or do not change over time, as well as to measure the impact of the instructional intervention. This investigation answered research question number 1 (details in chapter 3).

The Astronomy Questionnaire: Understanding Engagement of Distance (AQUED) was developed following the results from the IAQ_SD. The AQUED was developed to probe students' intuitive understanding of distances, starting from tangible to intangible distances (full details in chapter 4). This instrument collected qualitative data in the form of written responses. The questions were framed as a response to a blind friend (more details in chapter 4). The responses to these questions enabled us to have a clearer understanding of students' ideas about distance, hence offering insights as to why certain teaching interventions (especially those dealing with astronomical scales and sizes) did not yield positive results in students' comprehension of these aspects in astronomy. The AQUED was administered only as a pre-instructional tool, in which we probed students' knowledge before they received any teaching in the course. All questionnaires required the participants to answer them individually, none of the questions were group work.

1.5.2 Sample

The sample of the study was students who were registered for the introductory astronomy course which is offered at the University of Cape Town. The introductory astronomy course (AST1000F) covers the basics of astronomy by providing an overview of the field, thus exposing students to different fields of research, and showing how scientific knowledge is gained. This course is similar to the typical undergraduate "Astro 101" course offered by universities in the United States.

The AST1000F course is an entry-level course, which is open to any student from any faculty within the University of Cape Town (UCT). Since it has no strict prerequisites, the class is made up of a diverse group of students with different backgrounds, cultures, languages, and fields of study. As such, this diverse group of students is suitable for our studies as they provide a wide range of ideas/conceptions.

Table I. Summarizes the samples of the research studies over the years 2018- 2020 (three-year period), together with the total number of students and the research instruments used for data collection in each case.

Sample	**Year**	**Total Number of students**	**Instruments Used**
1	2018	111	Introductory Astronomy Questionnaire: Size & Distance (IAQ-SD) - Pre and Post
2	2019	86	Astronomy Questionnaire: Understanding Engagement of Distances - Pre
3	2020	124	Introductory Astronomy Questionnaire: Size & Distance (IAQ-SD)- Pre and Post.

Table I shows a summary of the student sample in the period of three years 2018 to 2022 respectively. Different research instruments were used in this study as shown in the table. For example, in 2018 we had a total of 111 students, we administered the Introductory to Astronomy Questionnaire: Size and Distance (IAQ-SD) as a pre-test & post-test. Chapter 3 covers the results of the 2018 study. In 2019, we had a student sample size of 86, we administered the Astronomy Questionnaire Understanding Engagement of Distance (AQUED), which was a written response questionnaire, the results of this study are in chapter 4. In 2020, we had a total of 124 students, we then administered the IAQ-SD as a pre-test and post-test, and administered a short evaluation post the intervention task, this is documented in chapter 6.

1.5.3 Ethics

Ethics clearance for this project was granted by the Faculty of Science Research Ethics Committee (protocol no FSREC 009 – 2021). The following ethics measures were taken to ensure that we prevent any harmful or wrongdoing of others in the process of collecting data. (1) Anonymity of students, so that their personal identity is not available to anyone outside the research group; and (2) The questionnaires do not contribute to students' overall course marks.

Access to the students was gained via the lecturer of the course, who is also part of the project (supervisor). Students were informed at the appropriate time that they are voluntarily taking part in an educational research exercise, and they can choose not to participate. All aspects of the broader context of the research were clearly stated on the Informed Consent Form (See appendix I) and the details of the form were explained to students. They were also informed that the data gathered is anonymous, other than the student number, which needs to be recorded on the response set. This is to allow for the key aspect of the study, which is to see how students' knowledge and understanding has changed as a result of the teaching interventions.

For the data analysis phase, respondents were assigned a random "respondent identification number" (RIN). The mapping between student numbers and the RIN was stored in a separate protected folder that is only accessed for matching purposes by the researchers. Once the post-test has been completed and corresponding RINs matched the mapping file between student numbers, they were then deleted and the anonymized data (was no longer identifiable to anybody) and was analysed further. We also stored the data in archives for potential future use with only the RIN linking the pre- test and post-test response sets.

1.5.4 Analysis

Since our study was empirical, it was not theory-driven, but rather purely driven by the collected data. A Grounded Theory Method (GTM) was the most appropriate to employ in analysing the data, as the data were likely to provide a wide range of varied responses. The grounded theory method was first coined by Glaser & Strass, (1967), and aimed at generating a theory from the data collected. The emphasis of the grounded theory method is on the fact that a theory is directly grounded/ based on the data (Kinnunen & Simon, 2012).

The data i.e., the student writing that was generated from these questionnaires were analysed at a fine-grained level (directly coding student response as provided) to identify key ideas. The key ideas were then grouped according to common themes, which then generated the big emergent categories. This was an iterative process, which was done over time to keep on refining the codes (see Chapter 4). These emergent categories especially were further analysed using the explanatory framework from cognitive science and the results of this analysis were used as the basis for constructing a teaching intervention.

The analysis was carried out by me (first author), my research partner (Alex), and the PhAsER research group later met with us to discuss the emergent key ideas (which we called codes) (see chapter 4). Before continuing with the analysis, we needed to reach higher inter-rater reliability

(IRR) score, meaning that we needed more people (hence the PhAsER group) to review the responses and the identified key codes to ensure the credibility of our results.

1.6 Explanatory framework

While looking at the emergent categories in Chapter 4, we decided to look at the data using a cognitive science lens. We then used the cognitive science approach, that is offered by embodied cognition from the cognitive-linguistic lens to further analyze the results. Embodied cognition asserts that all abstract thought is ultimately grounded in sensory motor experiences (Lakoff & Johnson, 1980). As such, understanding is ultimately grounded on our bodily experience with the environment in which we live (Barsalou, 2008). Embodied cognition further maintains that all concepts that we know are identified with the neural activation of our embodied experience. Thus, cognition is embodied, in that the specifics of our bodily encounters and experiences with the world are directly encoded in the cognitive structures which are the building blocks of thought. A full account of embodied cognition is provided in Chapter 5.

1.7 Thesis Outline:

Part 1: Probing student understanding of astronomical scales

Chapter one is an introduction to the thesis, which provides the state of astronomy in the South African context and the details of the Astronomy curriculum in South African Schools, as these provide the context of the study. The rationale, research problem, research questions are covered as well, to centre the importance of the study. A brief introduction to the research methods, analysis and theoretical framework are also provided.

Chapter two covers the astronomy education literature which is relevant to the current study. The chapter reviews existing work which allowed us to identify the research gaps thus showing the importance of the current study in this field.

Chapter three focuses on the relative scales of astronomical objects by answering the question "To what extent do introductory astronomy students have difficulty with astronomical distances?". The Introductory Astronomy Questionnaire: focus on Size and Distance (IAQ_SD), was used as the instrument for data collection.

Chapter four focuses on probing student notions of distances, using an instrument called "Astronomy Questionnaire Understanding Engagement of Distance" (AQUED). The main research question of this chapter is "how do students intuitively think about distances from tangible to intangible?". Chapter 3, offers much of the background to this chapter.

Part 2: Exploring the use of embodied cognition in astronomy: distances

Chapter five describes the explanatory framework, namely embodied cognition, used in the thesis. This framework is used to further analyze the data from Chapter 4.

Chapter six covers using the source-path-goal schema to teach distances in astronomy. A research-evidence-based activity was designed and is presented here.

Chapter seven consolidates the conclusions drawn from Parts 1 and 2. It also provides an overall conclusion of the study by critically reflecting on the research process and offering limitations of the study and future work to be carried out in this field.

Chapter 2: Overview of astronomy education research

Summary

This chapter outlines the important parts of this research in the bigger field of astronomy, astronomy education, and astronomy education research. It provides a brief overview of the extensive astronomy education research literature that has been produced over the years and the apparent gap which this current research study explores.

2.1 Introduction

Knowledge development is a process involving a continuous cycle of modification, refinement, and improvement according to the needs of the system at that time. My work is guided by the previous studies in astronomy education research (AER), as the refining of knowledge is not an isolated process. This section covers the relevant existing research studies carried out in AER. Firstly, an overview of astronomy education, which offers the history and context of AER, is covered. Then, the findings from research studies which investigated student conceptual understanding of astronomical concepts and that underpin our reasons for continued probing student knowledge are presented. A brief section on other research within AER is provided together with a brief review of the research methodologies that have been employed in the field. The chapter concludes by providing the background of the introductory astronomy questionnaire.

2.2 Overview of Astronomy Education Research

2.2.1 Big ideas in Astronomy

Earlier research studies in AER focused on testing student knowledge on the following topics: (i) Earth-Moon-System; (ii) Earth-Shape and gravity; (iii) The Solar-System and (iv) stars and galaxies; which made up the majority of the AER literature. This information was covered in a resource letter of 'Astronomy Education Research' (AER) which categorized the research done in the field up to that point (Bailey & Slater, 2005). These major topics were at the forefront of probing student understanding about astronomical phenomena. Out of all the issues raised that explicitly exist within the literature, astronomical scales (size and distance) were not explicitly researched (see Bailey & Slater, 2005). In 2010, Lelliott and Rollnick stated that astronomical scales, especially sizes and distances are two of the big ideas in astronomy, as important as the idea of gravity (Which some AER literature has looked at, Sneider, 1989; Treagust, 1989; Agan & Sneider, 2003; Sharp & Sharp, 2007; Lelliott, 2013; Plummer & Krajcik, 2010; Williamson et al., 2016).

Following the resource paper and the review by Bailey & Slater (2005), the aforementioned topics were grouped as big ideas in astronomy by Lelliott & Rollnick (2010). In their work, (Lelliott & Rollnick, 2010) provided an overview of astronomy education research done over 35 years, in which the notion of big ideas was structured. Big ideas are defined as "topics of importance for literacy in STEM" by the American Association for the Advancement of Science (AAAS) Project 2061. This is a popular notion in the science education field, which also feeds into the idea of Topic Specific Pedagogical Content Knowledge (TSPCK) (Loughran et al., 2004; Mavhunga & Rollnick, 2013). Lelliott & Rollnick (2010) focused on the 8 big ideas which they identified in studies that had been carried out over 35 years. The following topics were identified as the fundamental big ideas in astronomy: (i) the Solar system, (ii) gravity, (iii) stars, and (iv) the concepts of size and distance. The next four big ideas were topics that were commonly taught in the school curricula, (i) the Earth-Moon-Sun system, (ii) Earth shape, (iii) day/night cycle, and (iv) the seasons. These big ideas from Lelliott & Rollnick, have been classified using the “Big Ideas” framework, and, they are different from the main topics Bailey and Slater reported on. Lelliott & Rollnick (2010) did not however investigate studies which cover other fundamental ideas in astronomy, such as cosmology, modern astrophysics of Exoplanets, dark matter, dark energy, light, galaxies etc. These are all important concepts that are to be understood in astronomy.

2.2.2 Summary of Methods used commonly used in AER

Table II. Is a brief summary of the research methods used in Astronomy Education Research studies that include astronomical scales and sizes. The studies covered are from Primary schooling, Secondary Schooling and Undergraduate University.

Research Methods	**Studies**	**Type of research instruments used**
Quantitative	Zeilik et al, (1998); Sadler (1998); Bisard et al., (1994); Finegold & Pundak, (1990); DeLaughter et al, (1998); Trumper (2000, 2001a, 2001b) Miller & Brewer (2009)	Diagnostic tests, Surveys, Multiple Choice Questionnaires
Qualitative	Sharp, (1996); Taylor et al, (2003); Plummer et al., (2006); Sherrod & Wilhelm (2009); Wilhelm, (2009); Venville et al., (2012); Plummer et al., (2011); Plummer et al., (2014); Ka Chun Yu (2017); Taylor & Grundstrom (2011). Sivitilli et al.,2021/2022	Interviews Written Response Questionnaires Video Recordings (Most of these are also intervention studies)
Mixed method	Slater et al., (2016) Agan (2004) Bailey (2009) Makwela (2017) Plummer et al., (2014)	Surveys with follow-up interviews MCQ with long written responses Concept Maps (counting ideas and then analysing progression).

Research studies in AER have used different research methods, qualitative, quantitative, and a combination of quantitative and qualitative (referred to as mixed methods). Table II provides a brief summary of the different research methods that have been employed in AER, especially the studies that include astronomical scales to some extent. The quantitative studies that have been carried out usually included diagnostic tests, surveys, and multiple-choice questionnaires. These studies investigated student ideas across many different topics in astronomy, especially topics such as flat earth, that included gravity, seasons, eclipses, day & night (Zeilik et al, 1998; Sadler 1998; Schoon, 1992; Bisard et al., 1994; Finegold & Pundak, 1990; DeLaughter et al, 1998; Trumper, 2001a & Trumper, 2001b). Most of the studies prior to 2003, were mainly quantitative, and used diagnostic tests, surveys, and multiple-choice types of questionnaires which collected big samples of data.

Qualitative research is designed to explore underlying causal mechanisms occurring and investigates the process of sense-making of the participants' experiences, these are interpreted without the widespread use of traditional statistical analysis (Slater et al., 2016). Examples of such studies have investigated student ideas through interviews, written questionnaires, and video recording (Taylor et al., 2003; Plummer et al., 2006; Sherrod & Wilhelm, 2009; Wilhelm, 2009; Plummer et al., 2011; Wallace et al., 2011; Wallace et al., 2012a; Wallace et al., 2012b; Venville et al., 2012; Plummer et al., 2014). The findings of qualitative research studies bring out rich data that can be analysed in multiple ways to provide extensive evidence on students'/ teachers' notions pertaining to different aspects of astronomy. In most cases, a triangulation analysis is employed in strengthening the rigour of the findings, addressing the issues of trustworthiness and reliability of the studies. Triangulation means carrying out different analysis methods such as theoretical or conceptual frameworks to the same data, in order to confirm and strengthen the findings of a study.

Concept inventories are an example of diagnostic tests and MCQs that have been developed through qualitative studies. As such, they are commonly useful for diagnostic tests and identifying student challenges, here is a list of the existing astronomy concept inventories: Lunar Phases Concept Inventory (Lindell, 2001; Lindell & Olsen, 2002); Astronomy Diagnostic Test (Hufnagel, 2002); Light and Spectroscopy Concept Inventory (Bardar et al., 2007); Star Properties Concept Inventory (Bailey et al., 2009); Astronomy and Space Science Concept Inventory (T. F. Slater and S. J. Slater, 2008); Cosmology Surveys (Wallace et al., 2011); Astronomy Concept Inventory (Bilici et al., 2011); Test of Astronomy Standards (Slater, 2014); Size, Scale and Structure (Gingrich et al. 2015); Astronomy and Science Student Attitudes (ASSA) (Bartlett et al., 2018); Planet Formation Concept Inventory (Simon et al. 2019); and Moon Phases Concept Inventory (Chastenay and Riopel, 2020).

Slater showed that the combination of both quantitative and qualitative methods/measures were able to identify students' persisting alternate conceptions after instruction (Slater, 1993).

These types of studies are referred to as a mixed method approach, where both qualitative and quantitative methods are used to triangulate evidence-based conclusions from multiple sources of data which can then be interpreted with different philosophical perspectives and viewpoints (Slater et al., 2016).

2.3 Unpacking problem areas student thinking

Wall (1973) argued that it was not necessary for research to be carried out focusing on student understanding and conceptions of different phenomena in astronomy. Rather, he suggested that it was important to measure the effect and impact of the teaching materials used in teaching these concepts as this may provide insight. However, I disagree with Wall's conclusion as student conceptions are important for our understanding as researchers and practitioners so that we can be able to provide, suggest and develop the teaching material, practicals, and interventions needed to cater to student needs. On the contrary, Adams & Slater (2000) discuss the presence of astronomy topics in the American National School Education Standards and give a short review of related research results. They argue that due to the emphasis on conceptual understanding and teacher education in the standards, it is important to carry out future research on student understanding, which requires the development of research-based, and concept-specific assessment tools (Adams & Slater, 2000). Thus, several studies (Sadler, 1998; Sharp, 1996; Lindell, 2001; Hufnagel, 2002; Plummer, 2000; Trumper, 2001; Agan, 2004; Lindell, 2004; Bardar et al., 2006; Sadler et al., 2009; Bailey, 2008; Plummer et al., 2006; Plummer, 2008; Plummer, 2010a; Cheon et al., 2013; Plummer et al., 2011; Taylor et al., 2011; Plummer et al., 2014; Bailey et al., 2012; Gingrich et al., 2015; Simon et al., 2019, Chastenay & Riopel, 2020) were carried out, which probed student knowledge, understanding, and conceptions in astronomy.

The following insights coming from the (mentioned) studies show the need to continue refining how ideas are probed as well as the teaching of these ideas. For example, Plummer et al. (2011), carried a study where they investigated elementary students’ explanations of the patterns of the daily motion (apparent) of the Sun. Pre- and post- interviews were used to collect data and were analysed in their study, one of the key findings showed that about half of the student sample operated from their naive mental models that are based on their experiences and prior non-scientific knowledge. These naive models are generally not in line with the scientific explanations and concepts knowledge, required to fully explain the apparent motion of the Sun. This further provides motivation for teachers to be more aware of student naive mental models and include them in teaching and the framework of science, in order for students to recognize their incorrect notions as well as what is incorrect about their notions (framework theory by Vosniadou & Skompetili, 2014 and p-prims by diSessa, 1993). This key finding (Plummer et al., 2011) is a similar finding to that by Sharp (2006), where the results of the interviews carried out with the students’, showed that they had a poor knowledge base which was reflected in their intuitive and transitional nature of the mental models they used and expressed when answering questions regarding the solar system. Furthermore, it is argued that although students may use the correct terminology in explaining astronomical concepts, which implies that they have acquired a complete conceptual understanding of concept, when they are probed further through other research methods, it shows that the latter is not the case (Bailey & Slater, 2003). Hence, students hold these deeply rooted alternative concepts of science, especially in astronomy, even after instruction, and build on this knowledge with the newly learned content (Bailey & Slater 2003; Vosniadou & Skompetili, 2014; Makwela, 2017).

Additionally, in a similar study (with the planetarium) with another group of students, Plummer et al., (2014) carried out a study, in which they looked at student learning progression over time, when teaching about the universe from an Earth-based perspective and space-based perspective. Plummer interviewed students before and after instruction in the planetarium, where student ideas were noted. The main findings showed that although the intervention was aimed at enabling students to gain adequate sophisticated scientifically correct explanations, many of the students were unable to fully develop accurate explanations for daily celestial motion after a “good” instruction (Plummer et al., 2014). Studies by Ka Chun Yu (2017) have explored the role of planetariums in studying astronomical phenomena, using it as an intervention instruction to help students understand concepts better. In these studies, improvements in student understanding were recorded on those that had visited the planetarium unlike those who saw visuals on a flat plane, like a board/ whiteboard. Further research studies are currently being carried out at UCT (Sivitilli et al., 2021) to address the impact of improved planetarium technologies in the teaching and learning of astronomy content.

2.4 Spatial thinking

In an attempt to improve student knowledge, spatial awareness that has been mostly employed, is the use of planetariums and many other ways of visualizing astronomy phenomena.

More recent studies have focused on other aspects of astronomy education such as visualization which have explored the importance of 2D and 3D images in astronomy and their role therein (Eriksson, 2019; Wilhem et al., 2018). The aspects of visualization also touch on the issues of spatial ability especially in terms of moving between 2D and 3D images. People generally do not see the same thing when looking at images, especially 3D, thus Eriksson (2019) suggests a way in which professional astronomers and astronomy teachers can teach the extrapolation of 3D images to students. Disciplinary discernment is the term that Eriksson uses to describe this process, where one starts first by noticing something, then reflects on it, and constructs new meaning from a specific discipline perspective (Eriksson, 2014). Eriksson introduces the framework of social semiotics in astronomy, where social semiotics asserts that any form of communication within a specific discipline is known through the use of a semiotic resource or system (Airey & Linder, 2017). A semiotic resource/ system refers to a method of communication, such as formulas, graphs and equations that are used in a specific discipline.

The most recent review study in AER by Cole et al. (2018) focused on the idea of spatial thinking which is defined as "the perceptual and cognitive processes that enable humans to create and manipulate mental representations of the spatial properties that exist within and between physical or imagined objects, structures, and systems" (Cole et al., 2018, p.1). The ability to understand these external representations such as maps, diagrams, equations, graphs, as well as solving problems or making inferences about spatial properties (internal) also makes up spatial thinking (Cole et el., 2018). Cognitive science refers to spatial cognition when discussing issues related to spatial thinking (2018). Spatial cognition is defined as “the knowledge and internal or cognitive representation of the structure, entities, and relations of space; in other words, the internalized reflection and reconstruction of space in thought” (Hart and Moore, 1973, p. 248).

This review (Cole et al., 2018), looked at spatial thinking within the studies carried out in AER by looking at the research frameworks that are traditionally used to characterize and measure spatial thinking in astronomy. These frameworks include the work of the psychologist Piaget, whose work on children's cognitive development shed light on their spatial awareness, with emphasis on the children's sensory-motor experiences. The next framework was the psychometric approach which focused on describing and identifying factors of spatial abilities. This approach contributed to the understanding of spatial thinking by differentiating spatial abilities from other cognitive processes in astronomy and other related scientific fields. A cognitive approach put emphasis on identifying the mental processes used in decoding spatial skills. The cognitive approach framework, especially that offered by embodied cognition is the one which we use to further analyze and interpret results in our studies (see chapter 4).

Cole et al., (2018) have also shown that spatial skills have been probed in a variety of ways summarized as non-interventional, interventional, and learning progression studies. These studies used different research approaches and within each approach, improvement was perceived (see Cole et al., 2018). These studies cannot be directly compared with one another, thus only inferences are made from the findings. In our attempt to look at this notion of spatial ability in astronomy, we specifically look at the big idea of size and distance.

With regard to student understanding, studies have shown that students hold on to their alternate conceptions even after instruction, e.g., Sadler (1998) who concluded that students prefer these alternate ideas that fit their current worldview over scientifically correct notions. Other authors (Nussbaum & Novak, 1976; Sharp, 1996, Marsh et al., 1999; Lindell, 2001; Fanetti, 2001; Sharp, 2006) have expressed that student ideas change with age; for instance, younger children may have extremely limited ideas which increase to be more scientifically correct as they grow older (and are exposed to more content knowledge).

Additionally, huge efforts have been made in Astronomy Education Research to improve student knowledge and understanding of astronomical phenomena (McKinnon et al., 2002; Prather et al., 2004; Waller & Slater, 2011; Plummer, 2008; Prather et al., 2009; Rudolph et al., 2010; Plummer et al., 2011; Coble et al., 2013; Slater & Tatge, 2017). In the study by Rudolph et al., (2019) which used the Light and Spectroscopy Concept Inventory to determine students learning, showed that there was an increase in student learning with the increase of interactive teaching and learning strategies employed. Bailey & Slater (2005) further mention that these learning gains seen in these studies are influenced by several aspects, such as the teachers content and classroom interactions. Prather et al., (2009) suggests that one of the ways of improving learners knowledge, is to improve teachers and instructors professional development, which is key to closing the gaps in knowledge.

2.5 Student Knowledge on Stars

The topic of stars has also been identified as a big idea in astronomy by Lelliott & Rollnick (2010). However, studies that have investigated this big idea show that students' and teachers' knowledge is limited (See Makwela, 2017).

In a larger study on astronomy topics included within the National Science Curriculum of the U.K (United Kingdom), Sharp (1996) investigated 42 10–11-year-olds understanding of the Sun and the stars. Since these were young children, the issue of the shape of the star was noted. A majority indicated that the Sun and the stars have a "round" shape, however, it is noted that it was not clear if "round" meant "spherical". The results showed that 57% of the students had identified the Sun as a star, although they were not clear on what a star is, besides stating that "a star is like the Sun" (Sharp, 1996, p.697). This is a similar finding in a short study that Bletcher (In a private conversation) discussed, where astronomy undergraduates were unable to make proper distinctions between the stars and the Sun. More so, these undergraduates defined the Sun as a burning ball of gas, which was similar to the students in Sharp, who described the Sun as "a big ball of fire, gases, flames, and heat" (Sharp, 1996). Regarding the size of the stars in comparison to the Sun, Earth, and the moon, the students (10 -11-year-olds) had varying responses, which shows that this is also a problematic area in student understanding.

Agan (2004) conducted a study that explored students' understanding of stars, using semi-structured interviews to investigate student ideas. The population sample for the study included earth science high school students (ES), first year undergraduate students (UN), and junior high school students taking an astronomy module (AS). Since junior high school students had exposure to astronomy content, they had more scientifically accurate knowledge about stars. They were able to describe stars in a more sophisticated manner, such as the process of nuclear fusion in the core of a star, unlike the undergraduates (UN) and the earth science (ES) students who relied heavily on the secondary characteristics of stars such as their size and colour (Agan, 2004). One of the main findings showed that the earth science students (ES) had contradictory ideas about stars, which was evidence of students reconciling the new content knowledge learned with their prior knowledge. This is supported by a claim from Bailey (2009) and Taylor et al., (2003), that student prior knowledge is deeply rooted in their minds, mostly, because it is based on their empirical observations. Furthermore, the undergraduates and the earth science students still held that the sun is bigger than stars or that other stars are closer. Even more so, within these groups, some did not recognize the Sun as a star (Agan, 2004). Hence, these students had no clear idea of the distances nor the sizes related to stars (size). Which is a similar finding with the students in the study by Miller and Brewer (2009), where the distances to the nearest stars and galaxies were underestimated.

Bailey (2009) conducted a study using a survey (Student-Supplied-Response) focusing on students' pre-instructional ideas about stars as well as their formation. When asked about the nature of the stars, almost a quarter of the respondents gave a description which was some sort of physical characteristics about stars (e.g., size, colour, temperature). However, when probed further, students' ideas became inconsistent with many knowledge gaps. For example, when answering the question 'how a star forms', nearly half of students indicated that material is brought together in some fashion, with many details lacking, and with only 16% identifying gravity as the underlying factor (Bailey, 2009). Furthermore, students in the Makwela (2017) study also mentioned that prior to receiving any astronomy teaching, they defined stars in terms of their external properties, which is also evidence of little/ limited knowledge.

2.6 Problem of size and distance

Astronomical sizes and distance mostly formed part of other studies which focused on other topics as only 9 studies out of the identified 103 matched the criterion for Lelliott & Rollnick, in which the big idea of 'size and distance' was a part (2010). However, astronomical sizes and distances have remained a challenge in AER. For example, Sadler (1998) argued that the results of their study on models of students' conceptions in science, showed that the students were not able to accurately determine the distance of the closest star. Furthermore, they argued that even after interventions, students found it difficult to comprehend big astronomical scales that are beyond immediate human experience (Sadler, 1998). The quantitative studies that followed by Trumper (2001a, 2001b), in which a survey was used to investigate students' conceptions of basic astronomy concepts, concluded that astronomical sizes and distances were one of the weakest areas of student knowledge.

Distances and scales are not only important in astronomy but are anchoring concepts for many areas of science and engineering. Difficulties in teaching have been recognized in these areas, in particular where scales are beyond direct human perception (Magana, 2014). Thus, various studies in science education, physics and mathematics (Tretter et al., 2006; Jones et al., 2007; Pirolli, 2009; Swarat et al., 2011; Chesnutt et al., 2019) have previously looked into students difficulties with size, scale and distance.

Based on these previous studies, Lelliott & Rollnick (2010) contend that due to the lack of standardization, research on this big idea of size and distance has many contrasting opinions on the ability of students to fully understand it and the challenges that students have in that regard. Consequently, the current research study, which we report on in this thesis, solely focuses on probing student ideas on the relative sizes and distances of celestial objects. This current study follows a series of studies that were carried out at the University of Cape Town (UCT) in South African and Oslo, Norway (Rajpaul et al, 2014; Lindstrom et al, 2016; Rajpaul et al, 2018). The details of these studies are covered in the next chapters as they give background to the study.

