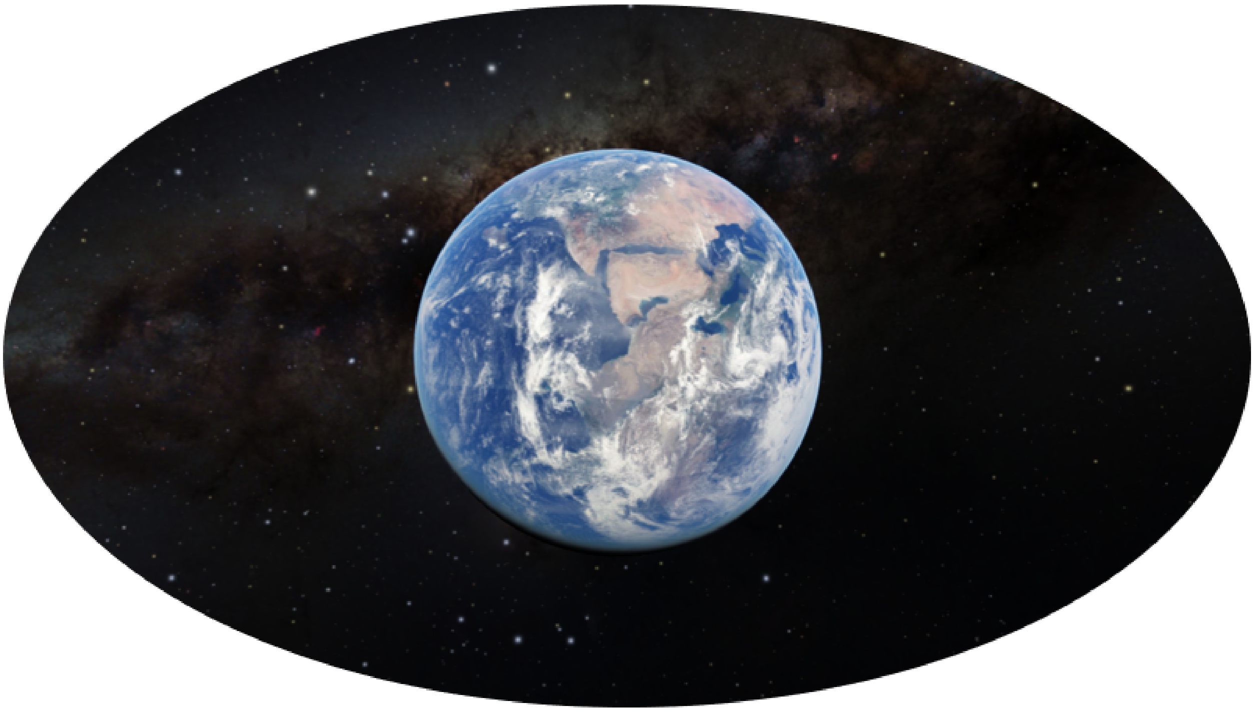

Learning in visualization exhibits

The general public's learning about space through visual data exploration in science museums

Master's thesis in Learning and Leadership

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DEPARTMENT OF COMMUNICATION AND LEARNING IN SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Screenshot of the Earth from the OpenSpace-exhibit, taken by the authors.

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Abstract

Digital visualization tools are entering the arena of educating the general public in museums. The science museum Universeum in Gothenburg has utilized this technology in building a visualization lab with the aim of accelerating learning. This thesis examines one exhibit in the visualization lab which concerns space-data-exploration. The questions examined are the following: Do learning take place when visitors explore this exhibit? And in that case: How does that learning take place? To examine learning, visitors' conversations are studied in a field experiment, during their exploration of the exhibit. The conversations are recorded and analysed according to what type of talk visitors use and what subject content it concerns.

The results show that on average 72% of visitors' talk at the exhibit concern learning, spanning the range of 40–90% between visitors. There is however a moderate amount of talk regarding confusion over the interface, especially among those visitors with a smaller percentage of learning talk, which raises concerns about how visitors would interact with the system when unsupervised. Thus the first conclusion of the study is that learning do take place, but to a varying degree.