One of the challenges with a variety of research instruments is the lack of comparison between studies, making it difficult to reach a unified conclusion of students' and teachers' knowledge and understanding of astronomical phenomena.

2.7 The Introductory Astronomy Questionnaire (IAQ)

When the Introductory Astronomy Questionnaire (IAQ) was developed, none of the existing research instruments in AER were suitable for the interests/ needs of the context (being improvement of learning in astronomy at UCT).

As part of ongoing efforts to improve the teaching and learning of astronomy, an instrument, the Introductory Astronomy Questionnaire (IAQ) was developed at the University of Cape Town (Rajpaul, Allie, & Blyth, 2014). The IAQ covered a wide range of topics that are taught in the introductory astronomy course. The following topics were included in the questionnaire: (1) motivation and expectations regarding the course, (2) ideas about what astronomy entails, (3) astronomy as a scientific discipline (as opposed to, e.g., astrology), (4) theories and evidence in science, (5) gravity, (6) radiation, (7) the SKA (Square Kilometre Array) and radio astronomy, (8) sizes or scales in the Universe, and (9) understanding of and ability to explain a few very basic astronomical entities (Rajpaul, Allie, & Blyth, 2014). This questionnaire was developed based on the current needs of the institution in terms of informing aspects of the astronomy curriculum, thus maximizing the learning and engagement of students' taking the course. This questionnaire also aimed at measuring how students' views change or do not change after taking the astronomy course. Research studies have investigated different areas of astronomy for teaching and learning purposes, however, none have been as diverse as the IAQ.

The IAQ was administered at the beginning of a new academic year to the class of students who registered to take the introductory course in 2014 at the University of Cape Town (UCT). The students were given the pre-course IAQ on their first day of lectures by a researcher; this was done after the main lecturer of the course had given instructions and discussed administrative issues related to the course. The post-course IAQ was given after the last lecture took place in May.

The IAQ was analysed thoroughly, and the main interest showed to be the results coming from the astronomical scales questions (sizes and distances of astronomical objects). These questions were framed as ranking tasks, where the students were asked to rank the astronomical objects in the order of increasing size or increasing distance from the Earth, as well as an explanation task. These results regarding astronomical sizes, revealed that a third of students had ranked a star to be the smallest object in the Universe (ranked before 'planet' which was one of the options). The distance task results showed that students had many incorrect views, which included the following: (1) Ozone layer being deemed further than the centre of the Earth from the Earth's surface, (2) Stars ranked to be within the solar system, (3) Neptune ranked as closer to the surface of Earth than the Sun. These poor size and distance results were noted in this study and gains were seen in the post-course survey. In the explanation question, there was an increase from 68% to 85% in correctness of explanation from the pre-test to the post-test, although it is noted that difficulties with this task were more widespread due to the diversity of the sample in this study. However, this particular part (sizes and distances) of the IAQ proved to be a predictor for overall success in the course, meaning that students who did poorly and did not improve in the post-course test IAQ, did poorly in the course (Rajpaul et al., 2014).

The IAQ was adapted in Norway and then translated into Norwegian (referred to IAQ-N) which probed the same aspects as at UCT. The IAQ-N also looked at optimizing the teaching of an astronomy course and maximizing meaningful engagement with its cohort of students (Lindstrøm et al., 2016). Similarly, to the original IAQ, the study set out to probe and explore students' basic knowledge of astronomical objects on the basics of scales, with a focus on students' perspectives of relative sizes and distances. The IAQ-N was administered as a pre-test and post-test to see how student views changed before and after instruction. The sample of the study was middle school students drawn from eight different schools and science pre-service teachers at the largest teacher education institution in Norway. The middle school students were chosen as they are in the year that marks the highest level to which Norwegian students receive compulsory astronomy education. Science pre-service teachers, receive astronomy education as part of their training before they start teaching science to future students in Norway.

The size and distance findings from the IAQ-N were summarized under the following research questions:

1. What are the most prevalent incorrect conceptions that students have?
2. Is there a correlation between students' qualitative knowledge and ranking knowledge?

The most incorrect views came from the ranking of the size and distance, in which the students (especially middle school) had ranked the star as the smallest object in the universe among the 5 given objects (star, planet, galaxy, solar system, universe). In terms of distance from the surface of the Earth, the Ozone layer was ranked to be further than the centre of the earth, the pole star was put closer than the edge of the solar system, the planet Neptune was put to be closer than the sun, and there seemed to be confusion from the moon to the edge of the observable universe (Rajpaul et al., 2018). Generally, pre-service teachers seemed to be more knowledgeable than the middle school students, thus the intervention (instruction) shows some gains with the pre-service teachers but not with the middle school students.

2.8 Conclusion

This chapter has addressed issues that are important in grounding this particular research study, such as (i) the importance of student conceptions, (ii) the big idea of size and distance, and (iii) spatial awareness in astronomy. The previous work, we see that it is important to get an idea of student current conceptions of various aspects so that we are able to run a useful intervention. Size and distance are identified as big idea/s in the literature but yet still relatively little has been researched about them specifically in terms of teaching effectiveness. Furthermore, the South African and Norway studies highlighted prevalent alternative conceptions in student thinking with regard to size and distance. Most importantly, interventions did not show any significant gains, as such, thus we believe the issues with size and distance are more conceptual (cognitive) than pedagogical. The next chapter, covers the first steps that were carried out to uncover whether the issues that have been previously identified persist in current settings

Chapter 3: Probing student understanding of astronomical scales (size and distance)

Summary: Preliminary Study abstract

This chapter focuses on the study from 2018 which followed a series of research studies carried out in the introductory astronomy courses in South Africa and Norway during the period 2014 - 2016. In this study, we used questions that focused on sizes and distances of astronomical objects from the research instrument (Introductory Astronomy Questionnaire, IAQ), that was used in those previous studies. Using these questions, we examined whether the poor result found in previous studies still held with a different group of students. The poor result, especially concerning astronomical sizes and distances was of particular interest and pointed to a fundamental challenge across countries of difficulties in comprehending large scales. As such, it was important to investigate this aspect, as astronomical sizes and distances are listed as big ideas in astronomy (mostly for pedagogical reasons that were unpacked Rajpaul et al., (2014)). In this chapter, we report on the results of the current study to compare it with previous studies.

3.1 Introduction, Context and Background

The introductory to astronomy course is the only first-year course offered by the astronomy department at the University of Cape Town (UCT). The main focus of the course is to introduce students to the terminologies; vocabulary; methods; calculations; techniques of measuring stars & galaxies (using telescopes); explaining natural phenomena such as eclipses and tides; learning about seasons as well as finding exo- planets. This course seeks to invite students to the wonders of astronomy both as a science and a career. This is done in two ways, (1) through compulsory lectures, tutorials as well as practicals, and (2) out of school learning such as the planetarium and visit to the South African Astronomical Observatory (SAAO), where some of the South African astronomers are based. It is in this course that students are free to ask their most burning questions about the universe and its evolution as well as why it works the way it does.

In 2014, as part of ongoing efforts to improve the learning and engagement of astronomy at UCT, it was important to identify students' perspectives and astronomical knowledge before and after enrolling in an astronomy class. This led to the development of the Introductory Astronomy Questionnaire (IAQ), which aimed to investigate students' engagement with multiple areas of astronomy (Rajpaul et al., 2014). Although previous research in astronomy education has been carried out using questionnaires; interviews; teaching interventions; planetariums interventions and concept inventories, none of these existing instruments were suitable for the purpose of the study in 2014. Thus, this new instrument was developed, which is now known worldwide as the Introductory Astronomy Questionnaire (IAQ). The pre-test and the post-test results of the IAQ (2014) showed that students had difficulties with the questions regarding the sizes and distances of astronomical objects, as we have covered in the literature review. Understanding these concepts had fundamental implications on students' performance in the astronomy course going forward, as these proved to be indicators of course success (Rajpaul et al., 2014).

The IAQ was subsequently translated into Norwegian and then referred to as the N-IAQ. The N-IAQ investigated pre-service science teachers' and middle school students' perspectives of astronomy; where the N-IAQ was administered as a pre-test and post-test (Lindstrøm et al., 2016; Rajpaul et al., 2018). The N-IAQ was modified to also suit the context in Norway. For example, regarding the distance question, the closest star after the Sun in the Southern Hemisphere is Alpha Centauri which is not visible in the Northern Hemisphere; as such it was replaced with the Pole star. Both groups, the pre-service teachers and middle school students' pre-test results were poor although the pre-service teachers' scores were generally higher than middle school students.

The “Introduction to Astronomy” course is the only first-year course offered by the Department of Astronomy at the University of Cape Town (UCT). The course aims at the following: to introduce students to astronomy as a scientific discipline and to highlights the range of areas and objects that the field of astronomy encompasses, starting with the Earth-Sun-Moon system, moving through the Solar System and exoplanets, to star formation and evolution and finally to the larger scales of our Galaxy and other galaxies and the large-scale structure of the Universe. As part of this, students need to be introduced to new terminology and vocabulary and methods and techniques of making astrophysical measurements.

3.2 Rationale

It was due to this poor result/ finding from the IAQ and N-IAQ, that we decided to further probe the notion of sizes and distances in order to (1) confirm whether this is an existing trend, and (2) to have a way to standardize the questionnaire for analysis purposes. In so doing, we modified the questions focusing on size and distance from the IAQ, to find out if there were any differences or similarities between the samples of our studies. This stage was carried out in 2018 at UCT, 4 years after the first IAQ was given. The size and distance questions were administered to the students as a pre-test on the first day of their lectures in 2018 before any astronomy content had yet been taught.

Over the years since the first IAQ (in 2014), the course lecturer explored different teaching approaches; techniques, and ideas of teaching these concepts (size and distance) In 2018, a planned and targeted teaching approach, which was developed over the years, was piloted/used/ as an intervention between the pre-test and post-test. This chapter reports on this specific study which we refer to as IAQ-SD (ranking size and distance).

3.3 Methods of Data Collection

3.3.1 Pre-test Instrument

In 2018, three questions with a focus on astronomical sizes and distances were modified from the original IAQ to further probe these key issues that were discovered to be challenging in the IAQ and N-IAQ (Rajpaul et al., 2014; Rajpaul et al., 2018). The first question focused on the ranking of celestial objects according to their relative sizes using the sign '<' (to represent smaller than) thus ranking them in increasing order; or '=' (to represent equal) if the celestial objects are equal or similar in size. The objects given in this question were; Galaxy, Universe, Earth, Solar System, Sun, and Star. The second question required the respondents to describe each of the astronomical objects given in the question. The question was framed as a written response, where the audience was chosen to be a grade 12 learner, who is at a level lower than the respondent (student first-year university level). This allowed the student (respondent) to be the 'expert', while they are giving the descriptions of these objects. The last question focused on distance ranking, in which the students were required to organize celestial objects in increasing distances from the surface of Earth, which is their frame of reference. Please note that the edge of the Solar system was taken as the hypothetical Oort Cloud distance, not the edge of the Kuiper

Belt. This was important for the ordering exercises here because, if we took the Kuiper Belt as the edge, then it would be closer to the surface of Uranus than the Sun since Uranus is at 20 AU and Neptune at approximately 30AU (which has an orbit intersecting with the Kuiper Belt). The following are the questions asked in the IAQ_SD (ranking of sizes and distances) and the full instrument is included in Appendix III.

IAQ_SD questions:

Q1. [RNKS1]

Write down the following in order of increasing size (smallest to largest),

using the symbols ‘<’ or ‘=’ (if they are similar).

galaxy; planet; star; universe; solar system; the sun

<u>Student answer:</u>

Q2. [EXP01]

A grade 12 learner who is interested in astronomy asks you to explain briefly to them what is meant by each of the following celestial objects in Q1. (Write one sentence per item.)

Q3. [RNKD1]

Order the following by their distance from the Earth’s surface. (Write the letter of each item next to the relevant number in the list below):

A = centre of the Milky Way;

B = edge of the observable universe;

C = edge of the Solar System;

D = the moon;

E = the Sun;

F = the nearest star to the sun (Alpha Centauri);

G = the ozone layer;

H = centre of the Earth;

I = Neptune.

3.3.2 Sample

The size and distance questionnaire was administered to a cohort of students taking the introductory astronomy course at the University of Cape Town (UCT) in 2018. The total number of students enrolled for this course in 2018 was 111. This cohort of students was very diverse, especially in terms of the intended degree of study. Out of the 111 students, 79% were registered for a Bachelor of Science degree. The students registered in this course came from quite different cultural backgrounds (urban, rural, and township) and educational backgrounds (private, government, and under-resourced schools).

3.3.3 About the course

South Africa is one of the most culturally diverse countries in the world. At UCT, the main language of instruction is English, which is a second language for most of the students taking the course. The introductory astronomy course is one of the courses offered through the Department of Astronomy at UCT and it is also an elective course in which students from other faculties can enrol, contributing to the large diversity in this group.

3.3.4 Administration

The distance and size questionnaire pre-test were given out by the members of the Physics and Astronomy Education Research (PhAsER) group on the first day of the academic year at UCT in 2018. The researcher SA* introduced the PhAsER research team and explained the purpose of the questionnaire to the students. SA also outlined the instructions to students regarding answering the questionnaire as this was an individual task and discussions between students were not permitted. Some of the important instructions that were given to the students included the invitation letter, which was formally asking for student participation in the study. The invitation letter also stated that the questionnaire did not contribute to their overall course marks. Students were also reassured about their anonymity; although they needed to provide their student numbers to be able to carry out a cross-analysis for the pre-test and post-test. The course lecturer (who was also the course convener) was present only at the beginning to introduce the other parts of the course that were mostly administrative, such as venues, assignments, and test dates.

3.3.5 Interventions

The development of this intervention was done outside of this dissertation and this intervention included two, one-hour lectures, where the concepts of astronomical scales, were introduced to the students. This was followed by a practical session divided into three tasks; in the first task, 10

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*Saalih Allie

images of celestial objects (the sun/ sunrise, a map of Africa, a galaxy, an asteroid, the solar system, a group of stars, planets, and a nebula cloud in the universe) were printed out on a same-size sheet paper. These were handed to students as an individual task, and they had to identify and describe what the objects were. In the second task (also an individual task), the students had to rank the objects in increasing size (smallest to biggest). The third task was a group task, in which students came together in a group of 5 to discuss what they had each done and finally to do the ranking task together by putting the pictures on the floor or a desk for everyone to see (including a tutor). During this task, a lot of discussion took place between the students and a course tutor was there to help students clarify their thinking by answering questions that they had. At the end of the tasks, students called the lecturer/tutor to confirm the ranking of their images.

In the third task, students participated in a 2.5 hour long practical that focused on astronomical distances. Similar to the first task (on sizes), this was an individual task, where students were required to identify and rank the celestial objects by their distances, from the surface of the earth. The second task required students to be in groups of 5 and do a matching task, where they had to match the astronomical objects with their actual distances. These distances were given in different units of measure, thus students had to do calculations and unit conversions so that they could accurately match the objects. Before students moved on to the next task, a tutor/lecturer had to approve their calculations, conversions, and matching of objects. In the third task, the groups of 5 merged to become groups of 10, and each person was then assigned the role of being a ‘celestial object’. Using the information from the matching task, students were then tasked with representing the universe accurately to scale using by placing themselves at various distances with respect to each other (with each student representing a celestial object). What was not explained explicitly (on purpose), but was designed to emerge from the exercise, was that students needed to identify a scale to organize themselves in relation to each other and relate it to distances. We also observed that the students usually failed to identity the scale to the final question at their first attempt, so we (as tutors) would give them hints until they figure out log scales for themselves.

3.3.6 Post- instruction instrument

The post-test was given a day after the tutorials, which was the last lecture of the week. Although the questions in the post-test were testing the same concepts, we made slight changes in the questions. The reason behind the change in the questions was that we wanted to make sure that students did not rote learn the order of the astronomical objects but rather measure whether they have a deep conceptual understanding about the concept of distances and sizes. Therefore, in the post-test, the frame of reference for the distance question was changed from the surface of Earth to the surface of Uranus. The PhAsER research group was present during this time, and the same instructions as the pre-test were given to the students. The lecturer of the course did not take part in the administering of the post-test.

3.3.7 Method of Analysis

The size and distance questions that were administered, were all modifications of the original IAQ task. Since the Norwegian IAQ had been administered and analysed, we decided to use the same analysis scheme, in order to achieve our second aim, which is to standardize the probing and analysis of sizes and distances in astronomy education research for comparative reasons across contexts. Therefore, the authors of the IAQ-N (Rajpaul et al., 2018), shared their analysis codes, which we applied to our data to generate the analysis matrices.

Question 1 (sizes) and question 3 (distances), were the ranking tasks in which students were required to rank different celestial objects in terms of increasing size or increasing distance. The following steps were carried out: for the size, we (1) counted the total number of students who responded to the questionnaire; (2) we assigned a number to each of the objects ranked, based on their actual position/rank, (1= Planet, 2= Star/Sun, 4= Solar System, 5= Milky way, 6= Edge of the Observable Universe); (3) we digitized the responses and accounted for incomplete ranks. A rank was considered not complete when: an object was assigned to more than 1 rank, for example (1, 1, 4, 5, 6)/ (6, 4, 2, 2, 5, 1); when an object was not ranked at all, or rather omitted from the ranking (6, 1, _,4, 5, 2)/ (_ , _, 4, 3, 5, 6); and all blank responses were not considered. We only anaysed fully completed responses, thus, incomplete, and incorrect are not the same.

We then computed matrices showing absolute ranks, pair-wise errors, as well as correct ranks. The absolute ranks show all raw data that captures both incorrect and correct responses. Using some colour-coding, we can identify where the challenging problematic areas were for students. The matrix for pair-wise errors was computed so that we were able to identify how students ranked the objects in comparison with the other objects given, for example, how many ranked a planet bigger than the Sun. This enabled us to further identify where the challenge of the conceptualization of celestial/ astronomical sizes was. We also computed a matrix showing the correct ranks, where we identified students' correct prior knowledge about the scale of the universe.

We carried out similar steps with digitizing the distance question as with the size question. However, there was no option for astronomical objects that are equal distance from the surface of a planet (it was not one of the options given in the questionnaire), unlike with the size question. We had 9 astronomical objects which were to be ranked. In digitizing the responses, we followed the same steps as with the size question and accounted for the invalid responses. The responses were invalid when: an object was assigned more than 1 rank, for example (1, 1, 4, 5, ,6, 2, 8, 9, 7)/ (6, 4, 2, 2, 5, 1, 7, 7, 8); when an object was not ranked (6, 1, _,4, 5, 2, 7, 8, 9)/ (_

, _, 4, 3, 5, 6, 8, 1, 9) and all the blank responses were considered invalid. This analysis system was also applied for the post-test questionnaire.

The responses from question 2 were analysed differently since the question required written responses. In the IAQ-N, a mark was assigned to the description given, such that 0 = incorrect, 1 = true but not entirely correct, and 2 = correct and true. In this work, however, we used a grounded theory method to identify student ideas from the descriptions that they provided. The IAQ-N method was effective in their study, but it created a lot of ambiguity in our work, in the sense that the marks were based on the markers' view of the level of how right the answer was. Since we were doing this as a pair, we found a significant difference in what we considered to be a 1 or a 2. In carrying out the grounded analysis we did a close reading of the responses to identify the main ideas which we then coded. We recorded the students' main ideas by grouping them into emerging themes and categories. This was an iterative process, with many discussions between my research group and me.

3.4 Results and findings

This section describes the results that were obtained from the pre-test and post-test IAQ_SD. First, the size and distance pre-test results are covered, showing the matrices which captured these responses. Then the results from question 2, yielded by the grounded theory method are covered. Lastly, the post-test questionnaire results are presented in their matrices.

<u>How to read the matrices</u>:

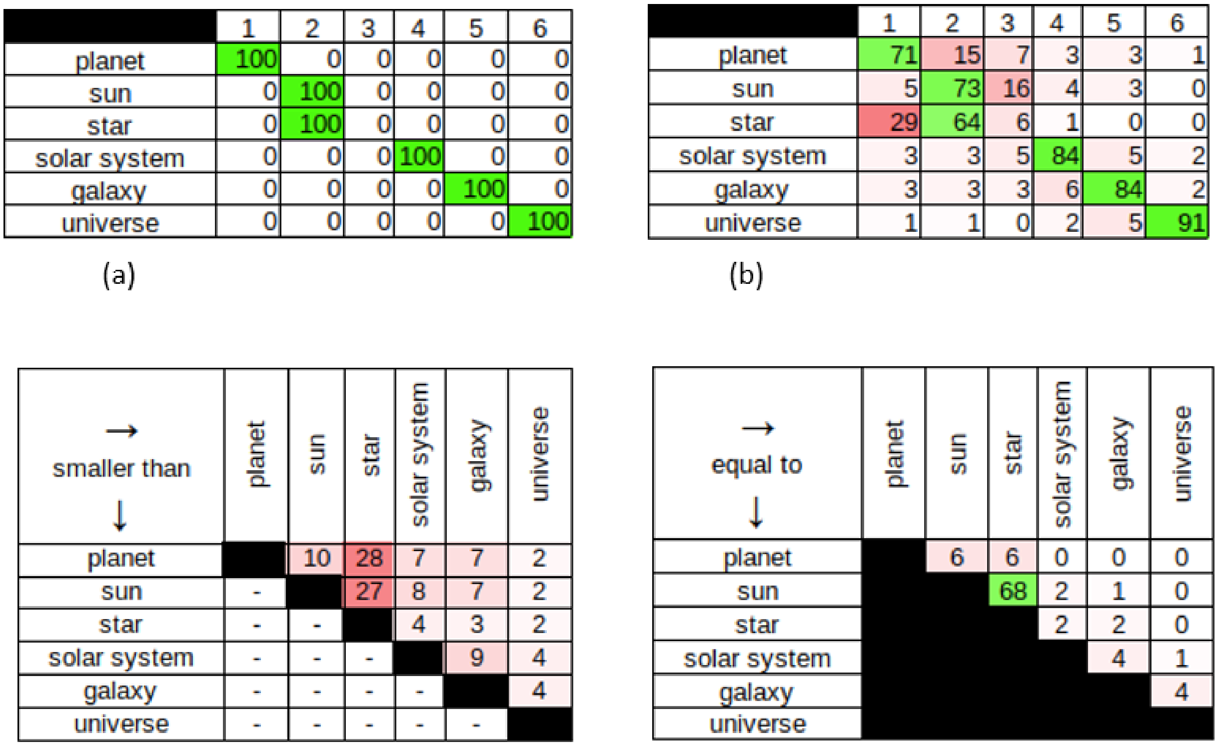
The objects in the matrices are ordered so that they correspond to the correct ranking of a celestial objects. In the case of the sizes, the planet is the first as the smallest object among the given six objects (IAQ questions). In the case of distances, the Earth’s atmosphere (Ozone layer) is the first closest to the surface of Earth among the given 10 objects. The percentages are calculated such that the total number of valid responses was n= 111, then 91/111 which gives 82%.

All pair-wise errors correspond to the correct relative rankings, which make up the lower empty part of the matrices (see fig. 3.1(c)) which are not shown. For example, matrix 3(c) shows that 28% of the students incorrectly ranked the planet to be larger than the star, which is calculated such that 31/111 gives the 28%. This stands, regardless of the absolute ranks that the objects were assigned.

3.4.1 Pre- instruction

The rows in the matrices in figures 3.1(a) and 3.1(b), show the position in which the astronomical object is ranked, while the column shows the objects in the order of increasing size. Figure 3.1(a) shows an example of the 'ideal' matrix, if all the students were able to rank the objects according to their sizes. The 3rd rank in figure 3.1(a) is expected to have a record 0%, this is the rank that should be skipped if the Sun and a Star are ranked as equal in size. Thus the 2nd rank then is expected to have both the star and Sun at 100%.

Figure 3.1(b) represents the absolute ranking of the astronomical objects from students' responses. The colours in the matrices represent the correct and incorrect ranks, with green representing the correct and red representing the incorrect. In addition, the more intense (darker) the colour concentration the higher the percentage of students agreeing with that view. The absolute ranks show the percentage of students who have ranked the objects in the 1st / 2nd / 3rd / etc., position. The absolute ranks are mostly about the position in which a celestial object is allocated, thus combing both the correct and incorrect ranks. Figure 3.1(b) is then different to figure 3.1(a) which was what the expectation is when students have correct ideas about astronomical concepts (especially of size). There is a spread in percentage between rank 1 to rank 3 in figure 3.1(b) which is identified by the spread between the red and green colours. This shows that there exists some form of confusion and uncertainty when it comes to knowing which is bigger than which between the first three objects. About 71% of the respondents ranked the planet correctly as the smallest object among the celestial objects provided. However, almost one-third of respondents incorrectly ranked the star as the smallest object (figure 3.1(b)).



	1	2	3	4	5	6
planet	100	0	0	0	0	0
sun	0	100	0	0	0	0
star	0	100	0	0	0	0
solar system	0	0	0	100	0	0
galaxy	0	0	0	0	100	0
universe	0	0	0	0	0	100

(a)

	1	2	3	4	5	6
planet	71	15	7	3	3	1
sun	5	73	16	4	3	0
star	29	64	6	1	0	0
solar system	3	3	5	84	5	2
galaxy	3	3	3	6	84	2
universe	1	1	0	2	5	91

(b)

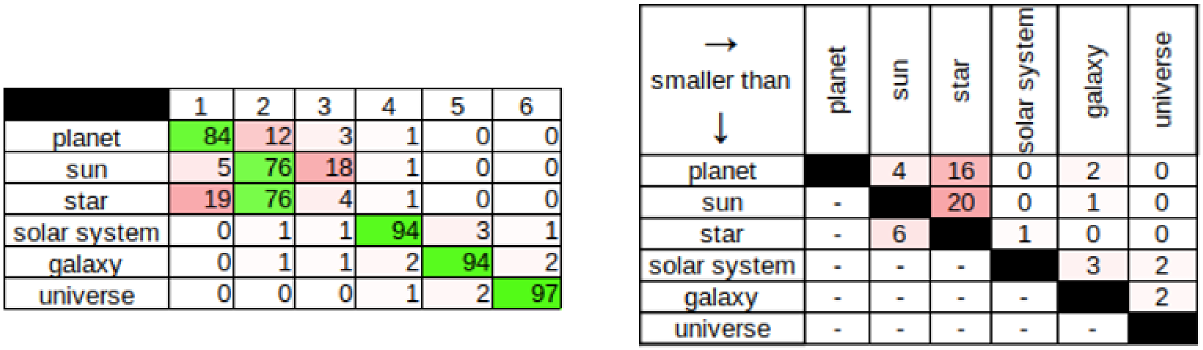
→ smaller than ↓	planet	sun	star	solar system	galaxy	universe
planet		10	28	7	7	2
sun	-		27	8	7	2
star	-	-		4	3	2
solar system	-	-	-		9	4
galaxy	-	-	-	-		4
universe	-	-	-	-	-	

(c)

→ equal to ↓	planet	sun	star	solar system	galaxy	universe
planet		6	6	0	0	0
sun			68	2	1	0
star				2	2	0
solar system					4	1
galaxy						4
universe						

(d)

Figure 3.1: Matrices representing the size ranking task results of the pre-instruction IAQ (SD). Each of the matrices represents students percentages of the ranking tasks; with (a) showing an example of an ideal 'expected' matrix, (b) showing the absolute ranks, (c) showing the pair-wise errors, in which students have ranked objects incorrectly based on their sizes, and (d) showing percentages of students who have ranked the astronomical objects to be equal.



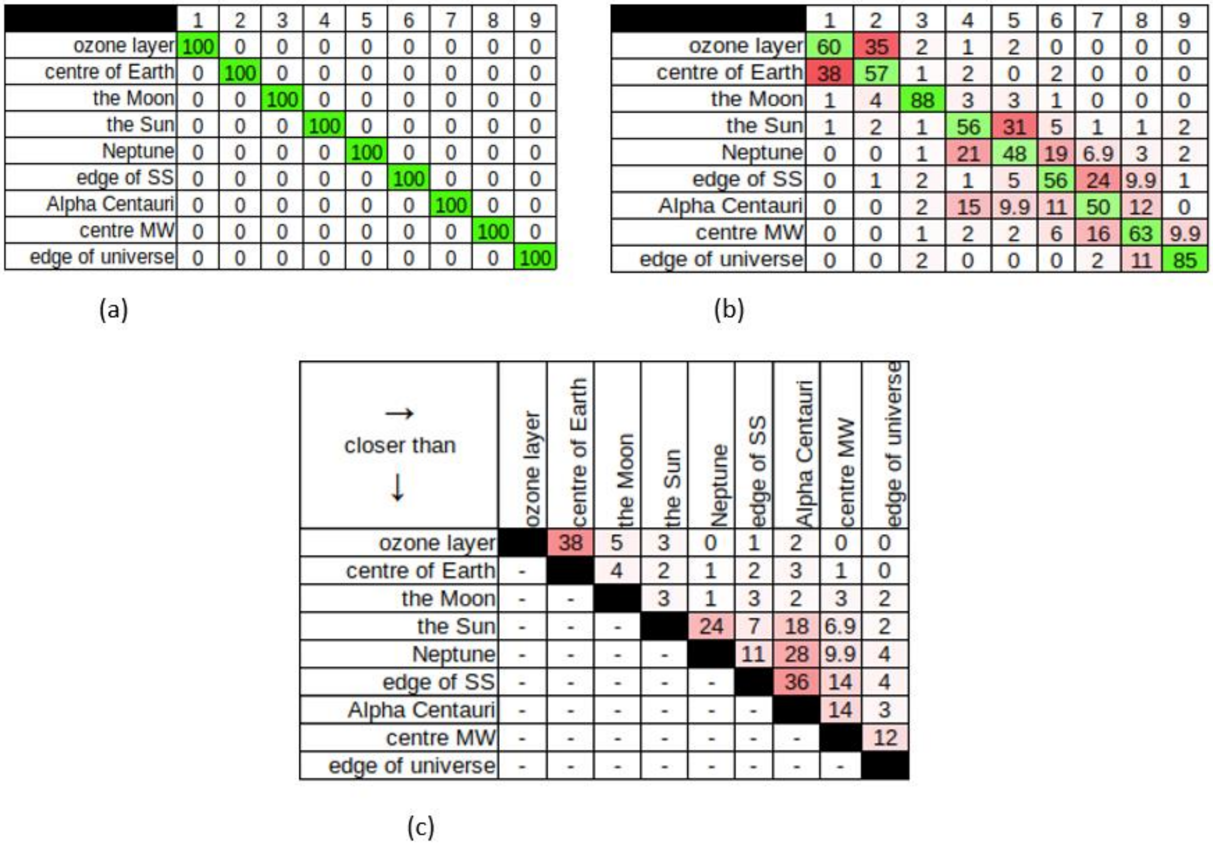
	1	2	3	4	5	6
planet	84	12	3	1	0	0
sun	5	76	18	1	0	0
star	19	76	4	1	0	0
solar system	0	1	1	94	3	1
galaxy	0	1	1	2	94	2
universe	0	0	0	1	2	97

(a)

→ smaller than ↓	planet	sun	star	solar system	galaxy	universe
planet		4	16	0	2	0
sun	-		20	0	1	0
star	-	6		1	0	0
solar system	-	-	-		3	2
galaxy	-	-	-	-		2
universe	-	-	-	-	-	

(b)

Figure 3.2: Matrices representing student percentages of the post-instruction size ranking task, with (a) showing the absolute ranks, and (b) showing the pair-wise errors



	1	2	3	4	5	6	7	8	9
ozone layer	100	0	0	0	0	0	0	0	0
centre of Earth	0	100	0	0	0	0	0	0	0
the Moon	0	0	100	0	0	0	0	0	0
the Sun	0	0	0	100	0	0	0	0	0
Neptune	0	0	0	0	100	0	0	0	0
edge of SS	0	0	0	0	0	100	0	0	0
Alpha Centauri	0	0	0	0	0	0	100	0	0
centre MW	0	0	0	0	0	0	0	100	0
edge of universe	0	0	0	0	0	0	0	0	100

(a)

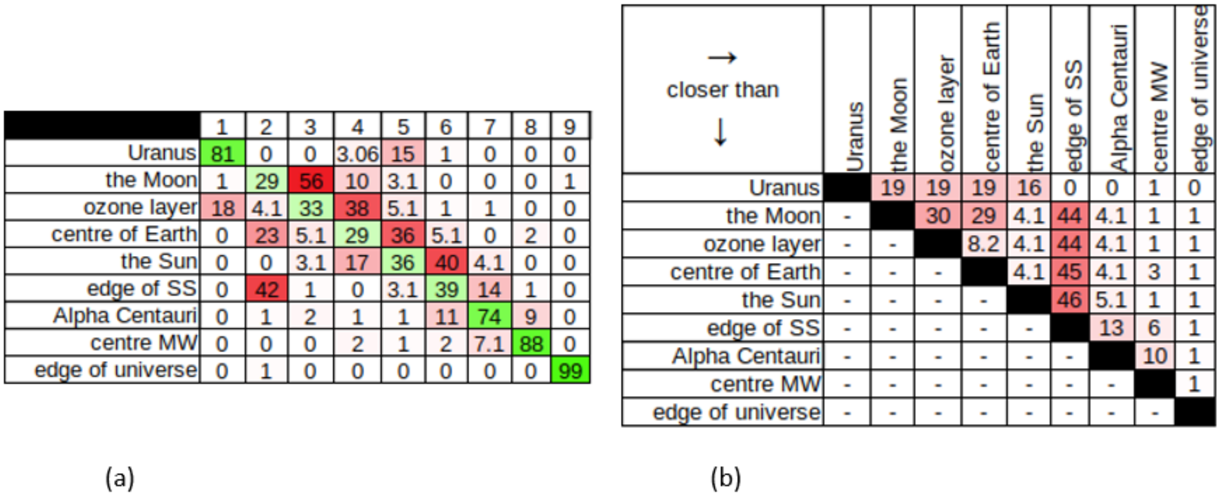
	1	2	3	4	5	6	7	8	9
ozone layer	60	35	2	1	2	0	0	0	0
centre of Earth	38	57	1	2	0	2	0	0	0
the Moon	1	4	88	3	3	1	0	0	0
the Sun	1	2	1	56	31	5	1	1	2
Neptune	0	0	1	21	48	19	6.9	3	2
edge of SS	0	1	2	1	5	56	24	9.9	1
Alpha Centauri	0	0	2	15	9.9	11	50	12	0
centre MW	0	0	1	2	2	6	16	63	9.9
edge of universe	0	0	2	0	0	0	2	11	85

(b)

→ closer than ↓	ozone layer	centre of Earth	the Moon	the Sun	Neptune	edge of SS	Alpha Centauri	centre MW	edge of universe
ozone layer		38	5	3	0	1	2	0	0
centre of Earth	-		4	2	1	2	3	1	0
the Moon	-	-		3	1	3	2	3	2
the Sun	-	-	-		24	7	18	6.9	2
Neptune	-	-	-	-		11	28	9.9	4
edge of SS	-	-	-	-	-		36	14	4
Alpha Centauri	-	-	-	-	-	-		14	3
centre MW	-	-	-	-	-	-	-		12
edge of universe	-	-	-	-	-	-	-	-	

(c)

Figure 3.3: These matrices present the student percentages of the distance ranking task prior to instruction. The frame of reference for the pre-instruction ranking task was the surface of planet Earth. Matrix (a) is showing the ideal 'perfect' matrix, while (b) showing the absolute ranks, and (c) showing the pair-wise errors.



	1	2	3	4	5	6	7	8	9
Uranus	81	0	0	3.06	15	1	0	0	0
the Moon	1	29	56	10	3.1	0	0	0	1
ozone layer	18	4.1	33	38	5.1	1	1	0	0
centre of Earth	0	23	5.1	29	36	5.1	0	2	0
the Sun	0	0	3.1	17	36	40	4.1	0	0
edge of SS	0	42	1	0	3.1	39	14	1	0
Alpha Centauri	0	1	2	1	1	11	74	9	0
centre MW	0	0	0	2	1	2	7.1	88	0
edge of universe	0	1	0	0	0	0	0	0	99

(a)

→ closer than ↓	Uranus	the Moon	ozone layer	centre of Earth	the Sun	edge of SS	Alpha Centauri	centre MW	edge of universe
Uranus		19	19	19	16	0	0	1	0
the Moon	-		30	29	4.1	44	4.1	1	1
ozone layer	-	-		8.2	4.1	44	4.1	1	1
centre of Earth	-	-	-		4.1	45	4.1	3	1
the Sun	-	-	-	-		46	5.1	1	1
edge of SS	-	-	-	-	-		13	6	1
Alpha Centauri	-	-	-	-	-	-		10	1
centre MW	-	-	-	-	-	-	-		1
edge of universe	-	-	-	-	-	-	-	-	

(b)

Figure 3.4: Matrices representing student percentages of the post instruction distance task, with (a) showing the absolute ranks, and (b) showing the pair-wise errors. This question was framed from the surface of planet Uranus.

The rows in figure 3.1(c) and (d) show the objects that are smaller or equal to the objects listed in the column. Figure 3.1(c) provides us with a clearer look into the data, as it shows the percentages of the pair-wise errors. The pair-wise errors show the comparison between the objects, such that objects are compared to one another, the bottom part of the matrix in figure 3.1(c) are the corrected pair-wise comparisons, the focus is on the incorrect responses. Hence, we identified that about 28% (almost 1/4 of the sample) of the respondents incorrectly ranked a star smaller than a planet (although typical medium-size star is still bigger than the size of a planet, thus it is problematic for students to hold this incorrect view about the size of a star.). And about 27% (almost 1/4 of the sample) have ranked a star to be smaller than the sun, thus, this shows that students think stars are small and different from the Sun (which is a star itself) is an indicator of not understanding the range of sizes for stars. However, it is important to acknowledge that there are many other stars in the universe bigger than the Sun.

In Figure 3.1(d) we have identified that about 68% of the respondents are aware that the Sun is similar/equal to a star. However, among the ones who did not think the sun = star, a small group held that the sun > star (27%). Therefore, we conclude that almost quarter of the respondents hold that the following notions: (i) star is smaller than the planet, and (ii) a star is smaller than the sun, which is inconsistent with astronomical knowledge of the sizes and definitions of stars and planets.

A positive result is recorded with the other astronomical objects beyond the sun. In most cases, it is less than 10% of the sample with incorrect views about the solar system, galaxies, and the universe. However, there seems to be a consensus on how big these objects are in relation to one another. The description question in Section 3.2 (ii) offers a clearer understanding of what the students think these objects are.

Figure 3.3(a) is a matrix showing the ‘ideal’ expected results we could get if all the respondents have ranked the distances correctly from the surface of the earth. Figure 3.3(b) shows the percentage of absolute ranks where we can identify the position at which the astronomical objects are placed from the surface of Earth by most of the students. The green and red colour codes were also applied in this analysis so that we can easily identify the spread of ideas (both correct and incorrect) on the matrix. With regard to positions 1 and 2 in figure 3.3(b), it can be seen that 38% of respondents' views about which object is closer to the surface of the earth are not clearly understood. 88% of the respondents positioned the moon to be the third closest object to the Earth, which shows that most of them have an idea of the distance to the moon compared to the ozone layer and the centre of the Earth. Between the Sun and the centre of the Milky way, we see another spread in the rankings, which suggests confusion from the respondents as to how far these celestial objects are from the surface of the Earth.

The pair-wise errors (figure 3.3(c)) enabled us to have a clearer idea of the percentages of respondents that hold the views expressed in figure 3.3(b). Meanwhile, Figure 3.3(c) shows that about 38% of the respondents overestimated the extent of the ozone layer to the centre of the earth, meaning that they assumed that the Ozone layer is much further than the centre of Earth. The star, Alpha Centauri, was ranked closer than the solar system by about 36% of respondents, this means that they assume the star is within our solar system. Furthermore, another 28% ranked Alpha Centauri closer than Neptune and 18 % ranked it closer than the Sun. The positioning of Alpha Centauri shows that students hold the idea that stars are closer than planets in the Solar System. 24% ranked the planet Neptune to be closer than the Sun. These results show that the respondents do not understand how big and how far in terms of distance celestial objects are from one another. These distance results show the ordering was more mixed up for the distance ordering than the size ordering as seen by the numbers in the matrices.

3.4.2 Nature of the object

The second question required the respondents to give a one sentence explanation to a grade learner, of each celestial object in question one. In our grounded theory method, we found out that descriptions of bigger, collective objects (Galaxy, Solar system, Universe) were more accurate than for individual objects (planet, star, and sun). In the case of the planet, most of the descriptions were based on the relative location of the object, for example, words such as “rotate” and “revolve” were used. These words were in the context of the planet being an object that “rotates” or “revolve” around a star, which also shows that the object is in motion. In the case of the Sun and star, the description was based on the composition of the object, for example: “burning gas” and “combustion of gases”. This, however, showed that students struggled with the descriptions of the individual objects, especially in terms of what the celestial object 'thing' is when it came to the planet and the Sun/stars. We also noticed that the student explanations do not relate to student ranking knowledge. Although, it can be argued that the respondents who provided a sophisticated definition/ description, were also able to rank the objects in question 1 correctly.

3.4.3 Post instruction

Figure 3.2(a) illustrates the absolute ranks of the size ranking task and figure 3.2(b) shows the pair-wise errors in which the objects are compared to one another in terms of their sizes from the post-instruction survey. The absolute ranks show that the percentages of students who ranked the planet to be the smallest object increased from the pre-test and the percentage ranking the star as the smallest object decreased. In figure 3.2(b), the pair-wise errors show that 16% of the participants ranked the star to be smaller than the planet. This shows that there was increase in student knowledge between the pre-test and post-test regarding the size of a star in comparison to a planet as well as the Sun. This also means, although there is an improvement, there are still respondents who held onto their initial ideas. The percentage increase can be linked with the impact that the intervention had on the learning gains of astronomical sizes.

In the post-test, the frame of reference was changed from the surface of Earth to the surface of Uranus. The reason of this change was so that we could test and differentiate whether the students actually understood the different distance scales, or whether they could just remember the ordering from the day before. We wanted to test the knowledge, not the memory. From figure 3.4(a), which represents the absolute ranks, we have identified that over 80% of the students ranked Uranus, centre of the Milky Way, and the edge of the Universe correctly. However, there is a lot of confusion between the 2nd and 7th ranks as shown with the dominating colour being the incorrect one (red). For a closer look at these results, we have the pair-wise errors analysis represented in figure 3.4(b), these results show that almost 50% of the participants placed the Moon, Ozone layer, centre of Earth, and Sun further from Uranus than the hypothetical edge of Solar system. Moreover, 29% ranked the centre of Earth closer than Moon and about 13% placed Alpha Centauri within the Solar system, which is about 23% less than in the pre-test.

3.5 Discussion

It is clear from the pre- and post-tests that the most confusion in the post-test comes about when setting up the new question from the surface of Uranus, is regarding the distance from Uranus to the inner Solar System compared to the outer Solar system. There are big red blocks in the matrix for the distances to the edge of the Solar System compared to the distance from Uranus to the Moon, ozone layer, Earth, and the Sun. The results of the post-test also pointed to issues of distances inside the Solar System, as well as between different objects in the Solar System and the overall size of the solar system itself. In this section, we further compare our results with previous studies in AER.

One of the main findings that the data showed with regard to students' understanding of the sizes of celestial objects, was that before instruction about 1/4 of the sample (28%), incorrectly ranked the size of a star vs a planet. Also, about 27% also incorrectly ranked the size of a star vs the Sun; thus, raking the star to be the smallest object among the given celestial objects. This is a similar finding from the IAQ (Rajpaul et al., 2014), where 17% of the students incorrectly ranked the size of a star as the smallest celestial object in comparison to other objects (i.e., planet). Similarly, 42% of the middle school sample (NIAQ), ranked the size of the star to the planet incorrectly, assuming it is smaller, while about 15% of pre-service teachers incorrectly ranked the stars as the smallest celestial objects.

Small gains are seen after the post-test in our study as well as with the IAQ (2014), and the pre-service teachers in Norway. In comparison, no gains were observed after the instruction for the Norwegian middle school students (Rajpaul et al., 2018), thus labeling the issue of size as one of the most prevalent alternative ideas that students hold. Rajpaul et al., (2014) argue that even at the tertiary level, not all students know that planets are (much) smaller than typical stars, which is reflected in our data. One of the 'plausible' reasons that the stars are often ranked to be the smallest objects, might be intricately linked to what/how we see them at night as small points of light compared to objects like the Moon and the Sun which appear relatively bigger on the sky.

The Sun was added as one of the objects in this study and the data showed that there is a percentage of students who think that the Sun is bigger than a star. This is also closely related to students' everyday knowledge and experience of the respondents. The inclusion of the Sun also showed a positive result, as the majority (68%) of the sample were aware that the Sun is an object similar to the star, although they were maybe unaware of how big/large the stars are. In an earlier study by Agan (2004), some students did not identify the Sun as a star, thus holding that the Sun is bigger than stars. As such, this correlates with the finding by Bailey et al., (2009) that although students have some prior knowledge about stars, this knowledge is often limited and "incomplete or incorrect in important ways that could negatively affect their learning" (p.14). Therefore, being aware that the sun is similar or is a star, may not necessarily mean that students fully understand this. Hence, the description question also allows us to see this distinction.

In the N-IAQ, pre-service science teachers had comparable results to the IAQ (2014) with regard to giving descriptions of the celestial objects. The respondents gave a description based on how they would teach it (pedagogical) (Rajpaul et al., 2014; Rajpaul et al., 2018), rather than what the celestial object is. This was not the case in our study, as we found that there is a difference in how the respondents described individual objects versus collective objects. In each case (individual vs collection), our results showed that the solar system, galaxy, and universe (collection) had mostly sophisticated descriptions, unlike the planet, star, and sun (individual). In a short research survey by Blecher et al., (private communication), they found that the 'locational' context was far more often invoked for planets than for the stars, and the mechanistic idea (what makes the object) was far more invoked for stars than for planets. This was also the case, in our study, where the planet was described based on where it is relative to a star (sun) and the sun/star description included "combustion", which is the mechanism. Agan (2004) states that professional astronomers define stars by their ability to create their own energy by nuclear fusion of elements, which is, in this case, the mechanism of the object. However, defining stars as objects that shine is not sufficient based on observations with the naked eye, as both stars and planets 'shine', although, the light of the planet is reflected starlight. Therefore, the distinction between the stars and planets need to focus on other characteristics other than the observable.

Furthermore, students in the Makwela (2017) study also mentioned that prior to receiving any astronomy teaching, they defined stars in terms of their observational properties (they shine), which showed evidence of little/ limited knowledge about the nature of stars. The latter is also recorded by Agan (2004) where they recorded those students in the Earth sciences class, did not understand the Sun to be the same type of object as a star. They used physical characteristics to distinguish stars from other objects such as planets, which were from certain images in textbooks. In addition, they had no specific notions of distance or scale related to stars.

Concerning distances, in the IAQ-N the authors noted that some of the most held incorrect views for both the pre-test and post-test involved the following aspects: (1) The over-estimation of distance to the Ozone layer, where students ranked it further from the surface of the earth than the centre of the earth. (2) The star (pole star) residing within the solar system, (in most cases thinking that it is also orbiting the sun with the planets). (3) The confusion of where objects lie in the universe beyond the moon. In the N-IAQ, although most pre-service science teachers were generally more knowledgeable than the middle school students, especially with the relative sizes, distances proved to be a challenge to them. Miller & Brewer (2009) also highlighted similar issues in their study, where distances between astronomical objects were inaccurate (either overestimated or dramatically underestimated). This is quite similar to the data in this current study, where all three identified prevalent incorrect views in the N-IAQ, were true for both the pre-test and post-test. Vosnaidou & Brewer, (1994) argued that as exposure to scientific knowledge increases, students attempt to reconcile their prior knowledge with the scientific knowledge hence forming "synthetic models*". However, we note that in our results even after post-test, certain prior ideas, especially concerning astronomical distances did not change. A'Hearn (2010) study on size and scale, also showed through interviews after instruction, that the use of large scales in astronomy such as the astronomical unit, parsecs and light-years, appear to be helpful in teaching scale to some students and not helpful to others.

Our data showed that even with an intervention/ teaching instruction (well-planned and thought out), there were some gains with the celestial scales especially with sizes, congruent with the IAQ and pre-service teachers' samples but not with middle school students in the N-IAQ. In terms of distance, the gains in distance ranking between interventions were seen with pre-service teachers but not with middle school students (Rajpaul et al., 2018) the latter was the case in this study, although the N-IAQ study kept the same point of reference as the surface Earth. These gains were easier to identify with a ranking task as (Coble et al., 2013) argue, that students may find ranking tasks easier than tasks dealing with absolute scales. The ranking task was an advantage for our work as it explicitly offered an avenue of thoroughly identifying where the challenging issues with size and distance appear to be.

*Synthetic Models are conceptions that are seen when students try to incorporate the taught scientific conceptions with their incomplete/ incorrect prior knowledge models. These are said to be internally consistent in explanation but inconsistent in reasoning (Vosnaidou & Skopeliti (2014).

The IAQ instrument developed in 2014 has shown to be an insightful way of looking at challenging aspects in introductory astronomy. Specifically, the questions focusing on the ranking of sizes and distances, have proven to be one of the effective ways of looking at this (pedagogical) big idea. Using the aspects of the IAQ in our study enabled us to standardize the way in which size and distance can be probed and analysed (for comparison studies). The IAQ (2014) enabled us to identify a common problem in astronomy education as well as how to probe it. The analysis of this instrument can be carried out in similar ways across countries without compromising any information. The IAQ has also proven to be a good teaching and learning evaluation tool, which has been adopted on PhysPort*.

3.6 Conclusion

Size and distance are key concepts that are important in the learning and teaching of astronomy. Student understanding of these concepts is important for deeper understanding of the subject (astronomy) as a whole. These concepts are also predictor of student overall course achievement when they are able to correctly rank astronomical sizes and distances. The presented results of the current study are particularly similar to the trends that have been previously identified in studies in both South Africa and Norway.

Similar poor results across countries by students with hugely different backgrounds (socio-cultural, economic, language, education especially mathematics and science teaching) have been identified, and this study confirms the existing trends. The poor student performance points to the difficulties that are embedded in comprehending large distances and sizes beyond immediate human experience. Therefore, this study has enabled us to set the groundwork on bringing focus to spatial cognition* in Astronomy. The notion of spatial cognition will enable us to further unpack the challenges of comprehending large scales.

The Introductory Astronomy Questionnaire (IAQ) has proven to be a useful tool to probe student notions about concepts in astronomy, size and distance. The questionnaire can be easily translated to another language and probe for the same things without it losing content and context (as seen with the N-IAQ). It can also be used in a different context with different samples ranging from school learners, university students, as well as pre-service teachers. It has proven to be an effective tool in unpacking these salient issues of sizes and distance. Furthermore, the analysis of this instrument has enabled us to compare results to previous studies more effectively. One of the challenges in AER has been the lack of standardization of the instruments and their analysis which this instrument has also addressed. This study has confirmed that the IAQ is an approach in which the size and distance of astronomical objects can be probed in different contexts across the world.

*Spatial cognition is defined as the “knowledge and internal or cognitive representation of the structure, entities, and relations of space; in other words, the internalized reflection and reconstruction of space in thought” (Hart and Moore, 1973, p.248).

*PhysPort: https://www.physport.org/

Our results show, that while good teaching strategies are fairly successful in addressing other concepts in astronomy. Students had difficulties particularly with comprehending large distances. Evidence to support this is that Norway has a science and mathematics education policy in place that is far better implemented than that of South Africa, however comparable results are seen in these two quite different contexts.

Thus, we suggest that the poor performance with respect to understanding astronomical sizes and distances across quite different contexts points to a fundamental cognitive issue that relates to comprehending sizes and distances that lie beyond direct human experience. As the next step, the following chapter explores the notion of distance, as we have recorded an increase (3 out of 9 objects) rather than a substantial overall gain.

Chapter 4: Probing introductory students' engagement of distances.

Summary:

Recent studies in South Africa (both in 2014 & 2018) and Norway indicated that students perform poorly on questions regarding distances and sizes in astronomy. Despite marked educational and language differences, students in both countries performed similarly which suggests the possibility of deeper cognitive issues when dealing with scales beyond immediate human experience. In this chapter, we report on an exploratory study using the grounded theory method, where we probed how students engage with distances that vary from tangible to intangible. We constructed and administered a short instrument in which three consecutive questions prompted explanations regarding a specific category of distance from the distance spectrum. We administered this instrument to a cohort of introductory astronomy students at the University of Cape Town in 2019. A grounded analysis of the student responses was carried out and the results showed evidence of students operating in different domains of explanation when moving from one form of distance to another.

4.1 Introduction

Size and distance are big ideas in the learning and teaching of astronomy, however, as the results in Chapter 3 indicate, a considerable proportion of students struggle with conceptualizing sizes and even worse, distances. There were learning gains recorded with astronomical sizes after intervention, and as for distances, improvements were recorded for objects outside the solar system but with objects within the solar system, students performed poorly. In this chapter, we explore the issue of distances further by probing student engagement with distances, starting from small (tangible) to large (intangible). We did this to explore the scale at which the comprehension of distance becomes a problem for students. As a first step, we developed an instrument that probed students' understanding of both every day and astronomical distances.

First, we explore the concept of a distance spectrum, which draws on the concept of the electromagnetic spectrum. Studying astronomy involves interacting with different wavelengths/ frequencies of light (photons) which are seen in the electromagnetic spectrum*. In the electromagnetic spectrum, only certain wavelengths or frequencies are accessible to the human eye/ human beings in the form of visible light. For the rest of the spectrum, telescopes need to employ detectors sensitive to non-visible wavelengths (e.g., radio, ultraviolet, etc.). The signals received by these telescopes are mapped onto the visible part of the spectrum (i.e., false color imaging) so that they can be interpreted.

We defined the ‘distance spectrum’ as follows: 'an entire range of all known distances, from the smallest (atom level) to the biggest (astronomy level)'. However, just as for the EM spectrum, only a small part provides direct sensory input (in the order of metres), meaning that only a small part of the distance spectrum is ‘tangible’ and everything else on both sides is ‘intangible’, thus we have ‘small intangible’ as well we ‘big intangible’. The developed instrument tapped into the idea of distance from the tangible to the intangible (astronomy).

4.2 Method

In this section, we report on how we carried out this step of our study by providing an account of the instrument development, and how the questions were framed. We have also outlined the sample, the data collection process, and the analysis approach.

4.2.1 Grounded Theory Method

Glaser and Strauss (1967) are the founders of grounded theory methods in qualitative research, where the goal/ aim of the method is to develop a theory inductively from the collected data. As such, the theory emerges from the data, or in simple terms ‘theory is grounded on data’ (Charmaz, 2006, Bryant & Charmaz, 2007c). This is different from other research inquiry

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*Electromagnetic spectrum is the entire range of wavelength and frequencies of all known radiation.

methods, where the theory guides the data and its interpretation thereof. Charmaz (2006) further states that both the methods of research and the content emerge during the research process, and this is not preconceived by some theory. This strengthens our argument for taking this approach as it is data-driven and not theory-driven (Charmaz, 2008; Henning, 2004).

Grounded theory methods are particularly useful in qualitative studies as they offer several open-ended strategies for administering an emergence inquiry (Charmaz, 2006; Charmaz & Henwood, 2017). This means that grounded theory method allows data to be explored in multiple ways that remain open to a variety of explanations. Therefore, there is no set route in conducting a qualitative study through the GTM, instead, it is an iterative process that allows creative problem solving.

In probing student intuitive ideas and notions of distance, we employed the grounded theory method with the purpose of developing a "theory" that helps to make sense of how students think of distances. Our assertion, as stated before, is that the way in which students explain the concept of distance, is the way they understand it. In section 4.2.6 of this chapter (analysis method), we explain how we developed codes from student writing (data) to develop categories which enabled us to develop a theory of how students intuitively think of distance.

4.2.2 Instrument development

The Physics Astronomy Education Research (PhAsER) group developed several questions in the form of scenarios/situations, multiple-choice, and simulations which were all intended to evoke students' understanding of a certain concept, in this case distance. As a group, we met every week to discuss and develop these questions. Some of the questions that we brainstormed were piloted on senior students (masters and PhD) and lecturers within the astronomy department at UCT. This particular piloting of the questions took place in an informal way, where we handed out questions randomly to the postgraduate students and lecturers. Their responses were collected after a week, and we performed a quick analysis by reading the responses we received. This process enabled us to revise our ideas before finalizing the questionnaire. As such, we revisited our ideas and brainstormed the form and framing of questions further. Therefore, this process was iterative, in which the PhAsER group modified and constructed new questions after a few rounds of piloting them.

In selecting the questions for the instrument, we put emphasis on how the questions were framed since the previous studies carried out within the PER area by the PhAsER group have shown that the context, perceived voice, mode of explanation, and the framing of the questions influence the response from the students (Takane, 2014; Tlowana, 2017; & Southey, 2018). Thus, the selection and framing of questions was done carefully so that the questions served as a tool to elicit the students' intuitive knowledge of distances.

4.2.3 Framing of the questions

The purpose of the instrument was to find out how students intuitively think about distances. Intuition draws on how one ‘feels’ about something, which draws on the senses of the person. There are five primary senses: tactile (touch), auditory (hearing), olfactory (smell), gustatory (taste) and visual (sight). The questions were framed in a way that limits one of these senses, which was the visual sensory modality of the person who was asking the question. This was done to see how students engage with distances within and outside of their experiences with one sense limited. The questions were therefore framed as an explanation to a blind friend, in order to ensure that students could not default to a visual explanation. We limited the visual modality due to the argument raised by Grady, where it is stated that sight is calibrated by touch (Grady, 1997) and that distances are related to the primary haptic (touching) experiences from childhood. For example, infants make sense of their surroundings by having interactions with them through the primary senses; sight, touch, smell, auditory and sound (Grady, 1997). This instrument was then referred to as the ‘Astronomy Questionnaire: Understanding and Engagement with Distance’ (AQUED).

The questions were as follows:

Question 1.

A blind (cannot see) friend asks you “I am trying to get a sense of how big 7 metres is”.

How would you help your blind friend make sense of 7 metres?

Question 2.

Your blind friend then asks you “I am trying to get a sense of 100 kilometres”.

How would you go about helping your friend?

Question 3.

Your blind friend then says, “I hear the moon is about 384 402 km from earth. I am trying to get a sense of how far this is”.

How would you help your friend with this?

These distances are chosen from the distance spectrum, with 7 metres being a tangible distance that students have experience with. The 100 kilometre distance is one that students have also had experience with, and we classified it also as a tangible distance. The distance to the moon is towards the end of the spectrum, as the distance is 384 402 km. We classified this distance as intangible, as it is far too large to have been physically experienced by the students. However, they have seen the moon and know about it.

4.2.4 Sample

The instrument was given to a group of students (n = 86) who were taking the Introductory Astronomy Course (AST1000F) at UCT in 2019. Although this course is an entry-level course and most of the students in the course are in their first year of study, it can be taken as an elective for those in other levels of study (year 2 – year 3). The class is made up of both science and non-science majors as the requirement for taking this class is that the student must be registered for an undergraduate degree at the university. This results in the large diversity in our student sample for this study, including differences such as language, traditions, and cultural background as well as high school teaching. A total of 75 students fully answered the AQUED (meaning that they answered all three questions), while all the students (86) answered question 1, the number reduced in question 2 and question 3.

4.2.5 Administration

The instrument was administered on the first day of the introductory astronomy lecture. In this introductory lecture, the lecturer introduced the content to be covered in the course, all the other administrative issues (such as venues for lectures/practicals, important dates for assignments/tests). The researcher (SA*) explained the purpose of the instrument and gave instructions that should be followed by the students when answering it. A letter of invitation and a consent form were handed out together with the instrument, in order to explain to students that the questionnaire was not an assessment that counts towards their course mark and that their responses would be anonymous. The student numbers were recorded for the purposes of the student-by-student analysis of the responses. After this was done, a Respondent Identification Number (RIN) was assigned to keep the student responses anonymous.

4.2.6 Analysis method

Figure 4.1 shows the cycle of our general grounded analysis method, where N is the number of participants and R is the number of responses. In carrying out this analysis, I started first by randomly taking one written response from question 1 and then (1) did a close reading of the response, (2) identified the main idea/s and (3) then assigned a code/s to it. Then, I randomly

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*Saalih Allie

picked another written response, where I either identified a new idea and coded it or assigned the same code as before. I did this first process with one of the researchers in the PhAsER group.

Therefore, we carried out the steps as follows; (1) performed a close reading, (2) identified the main ideas and (3) assigned a code to the idea. Then, we carried out a close reading of the next script, where we either assigned the same code or created a new one depending on the main idea of that response. We repeated this process with all scripts. When we were done giving codes to all 86 scripts for question 1, we grouped these codes into related key ideas. We, then identified the emerging categories, which we compared in the research group. We repeated the cycle until we were all in agreement because as we read the responses, more and more main ideas emerged, and we needed to be consistent with the coding system as sometimes I even ask if I agree with myself from the previous day. We repeated this process for question 2 and 3. Figure 4.1, shows the process per question.

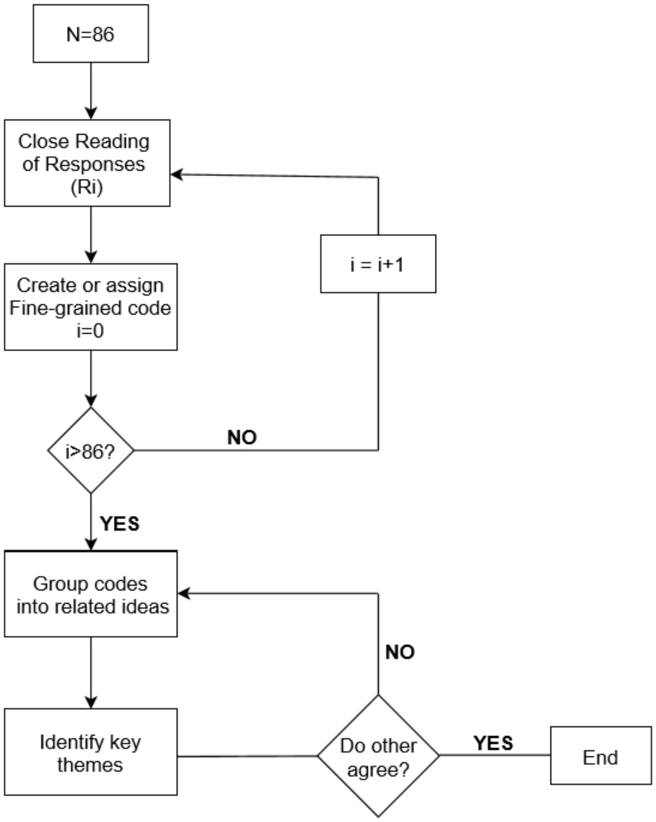

Figure 4.1: A figure showing the process of the grounded analysis as it unfolds, with N being the total number of respondents, i= the response/ idea, Ri= close reading of student response/idea. The total number of ideas is more than the number of respondents, as the identified ideas may be more than one in a students' responses. This process is applied per question. Therefore, we went through 241 written responses.

Figure 4.1 is a visual representation of how the grounded theory method analysis was carried out in this study. This figure (4.1) summarizes the intense process which we undertook when analysing data from student writing. In this study, we had a total number of 86 questionnaires that were filled. As a starting point, we randomly selected (about) 20 responses from question 1 and did a close reading of each response, and created fine-grained codes as we saw fit, we did this individually (AS* and I). We then compared the fine-grained codes we had identified individually and then coded the same response together in order to agree on the fine-grained code assigned. During the comparison of the identified codes a lot of discussion around the code or main idea of the written response took place. We then agreed on the codes we both identified, which we then used to continue coding the randomly selected 20 responses. These 20 responses were a starting point for our coding for the rest of the responses (data) for question 1 and a similar method was employed for questions 2 and 3. Note that these codes were fine-grained codes, which are identified at a micro-level, where we looked at what the student said exactly. Those main ideas in their responses become the fine-grained code. In this context, the main idea refers to an idea which if removed would render the response nonsensical.

We then performed the same close reading of the rest of the responses in question 1, assigning the fine-grained codes and creating new fine-grained codes as we saw fit (e.g., i=i+1). This was not done only once, but a few times to make sure that our coding scheme was consistent and unbiased as possible. While repeating this process, some responses kept their initial codes, while in other responses the code changed. These fine-grained codes were then grouped into related ideas, we then identified the key categories which emerged from the data, and the data (student written responses) was then grouped into these big emergent categories. When we, as the research group (PhAsER) did not agree on the emerging 'categories', we re-grouped the fine-grain codes and then determined what the emerging 'categories' were. When an agreement was reached, the responses were then coded and assigned a category. In most cases, the inter-rater reliability of this analysis was 99%, due to the constant discussions that took place during the analysis, thus ensuring that the results are valid and reliable. This analysis process was applied in all the questions. We processed 241 responses in total, 86 from question 1, 80 from question 2 and 75 from question 3.

Table III shows a summary of the emergent categories from question 1, followed by the key ideas which are the main descriptor of what made up each of the categories. A total of 86 students provided written responses for this question and a total number of 115 key ideas were identified. The total percentage of each category is shown in the table as well as examples of some of the responses with that main idea. Table IV refers to responses in question 2. As such, the emergent categories are shown, which are followed by the key ideas/descriptor for each category. A total number of 80 students provided written responses for this question and 94 main ideas were identified from the written responses. The total percentage of each emergent category is also

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*Alexander Sivitilli

shown in the table, together with some of the student responses. Table V is a record of the emerging categories from question 3, where the key ideas/ descriptor of each category is outlined. The total number of students that responded to question 3 was 76 and the total number of identified key ideas was 85. The total percentages per categories are provided, together with examples of responses. The RIN represents the Respondent Identification Number as per-ethics students' identities were kept confidential. Moreover, the student responses in the tables and within the text are recorded exactly how the student wrote it, no modifications of grammar and spelling errors were made to student responses.

Table III. Shows the emergent categories from the responses and the descriptors of what each code entails, the total number of students as well as the total number of key ideas with examples of responses. The RIN is the Respondent Identification Number.

Emergent categories	**Code/ Key Idea/ Descriptor**	**No of ideas =115** **N=86**	**Percentage**	**Example**
No movement	**Steps/counting steps**	85	74%	*RIN 1037: "One stride is roughly 1m so I would ask my friend to take 7 strides forward and they would thus be able to gain an idea of what 7m is".* *RIN 1019: "Make him stretch his arms out as to form a 1 metre hand to hand".* *RIN 1065: "(2) Open your arms wide open, and imagine 7 people joined of you holding hands like that, then it will be approximately a 7 metres chain of hands"* *RIN 1041: "7 metres is about approximately your height multiply by seven."* *RIN 1012: "I would give the person a 1-meter ruler, let them feel how long it is and picture it horizontally*
	Arm's Length/ Interlinked/ **Shoulder to Arm**			
	Height/Stacking			
	Metre rule			
Movement	**Walking 7m**	21	18.2%	*RIN 1040: "I would physically walk them 7 metres, informing them of each metre passed"* *RIN 1058: "Help them shuffle across a 7m distance while holding onto something to set vague of idea of distance traveled."* *RIN 1065: "(1) Walk from the other side of the wall with a stick, to the other opposite side. The distance that you moved is approximately 7 metres friend."*
	Walk towards an object (pole, ball)			
	Walking towards a sound			
Other	**Plotting/ scaling down**	9	7.8%	*RIN 1086: "Look at it this way: Just imagine plotting the shoes of your average adult in a linear array. All seven of the make your seven metres."* *RIN 1075: "Imagine a pen which is basically 2cm in width at most times, now imagine half a pen which is 1cm, now imagine a 100 half pens now imagine 600 more half pens thats 7 metres."*

Table IV. Is a description of the emergent categories with the key ideas of each category for question 2. The total number of students who responded was 80 and the total number of ideas is 94. The examples of student responses are also shown. (Respondent Identification Number RIN).

Emergent categories	**Code/ Key Idea/ Descriptor**	**No of ideas=94** **N=80**	**Percentage**	**Example**
No movement	**Step/Counting steps**	23	24.5%	*RIN 1022: "tell him/her that "its 7metres x 100 000 divided by 7".* *RIN 1052: "I would tell them that 100km is the equivalent of walking 7 meters approximately 14280 times."* *RIN 1011: "I would use his body to measure a single metre, if his arm is 1 metre, then I'd tell him that it's 100 000 times his arm's length."*
	Arm's Length/ Interlinked/ **Shoulder to Arm**			
	Height			
Movement	**Walk/ run/**	51	54.2%	*RIN 1004: "I would run 10 km with him and tell him that it is 10 times further."* *RIN 1030: "I would take him and drive a car then accelerate I would tell him he had experienced the distance of 100km."* *RIN 1079: "Take this 10cm ruler. Lets say that this ruler us the 1km journey that you take to school every day. Now line up this ruler 100 times and think about your journey on the scale of rulers. The line of rulers is 100km."*
	Drive			
	Journey			
Time	**Speed** **Minutes/ Hours/**	18	19.2%	*RIN 1033 "It takes about 10 minutes to walk 1km, so imagine, having to walk for 1000 minutes".* *RIN 1021 "A 100km is being in a car that moves at a speed of 100km/h, for an hour".*
Other	**Mathematical conventions**	2	2.1%	*RIN 1049: "Explain in terms of maths 1 metres is 100 kilometres the ratio is 1:1000, so imagine have 1 metre multiplying it by 10 then multiply 10 by 1000 kilometres that how big a kilometres."* *RIN 1073: "I'll help him by demonstrating the size of 100km/ applying mathematical convention"*

Table V. Shows the emergent categories, with the key ideas as well as example of what each code entail for question 3. A total 75 students provided explanations and 85 ideas were identified from the written responses. (Respondent Identification Number RIN).

Emergent categories	**Code/ Key Idea/ Descriptor**	**No of ideas= 85** **N=75**	**Percentage**	**Example**
No movement	**Step/Counting steps**	25	29.4%	*RIN 1066: "give them a reference for a more scaled-down situation, like on a piece of A4 paper and then a reference to a more sensible distance" and* *RIN 1067: "I would say the moon is very big and explain how I would view the moon up-close, then I would hand him/her an orange and explain the further away something is the smaller it seems to be, the moon looks like the size of an orange whilst its actually roughly 1/5 of earths size that how far the moon is".*
	Arm's Length/			
	Height			
	Circumference/ diameter			
Movement	**Walk/ drive/ journey/ run/**	27	31.8%	*RIN 1034: "We would walk around a 400m athletics field, the distance to the moon would almost be like walking around the field 1000 times".* *RIN 1041: "That's like moving from the North Pole to the South Pole"* *RIN 1046: "We would fly from Australia to North America and back a number of times, we would have made sense of the 384402km is like, doing return trips."*
	Walk towards an object (pole, ball)			
	Walking towards a sound			
Time	**Hours/ Weeks/ months/ years**	21	24.7%	*RIN 1023: "384 402 km is what/how long it would take a fully-equipped spaceship a month to get to".* *RIN 1030: "I would say it would take about 384 hours to reach the moon when you travel at 100km/h which is the speed he usually experiences in a car".*
Other	**Cant comprehend/ ask someone else**	12	14.1%	*RIN 1064: "I would not cause I can not. I font even get the sense of how far this is and I can see it almost everyday."* *RIN 1005: "It is difficult to comprehend even with sight. Way further than any journey from one place to another on earth."*

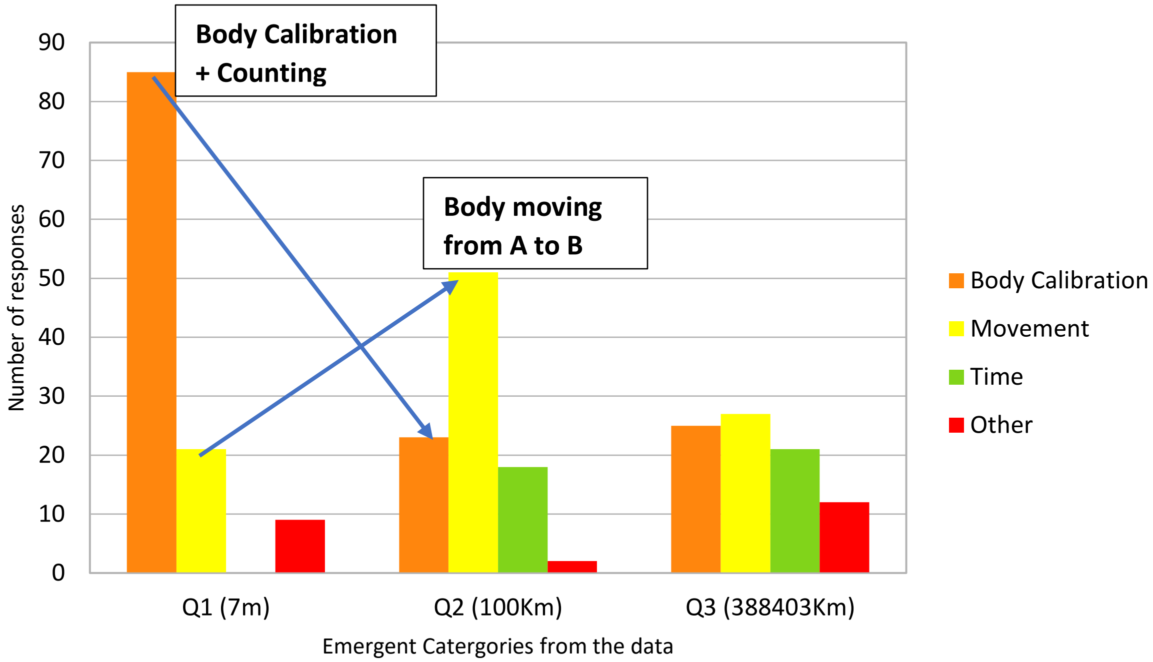


Figure 4.2: Is a bar graph that represents the total number of student responses for questions 1, 2, and 3, grouped into the identified emergent categories across all three questions. The identified categories were mainly, (body) static/ stationary/ non-moving; (body) movement (body actively displaced; time (with speed), can't comprehend as well as other. The most dominating response for question 1 (7m), shows to be the static category, while in question 2 (100km) the dominating responses show to be in the movement category. For question 3 (to the moon), the responses seem to be spread across the three main emergent categories.

4.3 Results

This section describes the results from the analysis of questions. A bar graph (figure 4.2) illustrates the total number of responses per question against the emergent categories across the three questions. Full details of these results are discussed, starting with question 1. A further analysis of the results concludes this section as we compare the results on a question-to-question basis.

Figure 4.2 represents the total number of responses for the emerging categories across all questions. Each question had a different number of total ideas (main ideas), this is because students would have more than one idea in their written responses, which were then coded as separate ideas. Question 1 had a total of 115 ideas, question 2 had 94 ideas and question 3 had 85 ideas from the student written responses. The emerging big categories that we identify across the three questions were (i) Body- Calibration (non-moving), (ii) Movement (locomotion), and (iii) Time.

- “Body calibration” refers to responses that does not show that the two bodies (the blind friend and the student/respondent) are changing position, instead they remain in one place (stationary), meaning that they are in one point as per the provided frame of reference. Or the counting of the number of steps the blind friend needs to take.

- “Movement” (locomotion) refers to responses which suggest that the body or bodies are being displaced, such that they are changing their position/ moving from one point to another based on their provided frame of reference. For example, known places (between Johannesburg and Pretoria).
- “Time” refers to responses that mostly use time and or speed (in most cases traveling time) to describe the distance. (This was not applicable in question 1).
- “Other” refers to responses that were interesting but do not fit the big emergent categories, such as “applying mathematics” or “incomprehensible”.

These emergent categories are based on the ideas that were identified at a micro level of coding student responses.

4.3.1 Question 1: 7m

*A **blind** (cannot see) friend asks you “I am trying to get a sense of how big 7 metres is”.*

How would you help your blind friend make sense of 7 metres?

The total number of students who answered this 7m question was 86, which was the total number of students in the class. The question was requiring students to explain a 7m distance to a “blind” friend. The “blind” (cannot see) friend complex is explained in section 4.2 (instrument development). Table III shows an example of student responses to this question. In the first phase of the analysis, we took note of the words and/or *ideas* that were used in student responses to this question. As explained previously, the analysis was an iterative process, therefore the second phase did not mean doing something different, rather it meant that we went through the data again to see if what we identified still held.

Out of the 115 key ideas identified in question 1, 85 of these were grouped and they formed the body calibration category. Most of these responses started the description of 7m by first calibrating the “idea” of 1 metre (1m) and then proceeded to explain the 7 metres (7m) which they were asked about. The calibration of the 1m was done in different ways, which involved using the body (of the blind friend). The legs, arms as well as height were the most commonly used in the student explanations (See Table III). The other calibration was using something outside of the body, such as a metre rule, a measuring tape, a string and pacing out small objects in-between the distance, so that the blind friend can feel these objects to get a sense of 7m. All of these explanations involved an element of touching, physically feeling with the hands and feeling the actual distance without the blind friend moving from their initial position.

These 85 responses made up 74% of the total responses for this question, where the distance was described by calibrating it using the body of the blind friend. These explanations were identified in the body calibration (non-moving) domain. In this domain, (tactile) senses via the body parts (feet, arms, and height) are crucial in explaining the distance of 7m.

The responses involving the use of legs by giving these terms *‘Step, Leap, Stride*’. An example of this is seen in the responses from this student; RIN1037 and RIN1079:

> “*One stride is roughly 1m so I would ask my friend to take 7 strides forward and they would thus be able to gain an idea of what 7m is*” or
>
> “*Take a big step forward. That is one metre. Now if you take 7 of those steps, that is roughly 7 metres*".

In these explanations, it is clear that a step/ stride relates to feeling the distance through the sensation of touch. Thus, this suggests that the focus is on the pacing and counting of the distance and not necessarily the movement from one place to another. Lakoff and Nuzez (2000), mention that taking a step or pacing, taking strides involves a huge element of counting which is quasi-static. For this reason, we assert in this study that counting steps (to get to 7m) is different from walking a 7m distance (this idea will be explored further in the next sections), thus this was grouped into the body calibration (non-moving category).

Another calibration was the use of arms of the blind friend. This is also a static (non-moving) explanation, in which the sensation of touch is important in anchoring this idea. In these responses there is no sign of movement but rather the person is in the same place (one point in space). Some of these respondents have said the following in responses RIN1019 and RIN1027:

> "*Make him stretch his arms out as to form a 1 metre hand to hand*” and
>
> “*Spread out your hands, they are about the length of a metre, now think about seven of them interlinked*”.

Height was also used as a calibration of the 7m distance, such that the responses described the distance by relating it to the height of the person and or other people around them. Some of these responses can be seen with RIN1041 and RIN1038:

> “7 metres is about approximately your height multiply by seven” and
>
> “*your upper arm is about 30 cm long while 7m is 700 cm as it is about 23 times the length of your upper arm. Since your height is likely to be about 1.6m then its also about 6 times your height*”.

These descriptions show that the person is not changing their initial position thus they are in a static (non-moving domain).

Some responses provided a “none- movement” description by calibrating on external (to the body) objects such as a metre rule or a measuring tape. In these descriptions, the blind friend is to feel how long the 1 m is then 'imagine' that length multiplied by 7. Such a response is grouped into the body calibration (non-moving) category. An example of a response in this category is as follows RIN 1012:

> "*I would give the person a 1-meter ruler, let them feel how the long it is and picture it horizontally”*, shows that there is an element of the sense of touch.

About 21 of the responses in question 1 were grouped to form the emerging category of movement. Some movement was calibrated external of the body by measuring out the 7m distance without making the blind friend touching or feeling anything by themselves such as respondent RIN1059:

> *“I would mark out 7 meters. Ask my friend to walk forward and then I would say stop once her has walked 7 meters. Repeat this process until the friend feels he can comfortably judge 7 meters*".

Another respondent measured this distance with sound, such that the blind friend will walk the distance while the friend shouts out to them. This shows that the blind friend is moving the distance of 7m, thus changing their initial position. The other responses did not calibrate the 1m, as such RIN1019:

> "*Let them walk seven metres to help them understand. Then they will have experienced and felt how long seven metres is*", is an example of a response from this category.

Another response from RIN1023:

> "*I'd walk with my friend on a straight path and notify them when we have reached 7 metres*".

These kinds of responses were coded under the big category of movement and were not a popular response for question 1, making up 18.2% of the sample.

In most cases, the calibration of the 1m first, yielded a non-moving response, such that the body of the blind friend and respondent remains in their initial position. When a body does not change position from its initial one, the body is stationary. Concerning this 7m distance, most responses showed to be stationary with a huge reliance on the bodily senses, especially touching and feeling. Since we restricted the visual modality by referring to a 'blind' friend, we see students drawing on another primary sensory-motor experience, in this case that of touch.

4.3.2 Question 2: 100 Km

*Your **blind** friend then asks you "I am trying to get a sense of 100 kilometres".*

How would you go about helping your friend?

The static (non-moving) responses were mostly adding on the response from question 1. For example, respondent RIN1039:

> "*Using those steps, he/she now is familiar with the unit of measure, steps, I would just tell them that if x steps = 7 metres, then 100 km is equal to xy steps*".

RIN1039 used a similar idea and reasoning as in their explanation in question 1. The same principle as the first response, therefore, applies in this question. 23 responses (24.5%) were coded as static (non-moving) in this question.

51 (54.2%) of the responses were grouped into the movement category. This category referred to responses that explicitly suggested the actual movement of the blind friend and, as such, the blind friend changed position from their initial one (displacement of the body). Many responses included phrases such as:

"Driving from location A to B",

"Taking a trip to and back",

"Walking from points A to B",

"Taking a journey from JHB to PTA".

Some of these responses are shown in Table IV, for example, RIN1058 and RIN1067:

> "*it is about a distance you travel from Johannesburg to Pretoria*"
>
> "*Get him/her to walk a kilometre after getting a sense of how big a kilometre is I would explain that 100 kilometres would be walking the same distance a 100 times*".

These responses show that the blind friend together with the respondent are moving and changing their position, to enable the blind friend to get an understanding of 100km. The respondents in this category demonstrated that the understanding of a distance such as 100 km requires one to experience it by moving from one point to another. The description of this movement varied from walking, running, driving, taking a trip, and traveling that distance. Thus, these show a change in position, which is also evidence of a body being displaced.

18 (19.2%) of the responses in question were grouped into the category of time. Examples of responses that used the time explanations included the use of phrases such as 'hours’, ‘weeks’, ‘minutes’, ‘days’ as well as ‘speed'. In some cases, time was introduced as an extension of movement, as such traveling with time or for a certain time. RIN1033:

> "*It takes about 10 minutes to walk 1km, so imagine, having to walk for 1000 minutes*"

is an example of traveling with time; while RIN1021

> "*A 100 km is like being in a car that moves at a speed of 100 km/h, for an hour*",

is an example of a time explanation without traveling or being in physical motion. Time as an anchoring idea is an interesting one, as it gives rise to space being calibrated on time. Time is a complex entity, which many physicists and neuroscientists are still researching.

Only 2 responses were coded as ‘other’, in this category. The responses did not have any similarities with the identified ideas but showed a different yet interesting angle. Respondent RIN1073 is an example of a response in the "other" category. RIN1073:

> "*I’ll help him by demonstrating the size of 100km/ applying mathematical convention*”

However, the assumption here is that the blind friend is familiar with mathematics.

When we look at the categories as a form of domain explanation, we realise that there is more than one way of thinking about distance. According to the responses, a movement domain is useful in explaining a distance that is not small enough to feel and get the sensation of touch. A static (non-moving) domain is useful in understanding a smaller distance. This smaller distance is the metres in the distance spectrum.

4.3.3 Question 3: Distance to the moon

*Your **blind** friend then says, “I hear the moon is about 384 402 km from earth. I am trying to get a sense of far this is”.*

How would you help your friend with this?

Table V shows the coding system that was used for this question.

The body calibration (non-moving) category was similar to the explanations in questions 1 and 2, however with an addition of ‘diameter’ and ‘circumference’. The responses showed that the blind friend is not moving but either using their body (by touching objects) or scaling down the distance to explain how big the diameter/circumference of the earth is and then relating it back to size of the earth and then the distance to the moon. Examples of this are seen in respondents RIN1066:

> "*give them a reference for a more scaled down situation, like on a piece of A4 paper and then a reference to a more sensible distance*"

and RIN1066:

> "*I would say the moon is very big and explain how I would view the moon up-close, then I would hand him/her an orange and explain the further away something is the smaller it seems to be, the moon looks like the size of an orange whilst it is roughly 1/5 of earths size that how far the moon is*".

25 responses were grouped into this category, and these made up 29% of the responses.

In this question, about 27 of the responses were grouped into the emerging category of movement. The movement in this question was an extension of the journey/ trip that was described in question 2 by most students (respondents). While respondent RIN1034 said that

> "*We would walk around a 400m athletics field, the distance to the moon would almost be like walking around the field 1000 times*",

this shows an active journey/ traveling to help the blind friend with understanding how large the distance is.

Time as an emergent category, was coded in responses that included “hours, weeks, years and other measure of time”, as this showed to be the main idea in the response. An example is seen with respondent RIN1023:

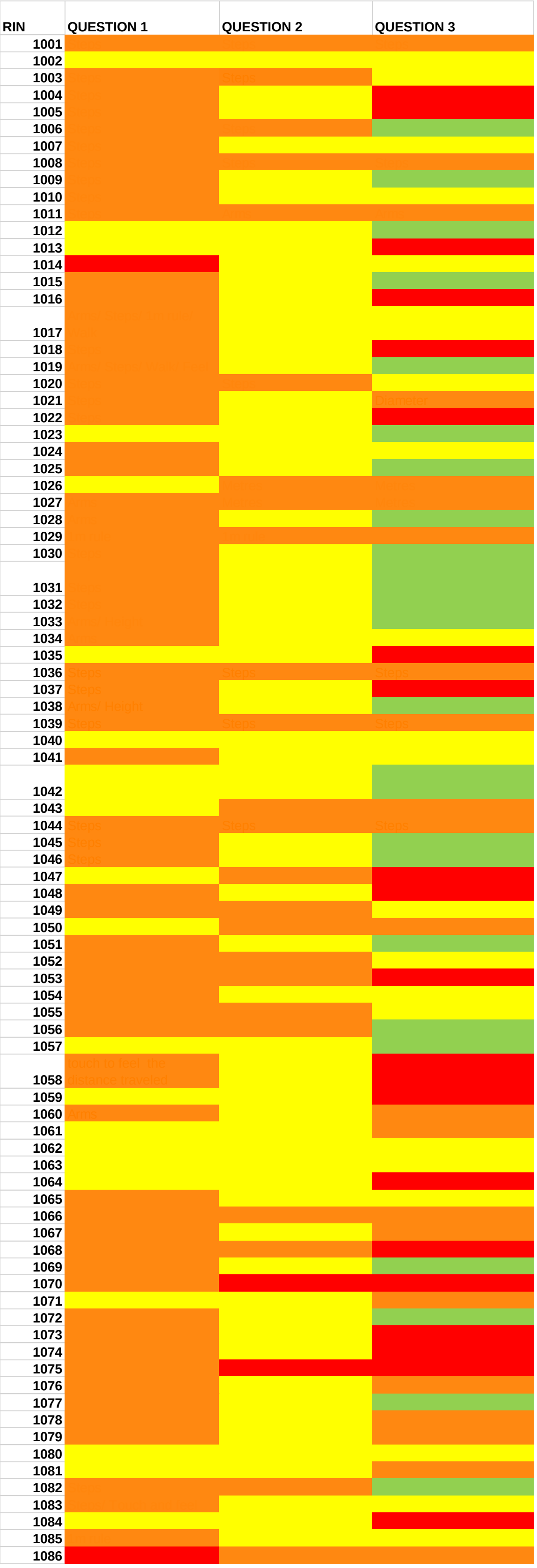
> “*384 402 km is what/how long it would take a fully-equipped spaceship a month to get to*”

or RIN1030:

> “*I would say it would take about 384 hours to reach the moon when you travel at 100km/h which is the speed he usually experiences in a car*".

The idea of time in most cases shows to be adding on the traveling response which was introduced in question 2 although this was different from the movement category due to the introduction of speed and the type of transport used to get to the place. The type of transport used also introduces the concept of speed, how fast the object is. 21 of such responses were coded in this question, which made up 25% of the responses.

The other category, also called the ‘incomprehensible’ category, shows responses which stated that this distance to the moon is incomprehensible to them and therefore cannot be explained to the blind friend or those who stated that they would refer the friend to a person who is more knowledgeable than them (for example a lecturer). These were honest responses from the students as distances outside of our immediate/ everyday experiences are not easily understood. This points to the issue at hand, of the challenge posed by astronomical distances in learning and teaching of astronomy. 12 of the responses were grouped into this category, which is 14% of the responses.



RIN	QUESTION 1	QUESTION 2	QUESTION 3
1001	🟧 Steps	🟧 Steps	🟧 Steps
1002	🟨	🟨	🟨
1003	🟧 Steps	🟧 Steps	🟨
1004	🟧 Steps	🟨	🟥
1005	🟧 Steps	🟨	🟥
1006	🟧 Steps	🟧 Steps	🟩
1007	🟧 Steps	🟨	🟨
1008	🟧 Steps	🟧 Steps	🟧 Steps
1009	🟧 Steps	🟨	🟩
1010	🟧 Steps	🟨	🟨
1011	🟧 Steps	🟧 Arms	🟧 Arms
1012	🟨	🟨	🟩
1013	🟨	🟨	🟥
1014	🟥	🟨	🟨
1015	🟧	🟨	🟩
1016	🟧	🟨	🟥
1017	🟧 Arms/ Steps/ 1m rule/ Walk	🟨	🟨
1018	🟧 Steps	🟨	🟥
1019	🟧 Arms/ Steps/ Walk/ Feel	🟨	🟩
1020	🟧 Steps	🟧 Steps	🟨
1021	🟧 Steps	🟨	🟧 Diameter
1022	🟧 Steps	🟨	🟥
1023	🟨	🟨	🟩
1024	🟧	🟨	🟨
1025	🟧	🟨	🟩
1026	🟨	🟧 Metres	🟧 Metres
1027	🟧 Arms	🟧 Metres	🟧 Metres
1028	🟧 Arms	🟨	🟩
1029	🟧 1m rule	🟧 1m rule	🟧
1030	🟧 Steps	🟨	🟩
1031	🟧 Steps	🟨	🟩
1032	🟧 Steps	🟨	🟩
1033	🟧 Arms/ Height	🟨	🟩
1034	🟧 Arms	🟨	🟨
1035	🟨	🟨	🟥
1036	🟧 Steps	🟧 Steps	🟧 Steps
1037	🟧 Steps	🟨	🟥
1038	🟧 Arms/ Height	🟨	🟩
1039	🟧 Steps	🟧 Steps	🟧 Steps
1040	🟨	🟨	🟨
1041	🟧	🟨	🟨
1042	🟨	🟨	🟩
1043	🟨	🟧	🟧
1044	🟧 Steps	🟧 Steps	🟧 Steps
1045	🟧 Steps	🟨	🟩
1046	🟧 Steps	🟨	🟩
1047	🟨	🟧	🟥
1048	🟧	🟨	🟥
1049	🟧	🟧	🟨
1050	🟨	🟧	🟧
1051	🟧	🟨	🟩
1052	🟧	🟧	🟨
1053	🟧	🟧	🟥
1054	🟧	🟨	🟨
1055	🟧	🟧	🟨
1056	🟧	🟧	🟩
1057	🟨	🟨	🟩
1058	🟧 touch to feel the distance traveled	🟨	🟥
1059	🟨	🟨	🟥
1060	🟧 Arms	🟨	🟧
1061	🟨	🟨	🟧
1062	🟨	🟨	🟨
1063	🟨	🟨	🟨
1064	🟨	🟨	🟥
1065	🟧	🟨	🟨
1066	🟧	🟧	🟧
1067	🟧	🟨	🟧
1068	🟧	🟧	🟥
1069	🟧	🟨	🟩
1070	🟧	🟥	🟥
1071	🟨	🟨	🟧
1072	🟧	🟨	🟩
1073	🟧	🟨	🟥
1074	🟧	🟨	🟥
1075	🟧	🟥	🟥
1076	🟧	🟨	🟧
1077	🟧	🟨	🟩
1078	🟧	🟨	🟧
1079	🟧	🟨	🟧
1080	🟨	🟨	🟨
1081	🟨	🟨	🟧
1082	🟧 Steps	🟧	🟩
1083	🟧 Steps/ Touch and feel	🟨	🟨
1084	🟨	🟨	🟥
1085	🟧 1m rule	🟨	🟨
1086	🟥	🟧	🟧

Figure 4.3: Is a colour coded spreadsheet that illustrates student ideas from question to question, including the number of phase/domain transition each student made.

4.3.4 Overall result

We viewed the emergent categories as explanation domains, in which students operate for explaining different distance questions. Hence, when doing further analysis, we developed a python script that would automatically colour- code the emergent categories in the responses (as explanation domains). Therefore, a colour was signed to each emergent category. In total there were four categories namely, body calibrations (orange, non-moving), movement (yellow), time (green), and other (red). These responses and the colour codes were computed into a spreadsheet which showed that there were domain transitions in student responses, while the other students responses showed no transition at all.

The spreadsheet allowed us to quickly identify which explanation domain was mostly used in each question. The most visible and biggest domain transition is between question 1 (7m) and question 2 (100km), where we see that the category that dominated the 7m (Bodily calibrations – non-moving) is not the dominating category in the 100 km (see figure 4.2). This shows that for the understanding of distances that we cannot "touch, feel" (small), there is a need for domain transition to an explanation that evokes movement and the displacement of the body (locomotion) for the blind friend to get a sense of this. In addition, the explanation domain went from a bodily calibration (non-moving) domain in question 1 to a movement domain in question 2. While both these distances are tangible and familiar (according to the distance spectrum), the way in which they are described and thus understood is different.

The last question (3) shows a spread in responses between the static, movement, and time. The responses in which students were coded static, were mostly respondents who did not change the domain of explanation for all three questions, or those that went back to the first domain in their explanations by introducing diameter and circumference thus mapping this large distance into something they can comprehend. The movement domain responses were an add-on from the response in question 2. Those in the time domain were mostly an extension of the movement domain, with an introduction of speed and time.

Looking at the spreadsheet (figure 4.3) we can also identify which respondents changed their explanation domain and those who did not. For this reason, it was important to record the students who did not complete the questionnaire but started it and we were also able to identify where the individual respondents had difficulties. Hence, according to our emergent categories, students can, at most have two domain transitions between the three questions.

With an establishment of the colours in the spreadsheet, an assertion we made was that, if a student has no understanding of the two tangible distances 7m and 100km, the distance to the moon would then be challenging for them to explain. We also asserted the following based on the spreadsheet; (i) if the student has no idea of 7m, they will not be able to describe the other distances, especially the distance to the moon and (ii) students that change explanation domains are likely to understand/ describe distances better than those that do not change. Furthermore, the data shows that there were no respondents that moved from a Static domain in questions 1 and 2 to a time domain in question 3. These respondents operated in one domain throughout their explanations, which might make it difficult for them to make the switch to another domain, when it is needed.

Therefore, we have evidence, presented by this data, that students think differently about different distances (re-distance spectrum), even those that are familiar to them. There are two modes (thus domains) of student thinking that we have identified, and they stand out in our data; (1) distances that can be explained by extending body parts and counting steps (non-moving). These distances rely on the sense of touch; thus, this seems to be effortless. And (2) distances that spontaneously involve switching over to walking and the notion of a journey (movement). Movement, on the other hand, requires the displacement of the body between two or more points. This requires effort unlike being in one point.

Furthermore, operating at only the body calibration (non-moving) domain has many limitations especially in astronomy, as it limits the comprehension of big, large scales which are introduced in this area. Hence, it was important to find out what comes before 'time', which we have established to be ‘movement’ in the form of a journey. We use these findings and embodied cognition framework (see chapter 5), to develop a theory based activity (see chapter 6) which can be used for teaching astronomical scales.

4.4 Conclusions and way forward

In this chapter, we aimed to probe the students’ notions of distance. This was strongly influenced by the students lack of deeper conceptual understanding, which were presented in the data in chapter 3. In doing so, we developed a questionnaire that focused on student engagement with distances. We introduced the notion of the distance spectrum and identified the distances that are comprehensible to humans. Three different distances were chosen to be key to finding out what are the notions that students use when engaging with distances.

The data showed that there is an explanatory transition from a static (non-moving) domain to a movement domain in going from tangible distances to larger distances. This proved to be the main finding from the data. The notion of being displaced between two points in space brings about the idea of a journey through active movement and is important for introducing larger distances, before the introduction of time as a descriptor. This helped us with understanding the importance of teaching distances in the appropriate explanation domain in which students operate.

In conclusion, if we regard the explanatory domain as the one in which thinking (therefore understanding) is primarily occurring, then teaching large distance in the static domain when the respondents operate in the motion domain has shown to be problematic. This is the reason we further interpreted this result from a theoretical perspective, which we explore in the next chapter.

Chapter 5: Explanatory framework: an account of the Embodied Cognition view in sense -making and comprehension of large scales in astronomy.

Summary: Chapter 5

In this chapter, we describe the theoretical framework which we used to further interpret the experimental data from chapter 4, after the initial grounded theory method (GTM analysis was carried out. We will refer to this framework as the “explanatory theoretical framework” or “explanatory framework". In chapter 3, we concluded that student difficulties with regard to comprehending large scales in astronomy, especially distances, might in fact be a deep cognitive issue rather than one resulting from poor teaching. While there are a range of theories that deal with cognition, the primal nature of distance suggested that an embodied cognition perspective would be useful. As such, we saw a cognitive perspective approach, especially that offered by embodied cognition, being one that is fit to enable us to get a deeper understanding of what the results mean. Embodied cognition assumes that the body and the mind are connected in thinking, reasoning, and comprehension. Moreover, embodied cognition through the lens of cognitive linguistics, especially that of Conceptual Metaphor Theory (CMT), explains the nature and structure of metaphorical thought. In this chapter, we explain this view in detail and its relation to understanding astronomy in teaching and learning.

5.1 Introduction

Our starting point is that all thought is ultimately grounded in our sensory motor experience. In other words, as Lakoff & Johnson (1980) state, “thought is physical”. This has two meanings that (1) “thinking” corresponds to the neural activation in the human brain and (2) that “abstract” thought arises primarily from physical experience. Essentially, this means that the body shapes human reasoning and understanding, making the body an important medium for acquiring conceptual skills (Kimmel, 2013). Therefore, as Lakoff and Johnson propose, abstract concepts are grounded metaphorically in embodied cognition. Hence, metaphorical ideas exist everywhere, and they influence how we think, speak, and understand concepts, which are all grounded in our primary physical experience with our environment. This is the basis of the theory of embodied cognition, that all abstract thought is based on this interaction, as such metaphors are conceptual (Reddy, 1979; Lakoff & Johnson, 1980; Hedblom et al., 1995).

Generally, as humans, we hold a lot of knowledge and information about our bodies such as closeness as well as situations (i.e., verticality/ spatial awareness) (Barsalou, 2008). Abstract concepts then draw on this knowledge and information metaphorically, so that we are able to make sense of them. Lakoff and Johnson argue that the conceptual system of humans is metaphorical in character, thus containing metaphorical and non-metaphorical concepts (1980). They further define non-metaphorical concepts as those that “emerge directly from our physical experience” (1980, p.202), whereas metaphorical concepts are then defined in terms of these non-metaphorical concepts. Examples of where these non-metaphorical concepts arise from are: (1) spatial orientations (up/down); (2) ontological concepts (container) and (3) structured experiences and activities (movement) (Lakoff & Johnson, 1980).

Furthermore, we are able to understand concepts of closeness in relationships, as we would say “I feel close to that person” = mapped onto spatial orientation (distance) or “what a warm person” = mapped onto heat. Both of these are suggested to be primary experiences related to an infant being held closely to the caregivers and experiencing bodily warmth (Lakoff & Johnson, 1980; Lakoff & Nunez, 2000). Another example relating to verticality, is when using phrases like “I feel down today”, thus expressing happy to be up (sad is down (downwards)) (Lakoff, 2014). These examples also show that these metaphors are structured and organized completely from recurring experiences that occur in infancy.

Similarly, the meaning of mathematical symbols and (mathematics) is not in the symbols alone, it is also ultimately in everyday meaning that is deeply rooted in embodied cognition (Lakoff & Nunez, 2000). For example, addition and subtraction are abstract concepts which are related to physically “putting things into piles” (building blocks in childhood) (p. 52, 2000). The latter is referred to as a grounding metaphor, as grouping a collection of things together which we unconsciously do in our everyday lives (this is also seen in the indigenous games which we grew up playing in South Africa, called Diketo, a collection of stones put into a boundary and stones added/ subtracted). Another example may be seen in geometry, where numbers are represented as points in a line, thus mapping them out in spatial terms. This is called the linking metaphor, which allows for more conceptualization of sophisticated abstract ideas (Lakoff & Nunez, 2000). These metaphors, however, arise due to mental structures that are based on the recurrent sensory motor experience, thus structuring our understanding of concepts.

5.2 Conceptual Metaphor Theory (CMT) & Image-schemas

Abstract concepts of communication (or semantics) are understood through a conceptual metaphor (Reddy, 1979, Lakoff, 2014); hence, metaphors are the basic means which makes abstract though possible (Lakoff & Nunez, 2000). The Conceptual Metaphor Theory (CMT) was coined by Lakoff and Johnson (2008), and suggested that humans are only capable making sense of abstract concepts by grouping them metaphorically on the concrete phenomena (Lakoff & Johnson, 1980; Feldman, 2006) (as mentioned above). They further argue that the human conceptual system develops through personal physical experiences as we interact with our environment (Amin, 2015). Hence, the conceptual metaphor theory aligns with the claim made by Gibbs (2005), that abstract concepts rely on the inferences made by or generated by the Image-schema. Or rather as Lakoff and Johnson put it, metaphors are based on complex experiential gestalts*(Lakoff & Johnson, 1980). The Image-schema can be seen as basic experimental gestalt that we come to know of based on our experience as infants.

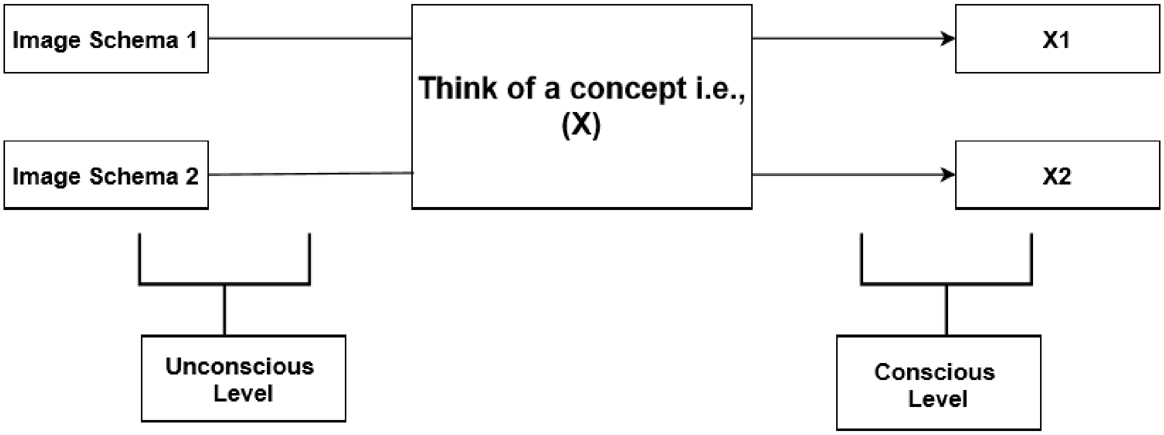


Figure 5.1: Is an incomplete skeleton structure of how we define the thinking/thought process in our work. Where X represents a certain concept; where X1 and X2 are the ways in which the concept X is structured in (i.e., a response), based on the image schema which is activated when one thinks of X

We will refer to figure 5.1, to properly narrate the view of thinking and understanding through the lens of embodied cognition. In figure 5.1, we highlight the notion of how the 'thinking' process occurs. Looking at the figure, we have centralized the notion of 'thinking of a concept'. As such when we "think of a concept", we draw on our recurrent primary experiences or knowledge structures that we have about that concept and in so doing we then structure the concept in terms of that/ those knowledge structures.

Johnson (1987) termed these recurrent knowledge structures that are based on our own primary sensory experiences as Image-Schemas. He further defines them as the recruitment or the gathering of recurring dynamic patterns of perceptual interactions and motor activities which provide coherency, logic and structure to our experience (Johnson, 1987). This means that an Image-Schema is a structure that captures our experiences, and as a structure it holds a deep meaning which we apply in understanding abstract concepts. Therefore, when we 'think' of concept X, we activate 'certain' image-schema(s), and depending on which image-schema is activated, we get a 'certain' kind of response, either X1 or X2. It is important to note that the Image-Schemas are activated unconsciously, while the outputs (X1 and X2) operates at a conscious level.

Looking at figure 5.1, we can apply this to how we understand the concept of 'time'. When we 'think about time' certain image-schemas are activated; for instance, the 'space' image-schema that structures time as 'intervals' and the 'contingent' image-schema which structures time as a 'flow' (time passes) (Lakoff & Johnson). If we structure time as space, we then refer to time intervals, however this does not actually indicate anything regarding the passage of time or the passing of time. Therefore, if one only structures time in this image schema of space, people who speak of time passing may not understand the 'time intervals' as they are operating in another schema of 'flowing time'.

This mental process also applies to when we are thinking about or referring to the concept of distance. Generally, we find that we 'think' of distances in terms of early sensory motor experiences (mostly in terms of space between two points). In astronomy, however, this poses a challenge as the distances and sizes (sizes) are far too large - they lie beyond human comprehension and direct human experience. These distances are so large that they are abstract. Due to this, we need to structure them in some kind of way and to do this we need the imagistic or image-schema.

Image-schemas (Thinking Templates) are acquired in infancy through the interactions with the environment by object manipulation, moving around a room, as well bodily proprioception (Hampe, 2008) and they form part of our experience. They operate beneath a level of conscious awareness (see figure 5.1). We are never aware of the image-schemas that we are using at a particular moment, they are almost natural (Hampe, 2008).

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*Experiential Gestalts are multidimensional structured whole arising naturally within and from experience (Lakoff & Johnson, 1980, p.202)

Why are image-schemas important?

Image-schemas are an important part of what makes it possible for our bodily experience to have meaning for us (Hampe, 2008). They play an imperative role in the emergence of meaning as well as our ability to engage in abstract conceptualization (Hampe, 2008). This is possible due to the former claim that they operate in the unconscious level, thus our actions and responses are based on the Image-schema that we draw on at that time. In our everyday lives, we observe an occurrence of contingent behavior between single object and the other, for example, when we switch on the plug, we expect something to turn on or the light to go on (Mandler, 1992). (This is referred to as the LINKED Path schema, which can also be observed when playing a game, where we take turns). Therefore, they enable the structuring of meaning and words through the sensory-motor (bodily) experiences.

What is the nature of these image-schemas?

Johnson (1989) further argues that image-schemas have a dualistic nature as they are neither body nor mind, but rather the body-mind characteristic is what makes them unique and thus important. There is no disembodiment when talking of image-schemas, rather we recruit bodily-based image-schemas logic to execute abstract reasoning (Johnson,1989). Dewey (1958) pointed it out as well, that image schemas are neither mental or bodily; they are contours of the body-mind, there is continuity that links the physical interactions in the world with the activities of thinking, imagining and reasoning.

Image-schemas and Conceptual Metaphor Theory?

Johnson, (1989), made a claim that image-schemas are mapped metaphorically to more abstract domains forming conceptual metaphors. Thus, image-schemas work within conceptual metaphors, and they enable us to employ the logic of our sensory-motor experience to carry out high-level cognitive operations for abstract entities and domains (Lakoff & Nunez, 2000; Hampe & Grady, 2005). As such, the necessary resources of our bodily experience are appropriated for abstract thinking in the form of conceptual metaphors. Many of these conceptual metaphors are based on schematic structures, such as the CONTAINER, PURPOSE, SOURCE-GOAL and relevant to this current work SOURCE-PATH-GOAL. Furthermore, activating an image-schema gives rise to some form of conceptual metaphor (thinking) which then yields understanding of a concept; for example, life, and in my work, seen with the findings from the AQUED, the use of the conceptual metaphor ‘journey’ is all based on the source- path- goal schema. The source- path- goal schema, is one of the most important schema for human understanding of not only physical movement, but purposive activity, thus there is a source and a goal which is the purpose (Forceville & Jeulink, 2011).

Metaphors are “primarily conceptual and secondarily linguistic, gestural, and visual” (Lakoff, 2014, p.1). Hence the Image-schema structures our experience independent of language (Kimmel, 2013). Prior to language children explore things and gain knowledge on how they work (understanding). Image-schemas fit language into the experience, thus reasoning and understanding precedes language (‘Women, fire and dangerous things’, Lakoff, 1987). It is through a study that employed the perceptual meaning analysis*, where it was found that image-schemas are pre-verbal (no language) as they observed children's interactions, therefore fit language to their experience (Mandler, 1992).

It is important to note that when engaging with concepts, some activation of neural networks is required. Embodied cognition tells us that the reason the specific neural networks are activated is due to the recurrent post-birth (infancy) sensory experiences and inputs. These primary patterns of activation are the basis of thinking templates (Image schemas). These are unconsciously activated on a millisecond time scale when we engage (Johnson, 1989; Johnson 2005). In cognitive neuroscience, Image-schemas are not the product of some non-existent neural modules for producing form, but they are patterns characterizing invariant structures within topological neural maps (Lakoff, 2014). Kant further argues that ‘Imagining’ is not a task of the ‘alleged’ pure understanding or reason in the mind, rather it is an embodied process of human meaning-making (in Johnson, 2005).

In other words, embodied cognition assumes that all cognition that includes the ‘processes in the brain’ are grounded in a variety of perceptual, bodily affection, and sensory motor-processes. This is to be contrasted with the more traditional theory of cognition which adopts a more mentalese, amodal view (Kimmel, 2013). Unlike the traditional approach, the grounded/ embodied perspective offers a unified view of cognition. It emphasizes the dynamic mind-body-environment interactions, together with the perceptual actions in reasoning and comprehension. Embodied cognition further puts emphasis on the role of the body in cognition, where the bodily orientations in relation to spatial awareness as well as metaphorical reasoning are key to understanding abstract concepts.

In addition, it is recognized that metaphors in general are a very big field of study, with a long history (Donoghue, 2014). However, the perspective of metaphor taken in this thesis is that of Conceptual Metaphor Theory (CMT) (Lakoff & Johnson, 1980), which is part of cognitive linguistics (Evans, 2009).

5.3 The journey metaphor and the source-path-goal

One thinking template for distance lies in touch (tap tap one/ haptic), through reachable haptic experience where no locomotion is involved. The second that involves the displacement of the body through movement (locomotion) arises from the source-path-goal schema. The source-

The *Perceptual meaning analysis is a process in which infants create meaning from the perceptual activities, Mandler (1992).

path-goal schema comes about in infancy, for example, when infants cannot reach their toys, they start crawling to get to the toy. As such they move through crawling, from where they are to where they want to be. This involves a sensory motor experience, and it requires effort to be made from a person.

Human movement can be characterized by the progress made from a point, which we refer to as a source, along a path (trajectory) to a certain destination or goal (Forceville & Jeulink, 2011). As mentioned, the source-path-goal schema makes up part of the foundational schemas of human conceptualization, together with the container schema and linked schema (see list of schemas in appendix G).

In chapter 4, we highlighted that the main result was related to a domain transition in student explanations, which occurred at a level we did not expect which was that of motion (movement). This showed that student explanation domain happens much earlier than we initially thought, as well as how we assume in teaching astronomical distances. In Chapter 6, we give an account of a theory-based activity (a journey), which was based on the findings from the data in chapter 4 to structure a teaching activity. The journey activity was constructed in order to activate this Source-Path-Goal template so that this would be the basis of student thinking during the subsequent activities in learning distances in Astronomy.

Chapter 6: Exploring the Source-Path-Goal schema for teaching distances in Astronomy: an account of a journey to the edge of the observable UNIVERSE along UNIVERSity Avenue

Summary

Understanding astronomical scales, especially distances has proven to be a challenge for students in different parts of the world as shown in previous studies. We contend that poor teaching cannot be the only reason attributed to the poor understanding of students but rather there is a deeper cognitive issue that lies with the comprehension of these large scales. To further explore this, we developed an instrument called Astronomy Questionnaire: Understanding the Engagement of Distance (AQUED), which elicited how students intuitively think about the concept of distance. The results of this questionnaire are outlined in chapter 4, where we found that students operate in different domains of explanation when describing tangible and intangible distances. In this chapter, we report on the practical activity that was grounded on the results and findings from chapter 4 with AQUED.

These results pointed to a fundamental conceptual metaphor of a journey. The notion of conceptual metaphors comes from the cognitive linguistic perspective of understanding human cognition. Conceptual metaphors are built from many non-metaphorical concepts which we use to think and therefore make sense of the world. These non-metaphorical concepts are called image-schemas and one that proved to be relevant for this work was the Source-Path-Goal schema. Using this image schema (Source-Path-Goal), in our attempt to provide a theory-based intervention, we framed it as ‘a journey to the edge of the observable UNIVERSE along UNIVERSity Avenue’. This teaching intervention was piloted in 2020 and the IAQ was administered to measure any learning gains between the pre-test and post-test. The post-test results show evidence of improvement in the ranking of distances especially from a different location in space unlike the surface Earth, and the comparison between the 2018 post-test and 2020 post-test is presented in this chapter.

6.1 Background and Introduction

In chapter 3, we highlighted the study that was carried out at the University of Cape Town in 2018. Using the size and distance questions from the Introductory Astronomy Questionnaire (IAQ), we probed students' notions of these aspects in astronomy. This questionnaire was administered as a pre-test and post-test, with a carefully structured teaching intervention that was implemented. The results from the pre-test to the post-test showed some gains for astronomical sizes but not for astronomical distances. This result was similar to that of previous studies in AER (Rajpual et al., 2014 & Rajpaul et al., 2018), where students performed poorly on questions regarding the sizes and distances of astronomical objects.

Since the results for astronomical distances did not improve in our study (see chapter 3 for full details), we then implemented the grounded theory method to probe students' ideas about distances. We developed the notion of a distance spectrum* with both ends of the spectrum representing intangible distances (smallest- atomic and biggest distances- astronomical). We chose three distances from the distance spectrum, which we used to probe how students engage with distances: 7 m, 100 km and 384402 km (to the moon). The questions restricted the visual modality of the intended audience. We specifically did this so that we could find out how students think intuitively about distances, starting with everyday distances (tangible).

In probing student engagement of astronomical distances, we constructed questions that were framed as an explanation to a blind friend, in order to limit the visual modality as Grady (1997) argues that distances can be calibrated through the visual sensory modality. The data showed that, for a tangible distance (7 m) students operated in the body calibration domain, in which most responses were based on sense of touch to help the blind friend with getting a sense of 7 m distance. For a distance of 100 km, most of the students switched to a different domain of explanation from a body calibration domain in the first question to a body movement domain in the second question.

Hence the following categories of students' thinking were identified:

A Distances that can be explained by extending body parts and counting steps

B Larger distances that spontaneously involve switching over to walking and the notion of a journey

C Distances that include a time explanation.

The movement domain was identified in most responses by using the "journey" conceptual metaphor which alludes to a change in location or position of the person. This brought us to a conclusion that understanding tangible distances outside the haptic mode, means mapping them out on a 'journey metaphor'. Following from the previous chapter (Chapter 5), we know that metaphors are embodied.

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*Distance spectrum is an entire range of all known distances, from the smallest (atom level) to the biggest (astronomy level)'

A conceptual metaphor that plays a role in our work is that we use expressions such as "life/ grief/ a career/ recovering etc. is a journey". This is explained in primary terms of an infant wanting to fetch something (a toy) that is beyond immediate physical reach and therefore resorts to crawling from a starting point along a path to a goal (Lakoff, 2014). The so-called 'Source-Path-Goal' schema (structure) is activated through the basic activities involving a person moving and changing location. Therefore, teaching students large distances in astronomy requires a change in the explanation domains, in this case a movement domain before switching to a time domain, since we have identified that the change in explanation domain occurs within distances that are familiar to students (between metres and familiar kilometres).

The data in chapter 4, show a distinct difference between counting steps (quasi-static, Lakoff and Nunez, 2000) and walking which is where we humbly suggest that two different primary domains are being drawn upon. We called the first Domain 1 (D1) and the second Domain 2 (D2). Following on from Barsalou (2008) where he argues that thinking is synonymous with running a mental simulation, we suggest that activating D1 leads to comprehending distances up to a particular level which we term the Distance Horizon (DH). Thus, D1 allows for simulation up to DH1 while D2 allows for an image schema to play itself out in a way that allows for a larger distance horizon DH2. A schematic diagram (figure 6.1) depicting this is shown below with a third Domain posited as the time domain, as it would appear to be the next "logical" step, which the data has also shown (see chapter 4).

Our previous teaching intervention, covered in chapter 3, gave a full account of how the 'carefully planned teaching sequence' was carried out. Through the data, we have come to realise that the interventions were previously structured and carried out in the body calibrations (stacking) domain (D1). The kinesthetic activity that the students did in chapter 3, was in the body calibrations (non-moving) domain, while the aim was to teach students to understand astronomical scales, which are beyond the distance horizon, which the first domain (D1) offers. This proved to be problematic as the distance results in chapter 3 showed. Therefore, the data (in chapter 4) has demonstrated that there is a need to change to the second domain (D2-movement domain) of explanation in the interventions to help students understand these distances.

A journey is a conceptual metaphor that is used for understanding many abstract concepts such as love, grief, healing, life, a career and so forth. A journey conceptual metaphor is a familiar and a generic one, used across many languages, and applied to many contexts, experiences and processes as mentioned (Feldman, 2006 and Lakoff, 1980). Therefore, since the journey metaphor is used in different ways, our data showed that large distances, especially in astronomy, could apply the metaphor to increase the conceptual understanding of distances.

However, to be able to activate this conceptual metaphor (journey), in astronomical distances, we need to go a level below this, which is the image schema. Forceville and Jeulink (2011) argue that the schema involved in understanding movement or moving objects is one of the most fundamental schemas of human conceptualization; the Source- Path- Goal schema. Level one of the Source-Path-Goal image schema is the spatial primitive, e.g., a PATH. Children notice things/objects in motion; the path on which they move, more than how fast the object is moving (Johnson, 1987). Furthermore, Forceville and Jeulink, (2011) show the application of this schema in their work, where they describe animated films and how humans are able to understand the anime (cartoons).

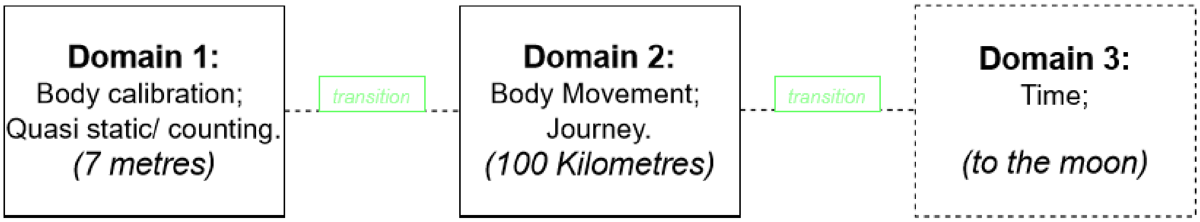


Figure 6. 1: Shows a schematic diagram of the explanations domains/ phases that emanated from the data in chapter 4. More so, each domain allows for a mental simulation to a certain distance horizon which is determined by the domain in which one is operating from.

6.2 The Design of the Activity

We developed a practical activity grounding it on the theory of embodied cognition and making use of the source-path-goal schema to activate an understanding of large distances. After much discussion with the research group and my supervisors including the course lecturer, we named the practical activity “The Journey to the edge of the observable UNIVERSE along UNIVERSity Avenue”. The Source-Path-Goal schema involves certain elements such as (i) source - the starting point, surface of the Earth (RW James Building, North end of campus), (ii) a traveler - the students, taking Astro1000F, (iii) a path - University Avenue (main road on campus), (iv) unintended goal – the hypothetical edge of the solar system (South end) and (v) intended goal – an intended goal is the edge of the observable Universe. The Astro1000F class is a huge class (>100 students), therefore we had starting points and ending points on both sides of University Avenue (on the left and right of the road). Figure 6.2 is a map of the University of Cape Town, we have highlighted the north-end and south -end of the University Avenue, where the journey begins. This makes Part A of the activity.

Astronomical objects were spaced out along the path according to their distances from the surface of Earth. Students were required to start walking from either the North-end or South-end, which is on university avenue to get to the edge of the universe. However, University avenue only allows students to get to the edge of the solar system, but the students are not aware of this during their walk. While walking, students needed to record the information (distances) of each astronomical object they arrived at, indicated by coloured pieces of cardboard taped to the ground (i.e., figure 6.3). Each card had an image or visualization of the object and three numbers listed as A, B, and C. The numbers represented the distance to each object from the surface of the Earth in different units – but the units were not provided. This could also be classified as an unrealised path, which is a path that was not seen as part of the journey, and includes students trying to make sense of the information given on the objects. The information (distances) on the astronomical object cards was recorded in a table as students continued to walk towards the goal. When students got to the end of University Avenue (most of them start predicting how far the edge of the universe would be from them at that point), then they received instructions from the tutor to continue with the walk. Figure 6.3 shows one of the astronomical objects which students needed to record while on their walk.

This walk is extended or rather the journey continues with Super-walker, which makes part B of the activity, who walks at a speed of light (3*10^8 m/s). The introduction of super-walker introduces two extensions of the SPG schema: speed and time. Knowing how fast super-walker moves, allows us to know "how long" they can take to get to certain places in the universe. Using calculations, students were required to find the location of the super-walker in space as well as how long it would take super-walker to get to other astronomical objects. Thus, mapping out the distance in terms of time (DH3). As students tried to figure out the location of the super-walker, the more astronomical objects they encountered (stars and galaxies) before getting closer to the edge of the universe.

This activity ended with students using all the information gathered from their physical walk on UNIVERSity Avenue and super- walker's journey to the edge of the observable universe. Students were then required to develop their Universe accurately on the floor of the Hall with the relevant astronomical images - they are provided with these images so that we know that everyone has the same set. The full Worksheet is in appendix F.

After students completed all activities, we administered a short evaluation that was aimed at measuring learning, enjoyment, and their overall experience. This evaluation was aimed to aid towards modifying and refining the activity further, as it was the first time piloting this activity.

RW James Building.

North- end

Sarah Baartman Hall

New Lecture Theatre

South- end

Figure 6. 2: Is a map of the University of Cape Town, Upper Campus. The highlighted parts indicate the starting and ending points of the "journey", which are the South-end and North end of the campus. Sarah Baartman Hall is in the middle of University Avenue.

Figure 6. 3: Shows one of the astronomical objects that was on UNIVERSity Avenue. This is one of the objects that the students came across during their walk. Students were required to record the information below on that image (Which is the distances from earth, in in three different units of measure) and later discuss what these numbers mean or what they are representing.

6.3 Administration (Description of doing the activity)

This activity was piloted on a new cohort of students that were enrolled for the introductory astronomy course at UCT in 2020 (before the covid-19 pandemic hit in March 2020). As outlined in chapters 3 & 4, the class is very diverse, in terms of backgrounds, cultures, languages and they are enrolled for different degrees. The total number of students registered in 2020 was 124, the biggest we have had since we started these studies.

The activity was done during the second week after teaching had commenced in February 2020. We scheduled the activity on a hot Wednesday afternoon (we did not plan for the hot weather), which is the course's practical class time (thus compulsory for the students to attend). The lecturer announced that the practical was going to take place at main hall; Sarah Baartman Hall (the main hall of the university, which is at the middle of University Avenue, see map figure 6.2). When students arrived at the hall, they were randomly assigned into groups of 5. As a group, students received the first worksheet with instructions for them to go to the starting points of their journey to the edge of the observable Universe (RW James, North end of the road and New Lecture building, South end of the road).

The course tutors were present during the practical, to assist us (the lecturer and I) with giving students instructions as they collected the first worksheet, and throughout the journey outside. When the students arrived at their last physical destination, the tutors instructed them to return to Sarah Baartman Hall, where the second worksheet was handed out. During the walk, students were required to record the information that each astronomical object had. This was to promote the students to engage with each other through discussions of what they thought about what that information represented. This information was included so that the students could use it to continue the Journey with Super-Walker (Worksheet 2). The third and last worksheet required students to represent the universe to scale in the hall, using all the information gathered during their physical walk and Super-Walker journey. The course tutors were available to assist students throughout the practical.

After the practical activity, students filled in an evaluation form (individually). The evaluation form measured the following areas: enjoyment, learning, and overall experience (see appendix H). The aim was to get input from students on how we can improve the activity in the future. The evaluation form was filled in anonymously by the students so that they could reflect honestly on the activity without 'fear' of being identified by the lecturer.

As students were doing the activity, the course tutors and I carried out unstructured observations, whereby we did not have a list of the things we particularly wanted to focus on, but rather, we observed as students did the activities, writing free descriptions of what was observed. One of the disadvantages of unstructured observations is that we can never fully record everything that is happening, especially in a classroom setting (Bertram & Christiansen, 2014). However, since this was a big class, we observed groups of students as we moved around to avail ourselves to all students who may have questions.

The IAQ (SD (Size and Distance)), post-test was administered to students in the next introductory astronomy lecture the following day. The change between the pre-test and post-test distance question was similar to changes made in 2018 (chapter 3), where the starting point for ranking distances, was from Uranus instead of the surface of Earth. This questionnaire was completed individually by the students.

6.4 Results

In this section, we present the percentage of students who correctly ranked the distances in the post-test IAQ from both 2018 and 2020, where the reference point is from the planet Uranus. To add context, we also show the percentage of student that ranked the distances correctly in the pre-test IAQ from both 2018 and 2020. We also present the results from the student evaluations, which give insights to student reactions with regard to the activity and most importantly what the students have learnt.

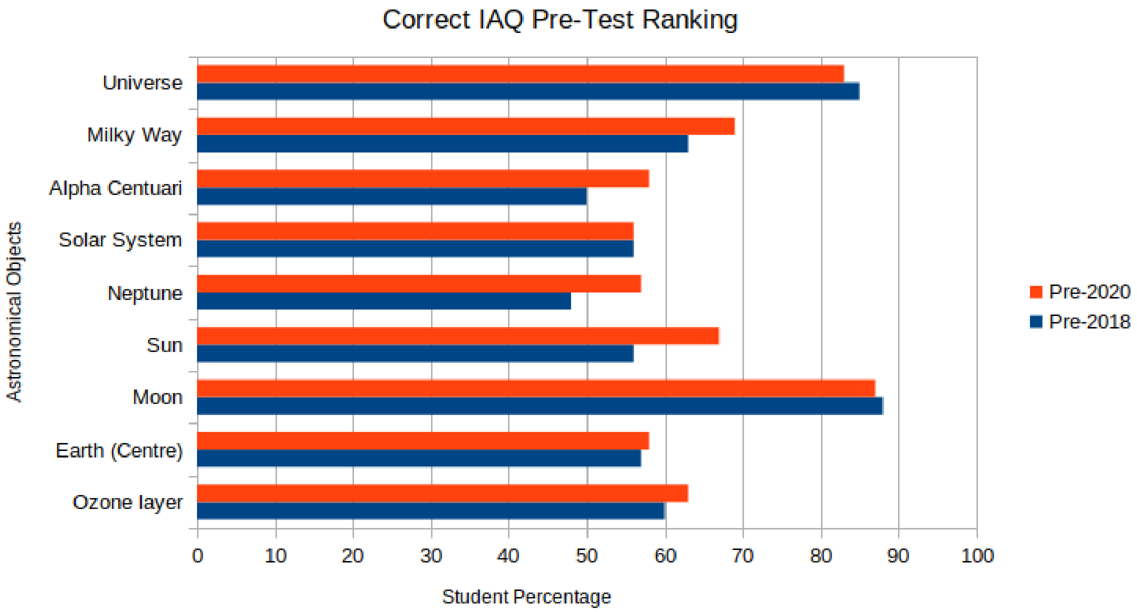


Figure 6. 4: Is a double bar chart that shows the percentage of the correct student responses from the Introductory Astronomy Questionnaire for the Distance ranking pre-instruction broken down by year. The blue bars represent the year 2018 while the orange bars represent the year 2020. The bar graphs show the results prior to teaching, with the surface of Earth as a reference point.

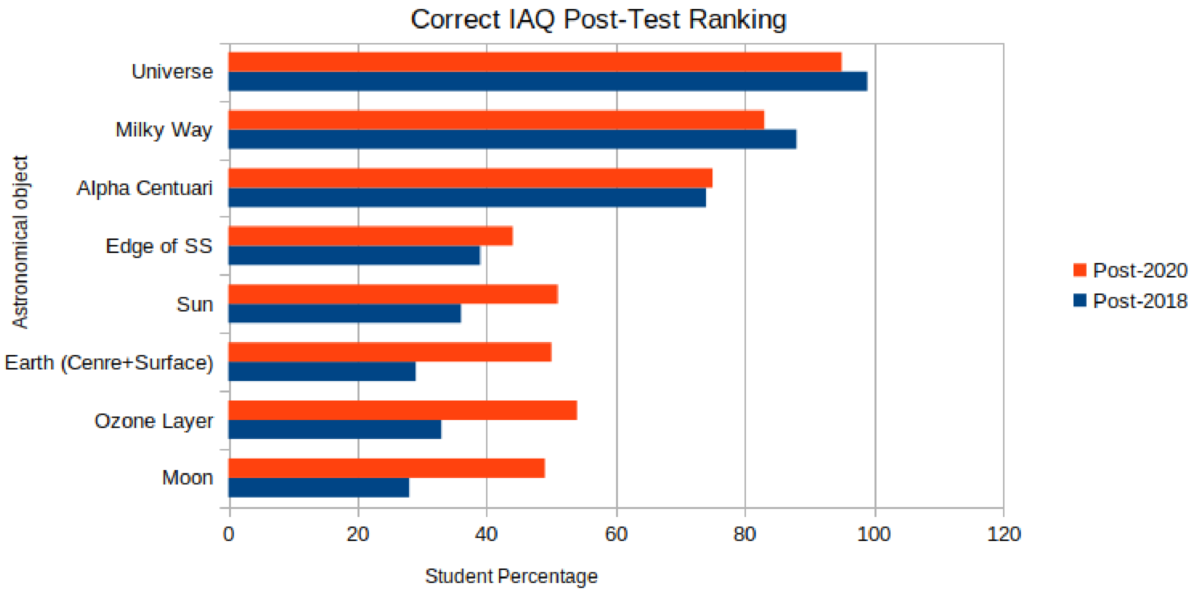


Figure 6. 5: Is a double bar chart that shows the percentage of the correct student responses from the Introductory Astronomy Questionnaire for the Distance ranking pre-instruction broken down by year. The blue bars represent the year 2018 while the orange bars represent the year 2020. The bar graphs show the results prior to teaching, with the surface of Earth as a reference point.

6.4.1 IAQ (SD) 2020

In 2018, the size ordering task (using images to rank objects according to their relative sizes) and the distance ordering task from the surface of Earth were carried out. These activities aimed to enable students to develop a better understanding of astronomical scales and sizes, especially celestial sizes and distances. Knowledge gains were observed after the activities for celestial sizes through the post-test IAQ (SD), however this was not the case with astronomical distances. In fact, the post-test distance results were worse than the pre-test (see chapter 3). In 2020, we administered a new teaching approach and activities for teaching astronomical distances, which were based on the data collected in 2018 (see chapter 4). This activity was called the "journey to the edge of the observable UNIVERSE along UNIVERSity Avenue" and we have outlined the details of this activity in section 6.2 of this chapter.

This section provides a comparison between the student percentages that had ranked the distances from Uranus correctly in the post-tests IAQ studies for both 2018 and 2020. The post-test Introductory Astronomy Questionnaire (SD) is similar for both years, with the frame of reference (a starting point) being the planet Uranus. The post-tests were administered after the teaching interventions had taken place in each case. The analysis of the 2020 post-test results were analysed the same way as the 2018 data, with matrices that show student ranking tasks (see chapter 3). In Figure 6.4, we show the pre-test results from both the year 2018 and 2020. As presented in chapter 3, a fair percentage of students (~30%), which is a quarter of the sample incorrectly ranked the distances from Earth in 2018 (especially the ones within the Solar System as well as the closest star). The 2020 distance ranking pre-test results are also similar to these (and also similar to the IAQ-N results), where there the different is negligible. Figure 6. 5 shows the percentages of students who ranked astronomical distances from Uranus correctly.

Figure 6.4 shows the percentage of students that ranked the astronomical distances correctly from the surface of Earth. Since this is a familiar starting point, one would expect that ranking astronomical objects from this perspective is a manageable activity; while the results show that the mean average percentage of students who ranked objects correctly is around 62% in 2018 and 66% in 2020. A quarter of students from both samples (2018 & 2020) were unable to rank astronomical distances correctly. In both cases, 2018 & 2020, teaching and learning interventions were employed in the hope to increase student knowledge regarding astronomical distances.

From figure 6.5, it is evident that students of both groups performed better with ranking objects that are outside of the solar system than those within the solar system. The results for Alpha Centauri, which was previously (in the pre-tests) ranked to be within the solar system, improved, with both student percentages above 70%. For the Milky Way galaxy and the edge of the observable Universe, percentages are about 80% for both cohorts of students, which is a positive result. The difference in percentage of these three objects, for the year 2018 and 2020 respectively, is small ~5%.

With regard to the objects within the solar system, the 2020 cohort showed some improvement in the distance ranks. This improvement is especially seen with the Moon, the Earth's atmosphere (Ozone layer), Earth (centre+ surface), and the Sun. While the results are relatively poor within the bigger picture, this was the first time we recorded an improvement in a ranking task from a different frame of reference other than Earth or the Sun. More so, the improvement is about ~15% more than the 2018 cohort of students. The Norwegian middle school students, also scored poorly in their post-test, which was carried out after the best science practices (see Chapter 3). Having seen some improvement with the 2020 cohort, we can deduce that the teaching intervention employed is worth piloting again.

In addition, we argue that this teaching intervention has produced a positive result, as it was purely grounded on student data, which was further analysed with a cognitive lens. As such, developing an activity that draws on students' primary cognitive experiences enable them to draw on these cognitive resources through the 'journey through the edge of the universe' walk, to understand the extent of the observable universe. The explanation domain that we activated with this activity was the "moving/ movement" domain, which was the second domain identified from chapter 4. This domain involved the fundamental cognitive resources invoked in walking/journeying, which is that of the Source-Path-Goal image-schema.

6.4.2 Evaluations

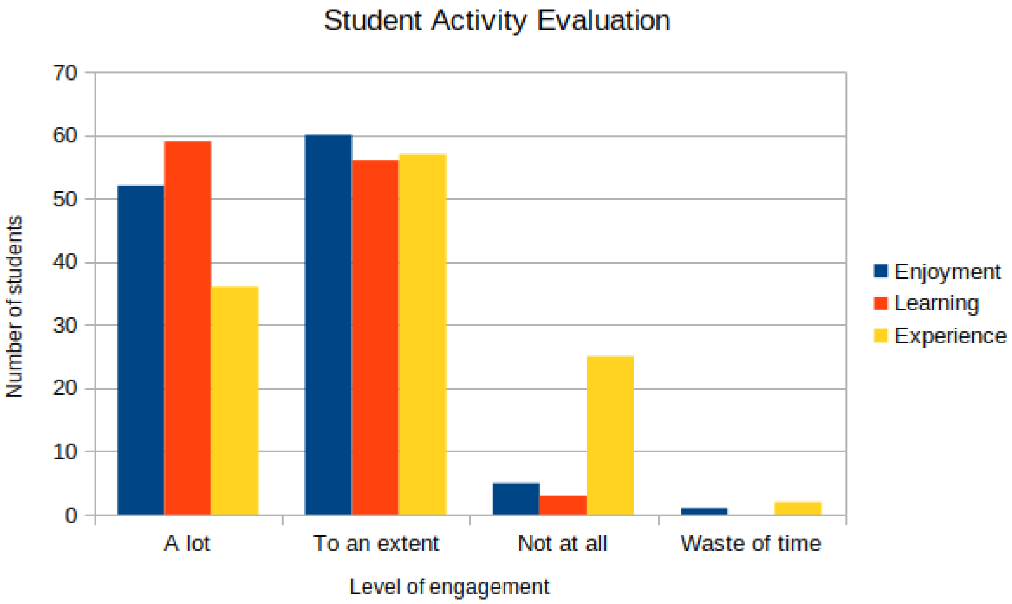


Figure 6. 6: Shows the results of the student evaluations, where students were probed on the level of engagement during the Journey activity. Three aspects of engagement were probed namely: Enjoyment, Learning and Overall Experience.

We measured the level of engagement by administering a short evaluation form (Appendix H) that students filled in after the practical activity. The questions asked in the evaluation form were framed as a Likert scale which enables us to measure students varying attitudes and opinions. The students needed to provide answers to this evaluation, by first choosing an option, which is a number on the scale and then provide a written response for their choice. The scale had only 4 options, the first being a positive response, as the number increases the less positive the answer is (1= excellent and 4= worst). The questions asked were based on three factors: enjoyment, learning, and overall experience. Tlowana (2017) study showed that it is important to separate these factors of engagement, as students tend to offload emotional responses (after practicals) before fully reflecting on their learning and experience authentically. Hence, we separated these factors by use of the feedback evaluations.

Figure 6.6 is a bar graph showing the results from the evaluation forms. In a class of 118 students, 52 indicated that they enjoyed the activity 'a lot', an example of a response from a student that chose this option:

> "*I enjoyed this because we didn't have to be in a room the entire time and discuss. Instead, we went outside in groups which isn't something we always get to do*".

Another 60 of the students indicated that they enjoyed the activity 'to an extent'. These are some of the written responses which were provided by the students:

> *"it was fun, but tiring also, especially walking in the sun";*
>
> *"it was fun but required a lot of thought and accuracy".*

These positive responses (from both 'a lot' and 'to an extent') make up 90% of our student sample. This demonstrates that the practical activity is fun for students to partake in, and the group work had a positive impact in student engagement as they were working together from the beginning of the activity.

In terms of what was learned or rather whether the learning took place, 59 students indicated that they learned 'a lot' such as these responses show;

> "*Just hearing the numbers doesn't really give me a clear picture of the universe, this way, I really got to understand what those numbers mean*".

A further 56 indicated that they learnt 'to an extent' and these are some written responses that support their choices;

> "*I learnt about how small earth is compared to the observable universe through the tasks we did today and also the distance calculations"*

and

> “*Learning the fact that the different astronomy objects are really far apart from earth as well as each other”.*

These written responses have demonstrated that what we had intended to teach in this practical activity has been learnt by 97% of the student sample. This positive feedback has made us more optimistic about this activity being useful for teaching and introducing astronomical distances.

In terms of student overall experience, 36 of the students indicated that their overall experience was generally 'great', and 56 indicated that it was 'good to a certain extent', while 25 indicated they did not have a good experience at all. Those that had a valuable experience with this practical stated in their written responses that they enjoyed working in groups doing different activities. Those that indicated that they did not have good experiences mentioned that they did not like the groups that they were working in (as seen from this comment by a student: *“some individuals dominated the group and did not let other participate”*), the activities were challenging for them, the practical was a bit too long and they did not enjoy the walk in the sun. There was not a significant percentage of students who said they did not learn much, as such those were mostly students who did not enjoy the activity and had a bad overall experience.

Overall, based on these outcomes, students’ level of engagement is incredibly positive, thus we are optimistic about this practical activity being an effective methods of teaching distances in astronomy. Moreover, this activity has a fundamental empirical/ experimental grounding, which is that of cognitive perspective, which has given us insight into the issues of cognition, thinking, understanding, and reasoning, even beyond teaching and learning astronomy.

6.5 Discussion

6.5.1 Interactions between students

Based on my observations during the practical activity, students seemed to have good interactions with one another as they walked along university avenue (they organized themselves in groups). One of the things that enhanced these interactions was the information about the astronomical objects that they had to record as they walked. This information represented the distances of the objects from the surface of the earth (which is their familiar place), however, as mentioned, these distances were given without units and without explanations. Thus, students needed to discuss among themselves what these numbers were and what they meant. At the end of their walk, they had discussions together with the tutor (at that point), about what these numbers were and took a guess of their units. Some guesses were correct while some guessed incorrectly, thus the tutor was available to guide students' thinking. Before proceeding to the next activity students had an idea of these numbers and their units. The other worksheets required students to move between these units in their work which also required discussions between the students (since this class is diverse, we cannot assume that they would all have the same level of mathematical competency). As such some of the students mentioned that the calculations were a bit difficult for them in the group and it took them longer to figure out some questions.

6.5.2 Content Level

The content (knowledge) covered in the practical activity is part of the course learning outcomes as outlined in the course manual. The introduction of the concept of scale and size is introduced in the lectures before the students came for the practical activity. Practicals are there to reinforce and support the teaching as well as to offer another way of explaining and exploring the content taught. Based on the fact that the students had some introduction to these concepts beforehand, the content covered in the practical activity was, therefore, appropriate for the students as it was not too difficult, and it drew on student prior knowledge (both conscious prior knowledge and unconscious (Image-Schema) prior knowledge (which we used to simulate the Source-Path-Goal schema).

Some of the comments from students' evaluations indicated that the content and applying it was somewhat challenging. In most cases, the mentioned 'difficulty' was with the questions where students needed to do calculations and conversions between Kilometres, Astronomical Unit and Light years; as well as finding the appropriate scale to use to represent the Universe accurately on the floor of the Sarah Baartman Hall. A possible explanation could be that after having walked on UNIVERSity Avenue, students may have been overwhelmed at how large the observable UNIVERSE is, hence when they were trying to represent it in a smaller room, it took them a long time to figure out what they needed to do.

We also observed students trying various interesting methods to measure out the universe, such as lying on the floor in the hall, counting the block tiles in the hall, and using their feet or hands. As a starting point, students needed to decide on which unit of measure they would be using, out of the three given to them (km = kilometres, AU = Astronomical Units or ly = light years). It took students a while to figure out that they could use the log scale, in km or ly to represent the universe in a smaller venue. This, however, was not beyond the student level of comprehension, as in this activity students were applying the knowledge learned and creating a similar model (as the walk) but now with information at hand.

I generally think it was good that this activity was done after the students have been introduced to the terminologies that are normally used in astronomy, to familiarize them with the field. By the time students take part in this practical activity, they have been taught about their place in the universe, the earth, earth and moon system, units of measure in astronomy, as well as sizes of astronomical objects. All this new information was crucial for them, as they could have meaningful conversations about the information that each astronomical object had and what it meant.

The journey has proven to be an important conceptual metaphor to teach and learn about distances (in astronomy). This conceptual metaphor has been useful for understanding many abstract concepts which allude to something being a process in which the body is being displaced between two or more points (such as recovery, from being sick to the process of healing). In planning to modify this activity with the pandemic in a mind, we need to incorporate this conceptual metaphor to activate the human primary experiences of the source-path-goal schema.

I acknowledge that this particular activity is a challenge for online learning, especially when we aim not to introduce the third Domain straight from the first go and skipping the movement domain. The third domain of explanation which we identified was ‘time’. At the beginning of our work, we had initially thought that most of the students would quickly switch from a tangible domain to a time domain, which led us to speculate that large distances might be structured in terms of time which in turn is structured in terms of tangible space (Borosky, 2000). However, when many students actually described a journey without time it led to the Source Path Goal Schema which is a basic Image Schema, which is said to be the most fundamental image-schema associated with movement (Forceville & Jeulink, 2011).

Furthermore, due to language, space and time share a conceptual structure (Borosky, 2000). This is because of the spatial relations (seen in the words such as ‘behind schedule’ or ‘ahead of’) that are useful for thinking about time as temporal information (Borosky, 2000). This claim is supported by Lakoff & Nunez (2000), who held that humans conceptualize time primarily in terms of a tactile domain which is that of space (i.e., bodily calibrations domain) (Buonomano, 2017). Therefore, in chapter 4, the third distance (384 402 km – to the moon), showed a decrease in the movement domain, while the bodily calibration and time increased slightly. This points out to the latter claim, that we need to draw on spatial relations and bodily experience, as time on its own is fully understood by metaphorical terms (whether intervals, or moving time) (Lakoff & Johnson, 1980).

6.6 Conclusion

The key experimental findings were that, as distances increased, different domains or modes of thinking were employed to makes sense of them. In this chapter, we have highlighted the theory-based activity which we developed after we had interpreted experimental findings from chapter 4 from a cognitive perspective offered by embodied cognition. Using this explanatory framework, we found that the movement domain of explanation was closely linked to one of the primary conceptual metaphors, which is that of a 'journey'. This conceptual metaphor is built on fundamental non-metaphorical concepts that are recurrent structures that are based on our concrete experience as we interact with the world, called image-schemas.

In our work, we referred to an image schema as a 'thinking template' as it is a structure of thinking and knowledge. One thinking template or image schema that is closely linked to the conceptual metaphor journey is the Source-Path-Goal schema. Using this Source-Path-Goal, we then developed a practical activity for students, which we called 'A journey to the edge of the observable UNIVERSE along UNIVERSity Avenue', which involved a physical walk. Having identified the ‘thinking’ framework allowed for a research-based construction of learning activities that lead to sense-making. Thus, the notion of the Source-Path-Goal Thinking Template/ Image-Schema was used to create an activity that would trigger this mode of thinking for large scale distances.

We piloted this activity with students who were enrolled in the introductory astronomy course at UCT in 2020. The post-practical test that showed an increased understanding of the distances – refer to Fig. 6.3 (b). Students also filled in an anonymous evaluation form, which was measuring student level of engagement by focusing on these three aspects: (i) Enjoyment (ii) Learning, and (iii) Experience. From these aspects and the post-test results, we have enough evidence to be optimistic that this activity is a useful tool for introducing and teaching distances in astronomy. The one aspect that makes this activity unique is the fact that this is closely linked to the fundamentals of the mind, thought, and reasoning. Hence, how we make sense, think, and the reason is based on our primary experiences that are essentially embodied.

This chapter has given an account of how the experimental findings, interpreted in an explanatory framework (embodied cognition, see chapter 5), were used as a basis for developing a practical activity. This practical activity was framed as a journey through the universe, to activate the Source-Path-Goal schema for students to conceptualize astronomical distances better. In this chapter, we reported on the outcomes of this practical activity. We are optimistic that this practical activity has shown positive results and feedback, which has unlocked the major challenge of teaching astronomical distances effectively for comprehension.

Chapter 7: General discussion and conclusion

7.1 Introduction

This chapter begins with a brief overview of the study, which gives insights to the context of the thesis and summarises the main findings. These are presented as reflections which provide a summary of all the important choices we made during the study, for example: the framing of the questions, the analysis, and the theoretical aspects of the study. The chapter ends by showing the contributions of the work as well as offering the recommendations for future work.

7.2 Overview and answers to research questions

Astronomy deals with many difficult concepts which at first sight appear trivial, such as the notion of astronomical sizes and distances. This notion of scales in astronomy showed to be a challenge in many reported studies in AER (see chapter 2), and recently in studies using the Introductory Astronomy Questionnaire (IAQ) in both South Africa and Norway. One of the key findings of the IAQ which led to the current research was that: (1) students performed poorly when answering questions regarding astronomical sizes and distances, and (2) that this performance proved to be a proxy for overall success in the introductory astronomy course. Different teaching approaches and activities were employed in both cases (South Africa and Norway); however, increased learning gains were recorded for astronomical sizes but not for astronomical distances. Therefore, we argue that the teaching employed was not successful in both contexts. The authors in both papers (Rajpaul et al., 2014, and Rajpaul et al., 2018) argue that this poor result with regard to astronomical scales, especially distance, is due to a possible cognitive issue, as well as poor teaching and the lack of teachers' astronomical knowledge. Following these findings, as a first step the guiding research question was:

1. To what extent do introductory astronomy students have difficulty with astronomical distances?

The Introductory Astronomy Questionnaire (IAQ) with focus on Size and Distance i.e., a truncated set of questions from the IAQ, was used as the instrument to collect data on student knowledge of the sizes and distances of astronomical objects in the 2018 study. It should be pointed out that cognizance was taken of the possibility that the results from a set of questions embedded within a larger instrument might not in fact activate the same responses when answered within a “bald” context. This would certainly be the case if for example a single scenario were posited and a number of questions were answered in sequence (Allie et al., 1998) as the cognitive resources would be primed along the way and would most likely influence downstream questions. However, the nature of the IAQ is such that most of the questions are independent of each other and any effect as described was felt to be negligible.

The IAQ_SD questions were framed as ranking tasks in which students needed to rank the given astronomical objects in the order of increasing sizes or increasing distances in each case. These ranking tasks were analysed using a coding system to group the results into matrices that provided information on how astronomical objects were ranked by the students. For example, the smallest astronomical object in the size ranking question is the planet. In the absolute ranking matrix, the planet is in position 1, followed by the next astronomical object bigger than the planet. Therefore, in the order of increasing size, the objects are: (1) Planet, (2&3) Star/Sun, (4) Solar System, (5) Galaxy, and (6) Universe. While the majority (~70%) of students ranked the planet in position 1, a significant number (~29%) of students also ranked a star in position 1, asserting that a star is typically the smallest astronomical object. Research in astronomy education has mentioned that students generally face challenges with astronomical scales however "to what extent?" has been a pending question.

The IAQ has therefore enabled us to identify the challenging area/s in astronomical scales through the ranking task. With sizes, as mentioned, the main challenge lies within student everyday experience of observing stars as little points in the night sky, while another challenge is with not recognizing or classifying the Sun as a star. Regarding distances, challenges were recorded where students (1) overestimated the extent of the ozone layer (Earth's atmosphere), and (2) the ranking of objects between the moon and the edge of the observable Universe incorrectly, including placing the star (Alpha Centuari) within the hypothetical edge of the solar system.

The first teaching intervention in which students took part in 2018 improved the result of these challenges in the post-test questionnaire, especially for sizes. However, with regard to distances, there were gains recorded with objects outside of the solar system, but not the ones inside the solar system. The intervention seemed to have had a positive result with astronomical sizes and this was not seen with distances. Therefore, from these results we concluded that the issue with distance is more complex as none of the interventions that were employed in South Africa (2018) as well as in Norway led to any improvement in student knowledge of distances. From this, we confirmed that the suspicion of the authors of 2018 that the performance was not only due to poor teaching, but that there is a deeper issue that lies with comprehending distances outside our immediate experience.

Consequently, the question we asked was: "Well, what can be done? What can we tell teachers and practitioners to do?". There is no one simple answer to these questions, hence in this thesis, we then probed student basic knowledge of distances. Therefore, the next phase of the research was carried out in the spirit of the Constructivist Grounded Theory Method as described by Charmaz (2006), and Charmaz & Bryant (2011) which involved constructing an instrument with the aim of eliciting (written) responses related to students' thinking about different distances. The questions asked were framed as a response to a friend, instead of an explicit or implied authoritative figure (i.e., instructor or no audience). In addition, we constrained the response space by specifying the friend to be blind, thus limiting responses that would include sight, for example, “can you see that 7 metres is about the distance to that door”. The study by Allie et al., (2008) showed that the students share more information when questions are posed to a friend or someone younger than them, other than with an authoritative figure, such as a teacher, who is deemed to be more knowledgeable. Therefore, the guiding research questions investigated the following:

2. How do students think about distances?

The data from the Astronomy Questionnaire: Understanding the Engagement of Distance (AQUED) were analysed using the Grounded Theory Method approach. The data that were produced were analysed by (i) identifying the key idea for each individual response after a close reading and (ii) grouping cognate key ideas to form larger categories. As with any such approach many cycles of grouping and re-grouping were performed before a final set of categories were formed. However, as pointed out in Chapter 4, section 4.2, there is no one particular way in which a Grounded Theory Method approach is carried out and the process itself is iterative. In other terms, even at the level of a key idea, re-reading an explanation often meant re-interpreting the ideas or modifying them.

As we grouped the key ideas into larger categories, a particular challenge with this method, seen especially in the first question, was in defining and categorizing “pacing, counting steps'' and “walking”. The issue arose when determining that “pacing and counting 7 steps”, and “walking 7 m” were not actually the same thing. Analysing the second question for 100 km offered more insight on how to analyze the first question of 7 m, where the counting of steps implied some form of stacking (pilling things up or building blocks), which is not the same as walking from position A to position B, i.e., locomotion of the body without stacking. As such, in the first question, the body or body parts (arms, legs, height) were commonly used for calibrating a 7 m distance, while the notion of traveling or a journey was used in the 100 km distance. The next guiding research question, following this finding was:

3. How do we theorize about the different thinking modes from guiding research question 2?

The emergent theory (Grounded Theory Method) from the data showed that there is more than one way of thinking about distances that were identified in these questions, besides the one of time (which we initially thought of). Therefore, this low-level theory suggests that distances are understood in terms of these important categories (1) that distances were explained using body calibration and counting steps or arm lengths etc., and (2) that distances were explained by moving the body from one place to another and (3) explicit use of time (to be looked into for further work). We focused on (1) and (2) as the second category was the largest one, which surprising as we thought would be time.

We then explored categories (1) counting and (2) journeying in more details. From these category descriptions two conceptual constructs were posited as being the cognitive elements or modes of thinking that were being activated: Counting and Journeying. To state it more clearly: the way in which students engaged with distance indicated that (at least) two distinct modes of thinking were being used depending on the “size” of the distance: shorter distances involved Counting while the longer distances required the Journey concept. At this point, we realised that activating the Counting mode would not be very productive where astronomical distances were concerned as comparison between very large numbers is not meaningful. In summary, the data have been reduced to a simpler description at the level of categories and thereafter to a mid-level pragmatic theory which can be regarded as a simple manifestation of some broader theories, in this case, theories of cognition.

While there are a range of theories of cognition, this low-level theory which emerged from the data seemed to be consistent with one theory of cognition, that of embodied cognition through the notion of a journey, which features prominently as the Source-Path-Goal Schema. Schemas, or “thinking templates” in general, structure the way in which we think based on prior experience. In embodied cognition such schemas are “grounded” during infancy when certain sensory-motor experiences are carried out repeatedly and at the same time activate the same particular neural networks which then form the basis of the schema, for example, the act of crawling in infancy from one location with all the aspects that are involved in self-propelling the body using many body parts and substantial effort and expenditure of energy.

In general, evidence from Cognitive Linguistics points to the fact that we structure abstract concepts through such perceptual grounding and express ourselves accordingly. Thus, we talk about the PhD journey or the Journey of Life to use the present Journey / Source- Path- Goal Image Schema to use the example under discussion. There is also evidence that the type of language used activates areas of the brain consistent with the descriptions of actions (Bergen, 2012).

In this work, one particularly interesting image schema, is the Source- Path- Goal Schema, which relates to the second way of thinking about distance (a journey). The question then arose of whether it would be possible to activate the Source-Path-Goal Image Schema just prior to an exercise dealing with astronomical distances and whether this would have an effect on student understanding of distances. Embodied Cognition considers understanding to be related to running a mental simulation and so the question would be whether activating the resources associated with the Source- Path- Goal Image Schema would lead to a more productive mental simulation.

Therefore, we developed a teaching activity that was focused on astronomical distances, with activating the Source-Path-Goal schema in mind. The activity was named “A Journey to the edge of the observable UNIVERSE along UNIVERSity Avenue”. University Avenue is a road at the University of Cape Town, which the students at UCT become familiar with. We placed astronomical objects along University Avenue, marked with their distances from the surface of earth in kilometres, astronomical units, and light years. As students walked along University Avenue, they came across different astronomical objects and recorded the information that the object had (see chapter 6). When students concluded the walk on University Avenue (outside) which only goes up to the hypothetical edge of the solar system, they returned to the hall where the walk continued with a Super-walker (a person walking with at the speed of light). Using all the information gathered during the journey on University Avenue and the journey by Super-walker, students then needed to design a way to position themselves with the pictures of the astronomical objects on the floor of the hall to ‘accurately’ represent the distances to the objects from the Earth’s surface.

4. To what extent does an activity based on activating the JOURNEY ‘Source-Path-Goal’ schema in Embodied Cognition address student difficulties with astronomical distance?

After the intervention activity, students completed an evaluation form followed by the IAQ (SD) post- test questionnaire the next day. The evaluation form gave insight to student learning experiences during the activity. The outcomes of the evaluation showed that students found the activity enjoyable, especially walking on university avenue which according to one student “*gave them a sense of how far each object is from each other unlike trying to imagine the numbers*”. Students were quite engaged in the activity, as discussions were encouraged between them and with the course tutors.

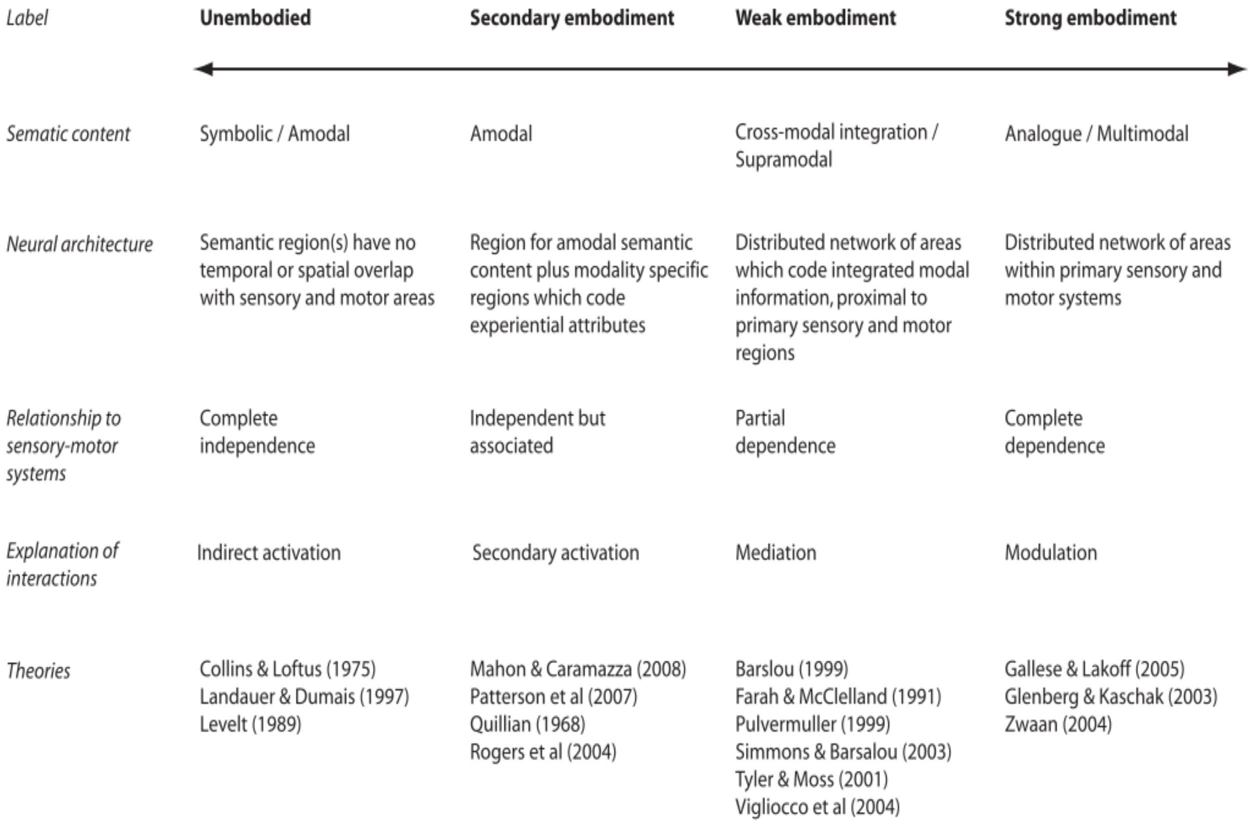
The IAQ (SD) post test results showed positive gains that have not been recorded in previous studies, especially the ones that used the IAQ (Rajpual et al., 2014; Rajpaul et al. 2018). We further argue that these gains are due to the nature of the intervention, which was developed with the Source-Path-Goal schema in mind, as a journey to the edge of the Universe. This intervention operated in what we found to be the movement/ journeying domain that activated cognitive resources that showed to be useful for students to engage with large distances, especially those in astronomy.

7.3 Contribution of the thesis

Social Semiotics have been used as the basis for gaining insights into student learning of physics based on the constructs of fluency of representational modalities (Airey & Linder, 2017). Recently this approach has been used in Astronomy as well as Astronomy Education Research, where astronomical concepts and images can be decoded for teaching and learning purposes, thus enriching students' knowledge, and understanding of the concepts (Eriksson, 2014; Eriksson, 2019; Airey & Eriksson, 2019). While Social Semiotics have opened the possibility of meaningful learning, the present work however points to an aspect that is not part of Social Semiotics, which is that of embodiment. Figure 7.1 from Meteyard et al., (2012) shows the classification scheme from disembodied (amodal) frame of learning towards embodiment (multi-modal).

If we accept that some form of mental simulation is involved in the processing of semantic meaning, then a question arises whether the participant's (i.e., one that is Earth-based) or observer's formulation of a situation plays a role. In the pre-test form of the IAQ (SD) distances are stated as being from earth which automatically presents itself as a participant (based on experience) view. On the other hand, in the post-test the distances are posited as from Uranus. Therefore, there are ways of engaging with this where the first is to move oneself mentally to Uranus and thus engage with what follows from a participant's perspective on Uranus. Alternatively, one could "remain on earth" and engage as an observer "as if on Uranus". For an expert this appears trivial as the Earth-Uranus distance is negligible on the cosmic scale and the two reference frames are to all intents and purposes coincident. However, reference frames and the differences between reference frames are fundamental to physics and differences of description or experience as per the Participant or the Observer can vary widely.

There is evidence that this also the case insofar as semantic processing is concerned and as a consequence has a bearing on conceptual engagement (Bergen, 2012). They explored the idea experimentally that use of "I" (first person), "you" (second person) or "they" (third person) "orchestrates the perspective you simulate from". Their finding was that the grammatical person ("I" or "you") played a role in directing the simulation. However, what is of interest is that in their experiments they point out that in a participant perspective there is no lateral change of position while being the observer introduces this dimension leading to different simulations and impacting on reaction times in their experiments. Thus, this is an interesting avenue to explore, namely whether 'A person who is stationed on Uranus' or 'You now journey to Uranus' forcing the participant perspective changes the level of productivity of engagement.



Label	**Unembodied**	**Secondary embodiment**	**Weak embodiment**	**Strong embodiment**
Sematic content	Symbolic / Amodal	Amodal	Cross-modal integration / Supramodal	Analogue / Multimodal
Neural architecture	Semantic region(s) have no temporal or spatial overlap with sensory and motor areas	Region for amodal semantic content plus modality specific regions which code experiential attributes	Distributed network of areas which code integrated modal information, proximal to primary sensory and motor regions	Distributed network of areas within primary sensory and motor systems
Relationship to sensory-motor systems	Complete independence	Independent but associated	Partial dependence	Complete dependence
Explanation of interactions	Indirect activation	Secondary activation	Mediation	Modulation
Theories	Collins & Loftus (1975) Landauer & Dumais (1997) Levelt (1989)	Mahon & Caramazza (2008) Patterson et al (2007) Quillian (1968) Rogers et al (2004)	Barslou (1999) Farah & McClelland (1991) Pulvermuller (1999) Simmons & Barsalou (2003) Tyler & Moss (2001) Vigliocco et al (2004)	Gallese & Lakoff (2005) Glenberg & Kaschak (2003) Zwaan (2004)

Figure 7.1: Is a representation of a continuum of embodiment, where theories are group in four main categories: (1) Unembodied, in which the sensory-motor information has no role in semantic knowledge they are symbolic (amodal). (2) Secondary embodiment, where the semantic knowledge is amodal, however with associations of different parts of the brain that represent the modal information. (3) Weak embodiment, in which semantic knowledge are partly made up of sensory-motor information; and (4) Strong embodiment, where knowledge is completely built from sensory-motor information and input (Meteyard et al., 2012).

It is important to note that this thesis does not claim that the Source-Path-Goal-Schema is the answer for understanding all astronomical distances. Rather we are exploring whether this schema can be useful for students' understanding of astronomical distances, which chapter 6 shows it may be. However, if we review figure 4.2 in chapter 4, the data for larger distances (i.e., to the moon) shows that it can be confusing as the time domain is introduced, and the notion of time itself is complex. As such, the notion of time continues to be investigated in physics and neuroscience (Buonomano, 2017).

What this thesis has shown is that the notion of distance is more complicated than we had originally thought and that there are two ways of thinking about distance that do not explicitly involve a time domain explanation. Therefore a question remains “how does one activate the Source-Path-Goal cognitive resources without actively taking the journey”?. As such, we further argue that there is an element of effort which contributes in the larger part to the Source-Path-Goal schema, i.e., the goal requires effort. Taking or making an effort towards something makes it feel more earned. Since the activity took place during a hot summer day, the journey demanded an effort to be made by the students, that bodily-felt effort contributed to students’ awareness of astronomical distances.

In summary, people think about distance in these ways, which is linked to their primary sensory motor experiences. The theory of embodied cognition shows that people think this way using the image schemas. Embodied cognition enables us to link the outside world to the mind (i.e., takes senses to the neural activity in the brain), where abstract thought is structured through repeated perceptual grounding. Embodied cognition offers a way of “thinking” about the process of “thinking” from the unconscious level to the level of consciousness. This is unlike the other end of traditional cognition, where the mind and the body are separate entities, and the mind makes sense of things based on the amodal nature of things. Furthermore, from this thesis, we recognize that our bodies influence how we think, understand and reason. The embodied cognition further gives insight into how some ideas and concepts in physics are poorly understood (see Brooks & Etkina, 2007).

7.4 Conclusions and Future Directions

Understanding concepts in physics and astronomy are challenging from several perspectives. Many of these difficulties arise from the fact that common words are often appropriated and used in a technical manner. As with ordinary polysemous words, the meaning that is intended is usually disambiguated from the range of possibilities through the context. However, the less familiar the context the more likely that misunderstandings are likely to occur. For example, John & Allie, (2019) studied how confusion can arise through the terminology and descriptions used in simple Direct Current (DC) circuits and how difficult it can be for instructors to realise that this indeed happening.

Words acquire meaning based on prior experience (Evans, 2009) and since individual experience is unique there is no simple way of knowing what (meaning) the listener (constructing) is conceptualising in the moment. From the Embodied Cognition perspective this is described via the area of Simulation Semantics (Bergen, 2012) which uses the notion that at the meaning of a word involves running a simulation. This approach would appear to make sense when a term like force is used as even in the domain of physics its meaning has been refined over centuries see

Brooks & Etkina (2009). However, it is less obvious that a seemingly simple word like distance could pose any problems. However, the power of Embodied Cognition lies in the fact that the grounding of meaning is perceptual and, in this case, leads us as shown in the data that there are at least two competing image schema. The one ends up with counting while the other involves effort etc.

The present approach (embodiment) and that one described by Eriksson (2014 & 2018) social semiotic, together form a spectrum of how meaning is constructed in the moment. At the extreme embodiment end (strong embodiment – from Meteyard et al., (2012)) perceptual grounding plays the dominant role in activating neural networks that lead to understanding; while at the extreme semiotic end meaning making involves activating neural networks that are not perceptually grounded. From the present work and the work of Eriksson, both have been shown to be productive insofar as teaching and learning of astronomy is concerned. However, from a cognitive science perspective the field is not yet at the stage where clear guidance can be provided as to how best to proceed, and empirical studies are still the best way forward. Even where both approaches are acknowledged it is still an open question as to the exact mechanisms and links between highly abstract concepts and perceptual grounding from Meteyard et al., (2012). While it may appear at first sight that perceptual grounding may be "put to zero" insofar as teaching abstract concepts are concerned it is interesting to note the results from a recent study that suggest that "embodied reactivations can precede multimodal??" semantic effects during language processing. The question is to what extent the activation of certain image schema may intrude upon technically refined abstract concepts and hinder the intended meaning in that context.

This work has explored a difficult area in astronomy education, which is a foundation of understanding many other important concepts in astronomy. While the issues with large distances remain a challenge, due to the lack of comprehension; grounded examples and explanations have shown to some impact in changing the way large distances are understood. Through this thesis we have come to realise that there is so much more to explore and research regarding students' thinking, reasoning, and understanding of astronomical concepts. Apart from developing a teaching intervention, we have, through this thesis, developed a low-level theory on how students generally think about distance, thus identifying a very critical stage, that of the movement domain, i.e., journeying.

The present work thus opens many possibilities for future directions both at a broad level as well as at a more astronomy teaching focus. At a broad level the last point suggests several studies that can be done both in physics and astronomy. For example, the more is UP schema may intrude on in the moment meaning making where representations are not consonant this schema.

Further work should investigate the modifications of this activity for online learning (which is likely to be more prevalent in post-covid-19 times). It will be important to investigate student data based on when the activity is carried out, to see whether the effect of the activity when the cognitive resources needed to deal with astronomical distances are activated at a different time. For comparison purposes, a more statistical analysis can be carried out to measure the change (delta) between different samples. Additionally, one of the open questions that remains to be explored is whether the mapping needs to be implicit or explicit, i.e do students need to be taught or do they draw from their lived experiences?, we wish to explore this int her future.

Moreover, one may further investigate this by understanding an experiment design methodology, where the sample is split into two groups. Meaning that half of the student sample would do the journey activity and the other half a similar intervention minus the actual physical walking. Therefore, the placebo intervention would be some sort of a scale picture the students could study and answer journey-like questions about. And further analyse the two interventions to see if they produce any statistically significant difference on the post questionnaire.

The view from Uranus instead of earth – does the mental simulation involved cast the respondent into a participant role or into an observer role (“God’s eye view”) and to what extent does this affect engagement, which is at this point out of the scope of this study.

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Appendices

Appendix A: Ethics Approval Letter

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

Faculty of Science
University of Cape Town
Rondebosch
South Africa 7701

E-mail: **shari.daya@uct.ac.za**
Tel: 021 650-2880

26 January 2021

Ms Tshiamiso Makwela
Department of Astronomy

Probing aspects of students engagement regarding distance in Astronomy.

Dear Ms Tshiamiso Makwela

I am pleased to inform you that the Faculty of Science Research Ethics Committee has approved the above-named application for research ethics clearance, subject to the conditions listed below.

- Restrictions on involving human participants in research must be adhered to, given current concerns about the spread of Covid-19. Please ensure that you are aware of and comply with UCT policy on this, as communicated by management.
- Implement the measures described in your application to ensure that the process of your research is ethically sound; and
- Uphold ethical principles throughout all stages of the research, responding appropriately to unanticipated issues: please contact me if you need advice on ethical issues that arise.

Your approval code is: **FSREC 009 – 2021**

I wish you success in your research.

Yours sincerely

Dr Shari Daya
Chair: Faculty of Science Research Ethics Committee

Cc: Professor Saalih Allie (supervisor)

Appendix B: Introductory Astronomy Questionnaire- Size and Distance Questions (IAQ_SD)

Student number:

Introductory Astronomy Questionnaire (IAQ)

Department of Astronomy
University of Cape Town

February 2018

Q1a. [FAC01]

Faculty registered in (circle one):

Science / Humanities / Engineering / Health Science / Commerce / Law

Q1b. [MAJ01]

Intended major(s) or programme specialisation:

____

Q1. [RNKS1]

Rank the following from smallest to largest:

galaxy; planet; star; universe; solar system.

Q2. [EXP]

A grade 10 learner who is interested in astronomy asks you to explain briefly to her what is meant by each of the following below. (Write one sentence per item.)

Galaxy:____

____

Planet:____

____

Star:____

____

Universe:____

____

Solar system:____

____

Q3. [RNKD1]

Rank the following by their distance from the Earth's surface:

centre of the Milky Way; edge of the observable universe; the asteroid belt; edge of the Solar System; the Moon; the Sun; the star Alpha Centauri; the ozone layer; centre of the Earth; Neptune.

1(Closest):____

2:____

3:____

4:____

5:____

6:____

7:____

8:____

9:____

10 (Furthest): ____

Appendix C: First Teaching intervention worksheets

Student number ______________________

ACTIVITY 0

Instructions: This activity is to be done individually.

1) What would you tell a friend each of the following images is?

A.____

B.____

C.____

D.____

E.____

F.____

G.____

H.____

I.____

Student number ________________________

2) Put the images in order according to whatever criteria/property you like. Explain your reasoning.

1. ____
2. ____
3. ____
4. ____
5. ____
6. ____
7. ____
8. ____
9. ____

You are now ready to move onto **ACTIVITY 1 –** and join a group!

ACTIVITY 1

GROUP SIZE: 5

Please fill in the names and student numbers of your group members:

Student names:	Student numbers:

Instructions: All the activities are to be done as a group and are to include everyone.

1) Describe what each image A-I shows in 1 or 2 sentences.

A.

B.

C.

D.

E.

F.

G.

H.

I.

2) Rank the objects **in order of size** by first placing them in order in line on the floor. Get a tutor/lecturer to check when you think you have completed the task.

Write down the objects from smallest to biggest in size below:

1. (smallest)____
2. ____
3. ____
4. ____
5. ____
6. ____
7. ____
8. ____
9. (biggest)____

You are now ready to move onto **ACTIVITY 2 -** please ask a tutor for the next worksheet.

ACTIVITY 2

GROUP SIZE: 5

Please fill in the names and student numbers of your group members:

Student names:	**Student numbers:**

Instructions:

(a) Rank the following by their distance from the Earth's surface:

A. centre of the Milky Way
B. edge of the Solar system
C. the Sun
D. the Moon
E. edge of the observable universe
F. centre of the Earth
G. the nearest star to the Sun (Alpha Centauri)
H. the Oort cloud
I. Uranus
J. the ozone layer

1. closest) ____
2. ____
3. ____
4. ____
5. ____
6. ____
7. ____
8. ____
9. ____
10 (furthest)____

You are now ready to move onto **ACTIVITY 3 (final activity)** - please ask a tutor for the next worksheet.

ACTIVITY 3

JOIN UP WITH ANOTHER GROUP OF 5 TO MAKE A GROUP OF 10

(a) Using your ordering in ACTIVITY 2(a), match the items in the list with its distance from Earth in the table. You will need to convert to units of *km* to more easily compare distances. Please write the *km* distances in scientific notation with only 1 number before the decimal point.
e.g., 125 km □ 1.25 x 10^2 *km*

For conversions:
1 AU (astronomical unit) = 150 million km
speed of light c = 300 000 km/s
1 pc (parsec) = 3.3 light years
1 billion = 1 x 10^9

A. centre of the Milky Way
B. edge of the Solar system
C. the Sun
D. the Moon
E. edge of the observable universe
F. centre of the Earth
G. the nearest star to the Sun (Alpha Centauri)
H. the Oort cloud
I. Uranus
J. the ozone layer

Distance	Distance in km (scientific notation	Object
4.4 light years		
5 billion km (5x10^9 km)		
1 AU from earth	1.5 x 10^8 km	C. the Sun
13.4 billion light years		
6400 km		
25 km		
2.6 billion km		
50 000 AU		
8000 pc		
385 000 km		

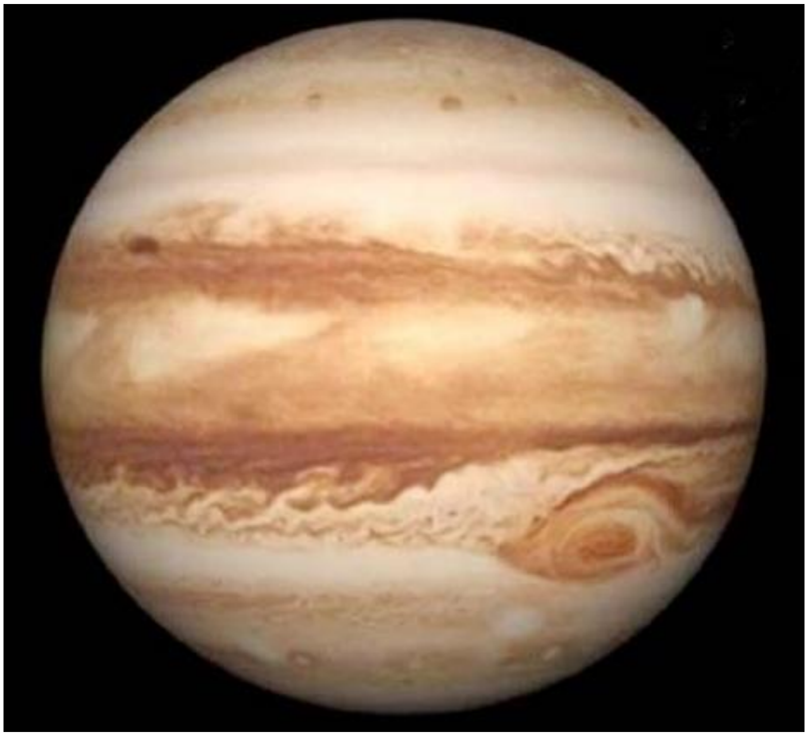
(b) Now each person in the group use a piece of paper to make a label for yourself: write one of the items on the paper and hold it. You are now the objects!

Now, given the distances to each object from the Earth, design a way to position yourselves to represent the distances to the objects. Try your best to accurately represent the relative scales in the distances and explain your system to a tutor/lecturer to get sign-off that you have completed the activity.

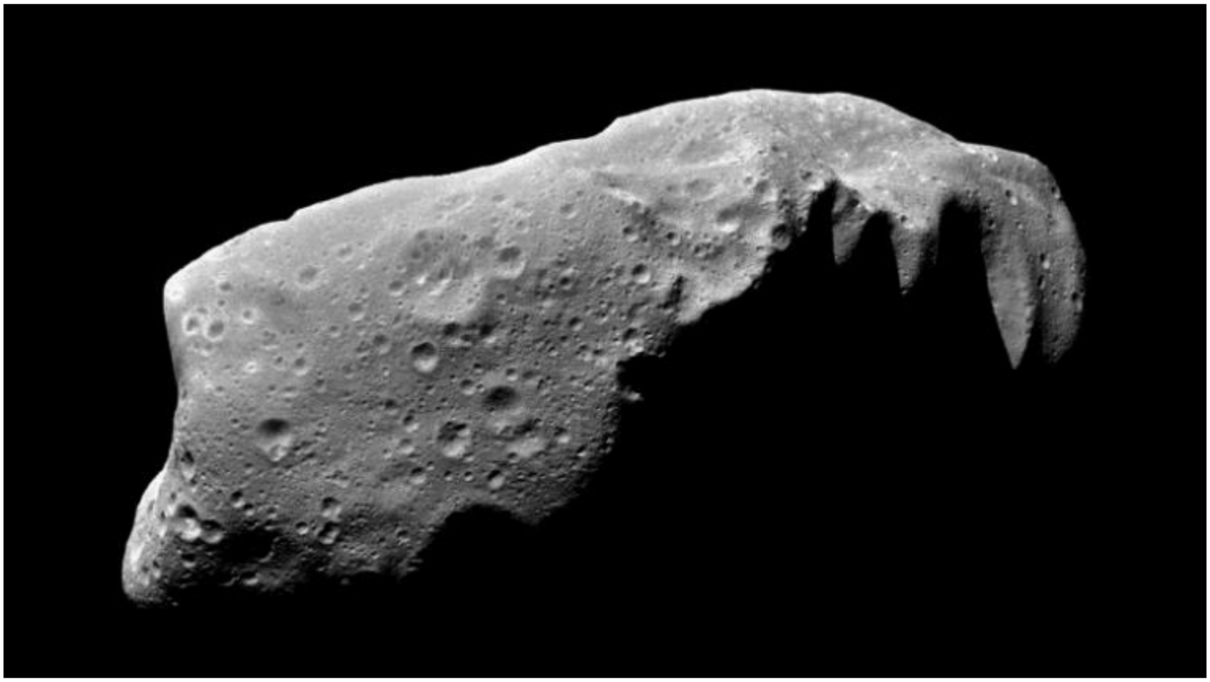
Please fill in the names and student numbers of your group members:

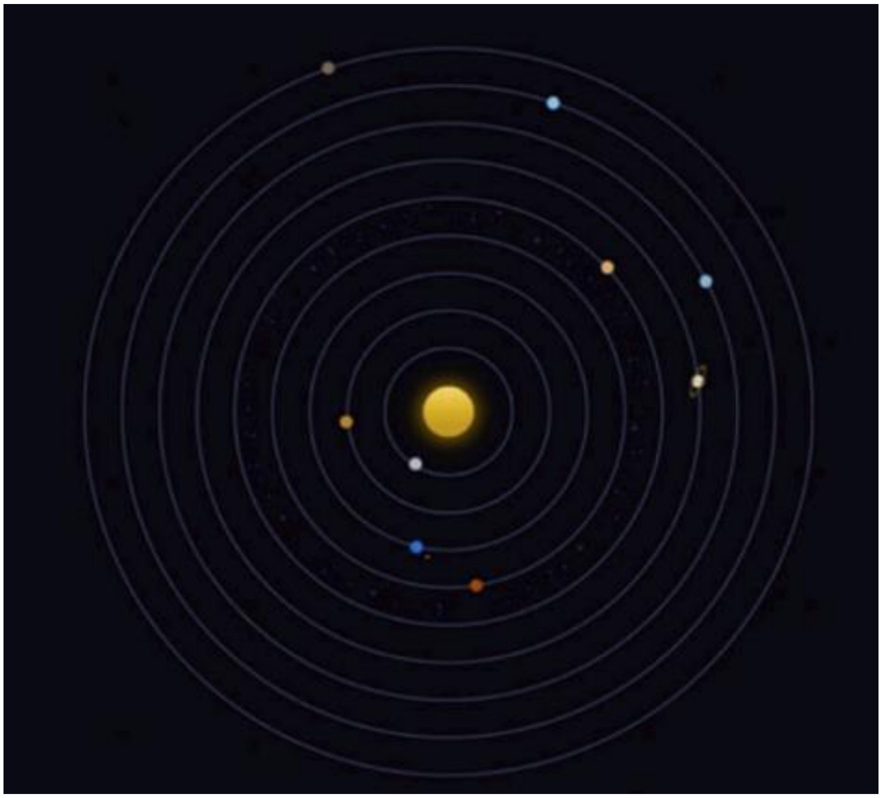
Student names:	**Student numbers:**

Appendix D: Intervention Images




Africa





Appendix E: Astronomy Question: Understanding Engagement

Student number:

Astronomy Questionnaire: Understanding Engagement of Distance

Department of Astronomy
University of Cape Town

February 2019

Faculty registered in (circle one):

Science / Humanities / Engineering / Health Science / Commerce / Law

Intended major(s) or programme specialisation:

____

Question 1.

A **blind** (cannot see) friend asks you “I am trying to get a sense of how big 7 metres is”.

How would you help your blind friend make sense of 7 metres?

Question 2.

Your **blind** friend then asks you “I am trying to get a sense of 100 kilometres”.

How would you go about helping your friend?

Question 3.

Your **blind** friend then says, “I hear the moon is about 384 402 km from earth. I am trying to get a sense of far this is”.
How would you help your friend with this?

Appendix F: Second Teaching Intervention (2020)

AST1000F - Worksheet 1

Please fill in the names and student numbers of your group members (5 students only per group):

	Student names:	Student numbers:
1		
2		
3		
4		
5		

INSTRUCTIONS:
In your group, you are going to take a journey through the UNIVERSe along UNIVERSity avenue. Your journey will begin at one end of UNIVERSity avenue (*either* outside RW James building *or* just below the New Lecture Theatre). Wait for a tutor to tell you which end of the road to start at and then please walk across there to start your trip.

You are starting your journey from the surface of the Earth. Along UNIVERSity avenue you will come across various astronomical objects. Write down each object as you pass by it and any information that is below that object in the appropriate column of the table below:

Object name	A (km)	B (AU)	C (light-years)	**FOR TUTORS: Metres scaling at which to place object cards along pavement**
Earth's surface				
Ozone layer	25	1.67 x 10-7	2.6 x 10-12	Basically, on the surface line
Centre of the Earth	6371	4.24 x 10-5	6.7 x 10-10	On the surface line
The Moon	384 000	0.00256	4 x 10-8	On the surface line
The Sun	150 000 000 (1.50 x 108)	1	1.58 x 10-5	0.3 m
Jupiter	6 x 108	4	6.3 x 10-5	1.3 m
Saturn	1.28 x 109	8.5	1.3 x 10-4	2.8 m
Uranus	2.73 x 109	18.2	2.9 x 10-4	6 m
Neptune	4.35 x 109	29	4.6 x 10-4	~10 m
The Kuiper belt	5.85 x 109	39	6.2 x 10-4	13 m
Oort cloud (edge of the Solar system)	3 x 1011	2000	3.2 x 10-2	666 m (basically at end of University Ave)

1. The numbers in the table are related to the objects, but they are missing their units. What does each column represent?

They represent distance!

A = km
B = Astronomical Units
C = light-years

The next part of the practical can be completed back in the hall. Please go back there and collect Worksheet 2.

AST1000F - Worksheet 2

For this part of the practical, you will be using your imagination (and a calculator!) to answer the questions below.

2.1 The average person walks at about 5km/h. The "nearest" star from the Sun, Alpha Centauri is about 2.7 x105 AU (Astronomical Units) away from us on Earth. How long (in years) would it take you to walk to Alpha Centauri? (***Hint***: use your table from Worksheet 1 to convert from AU to km.)

Distance: 2.7 x 105 [AU] x 150 x 106 [km/AU] = 4.05 x 1013 km

Time taken to walk:
t = 4.05 x 1013 [km] / 5 [km/h] = 8.1 x 1012 hours = 9.2 x 108 years = 920 million years!!!

2.2 a) Now, imagine a "Super-walker", who walks at about 300 000 km/s (speed of light). How long would it take (in years) for the Super-walker to get to the star Alpha Centauri?

t = 4.05 x 1013 km / 300 000 km/s
= 1.35 x 108 seconds (/3600 s/h / 24 h/d / 365 d/y)
= 4.28 years

b) What is the distance to Alpha Centauri in light-years?

4.28 light-years (see above)

2.3 Now imagine that Super-walker keeps on walking and finds themselves about 25 000 light years from the Sun. Choosing from the options below, where do you think the Super-walker is in the universe? (Circle the correct answer)
A. Just outside the solar system
B. At the centre of the Milky Way Galaxy
C. At the Large Magellanic cloud
D. At the Andromeda galaxy

2.4 Super-walker finds out that at their current speed, it will take 13.4 billion years to walk from Earth to the edge of the observable universe. How far away is it?
13.4 billion light-years

Check your answers with a tutor and ask for Worksheet 3

AST1000F - Worksheet 3

Now, given the distances to each object below from the Earth (refer to your table in Worksheet

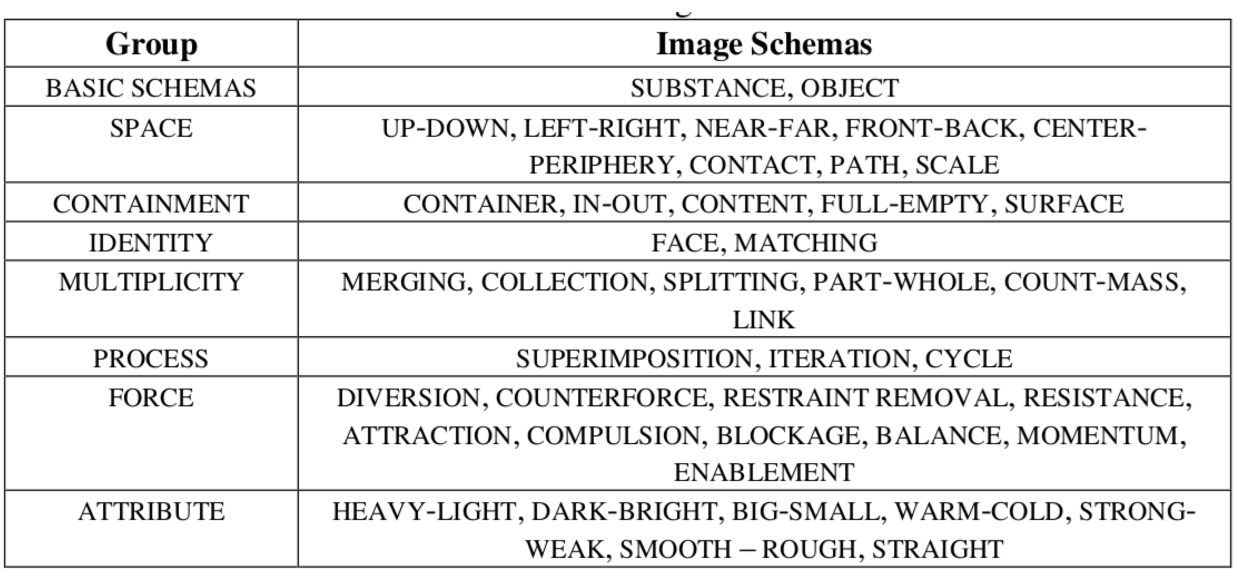
1) Design a way to position the pictures on the floor of the hall to represent the distances to the objects. Try your best to accurately represent the relative scales in the distances and explain your system to a tutor/lecturer to get sign-off that you have completed the activity.

A. centre of the Milky Way
B. Kuiper Belt
C. the Sun
D. the Moon
E. edge of the observable universe
F. centre of the Earth
G. the nearest star to the Sun (Alpha Centauri)
H. the Oort cloud
I. Uranus
J. the ozone layer

(Prestik will be provided for you to stick the pictures in position on the floor.)

We are expecting the students to eventually figure out that a log scale will work best to line up all these objects in terms of distance from the Earth's surface. Rough placement of the objects relative to each other should not be accepted – push the students to think further how they can more accurately represent the distances (but do not give the log scale away!). Hint – it is easiest if they use the km distances to get a nice log scale which does not start with negative exponents in the distances.

Appendix G: Image schemas



Group	Image Schemas
BASIC SCHEMAS	SUBSTANCE, OBJECT
SPACE	UP-DOWN, LEFT-RIGHT, NEAR-FAR, FRONT-BACK, CENTER-PERIPHERY, CONTACT, PATH, SCALE
CONTAINMENT	CONTAINER, IN-OUT, CONTENT, FULL-EMPTY, SURFACE
IDENTITY	FACE, MATCHING
MULTIPLICITY	MERGING, COLLECTION, SPLITTING, PART-WHOLE, COUNT-MASS, LINK
PROCESS	SUPERIMPOSITION, ITERATION, CYCLE
FORCE	DIVERSION, COUNTERFORCE, RESTRAINT REMOVAL, RESISTANCE, ATTRACTION, COMPULSION, BLOCKAGE, BALANCE, MOMENTUM, ENABLEMENT
ATTRIBUTE	HEAVY-LIGHT, DARK-BRIGHT, BIG-SMALL, WARM-COLD, STRONG-WEAK, SMOOTH – ROUGH, STRAIGHT

Appendix H: Evaluation Form

AST1000F: Evaluation of the first practical afternoon 2020

Circle/tick/ cross the phrase you most closely agree with

1.I enjoyed the activities: *VERY MUCH* *TO SOME EXTENT* *NOT A LOT* *NOT AT ALL*

Please explain further

2. I learnt: A LOT FAIR AMOUNT LITTLE NOTHING

Please explain further

3. Overall the afternoon was: *EXCELLENT* *GOOD* *OKAY* *WASTE OF TIME*

Please explain further

GENERAL COMMENTS/ SUGGESTIONS FOR NEXT YEAR (PLEASE WRITE ON THE OTHER SIDE OF THE PAGE)

We are It. The Dream is us. – Tshiamiso Makwela