The second conclusion is that learning in the exhibit may be described as mainly consisting of answering and asking questions, connecting new information to previous knowledge and interacting with the visual information of the exhibit. The most common subject content that the learning concern are the planets in our solar system and the universe as a whole, which may be seen to be content that are both familiar and intriguing.

Keywords: learning conversations, exploratory learning, science museums, data visualization, visualization exhibit, OpenSpace.

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Thank you!

Isak Pettersson & Maria Söderberg, Gothenburg, May 2022

Contents

1 Introduction

An institution that serves the purpose of educating the general public and contributing to a foundation for lifelong learning is museums. Even though not all museums primarily have an educative purpose, one type of museum that does focus on learning is science museums. These types of museums may be seen to, among other goals, aim to increase visitors' knowledge of and interest in science (Shaby et al., 2016). Thus the experiences that occur during a visit may both make the visitors learn science during the visit and make them more motivated to learn science in other contexts. This increase in both knowledge and interest may be seen as a form of foundation for continuing to learn science.

Due to the increase of digital technology in the society at large the learning experiences no longer have to be physical, but may also be digital. This has led to the emergence of certain digital exhibitions in museums. One such digital technology is data visualization, which may be used to quickly get a grasp on large amounts of data and to draw insights which otherwise would have been difficult. However, Ynnerman et al. states: "until now there has been a clear division between visualization enabling effective data analysis leading to scientific discovery (exploratory visualization) and visual representations used to explain and communicate science to a general audience (explanatory visualization)" (Ynnerman et al., 2018, p. 13) and advocates for a combination of the two in science museums. As the combination is in its infancy (Ynnerman et al., 2018), further research is needed to evaluate how this visualization technique is used by the public, how it contributes to their knowledge and what topics are well suited to be visualized.

One science museum that has acted on the idea of combining exploratory and explanatory visualization to display scientific data for the general public is Universeum in Gothenburg which has created a visualization exhibition. In this exhibition there is a range of different visualization exhibits. One exhibit in particular is about space-data exploration, which may be argued to be particularly well suited for a digital visualization. Space contains an enormous amount of objects and a simple physical scale model of the solar system would take enough space for a single exhibition. The space-data exploration exhibit is based on software from an open-source project called OpenSpace. The software "supports interactive presentation of dynamic data from observations, simulations, and space mission planning and operations" (OpenSpace, 2022). The exhibit is thus at its core an advanced software containing actual research data, though it is restricted to a specific interface to create a user-friendly exploring experience for the visitors to Universeum. This thesis will focus on examining the interaction between visitors and the OpenSpace-exhibit.

Universeum has the overall mission to "give children and adults the knowledge and power to make the earth a better and more sustainable place to live" (Universeum, 2022a). Besides this mission, Universeum has a specific goal for its investment in the visualization lab, of which the OpenSpace-exhibit is a part. The goal for the visualization lab is "testing if and in that case how visualization can accelerate learning and increase people's knowledge for a sustainable world" (Universeum, 2022b). Thus there is a more pronounced focus on learning in the visualization lab compared to the science center as a whole. Therefore this thesis will specifically focus on examining learning in respect to the interaction between visitors and the OpenSpace-exhibit.

Learning in digital visualization exhibits in museums has previously been examined by comparing them to traditional exhibits. In a study by (Horn et al., 2016), they let the participants either do an unscripted exploration of a digital evolutionary tree-of-life visualization exhibit or watch a representative video of the content. The learning was then measured through an interview where participants' reasoning and use of tree-of-life concepts were analysed. Similarly (Zaharias et al., 2013) compared the learning from an exploration of a digital visualization exhibit, regarding the historic walls of Nicosia, Cyprus, with a representative physical exhibit. Instead of focusing on what has been learned after an exploration, this thesis will focus on learning during the exploration.

1.1 Aim of study and research questions

The purpose of this study is to try to understand if learning takes place, and in that case how learning takes place during a typical exploration of the OpenSpace-exhibit by the general public. Thus similarly to (Horn et al., 2016), this study want to study an unscripted exploration of the OpenSpace-exhibit and in contrast to (Horn et al., 2016) as well as (Zaharias et al., 2013), the study will not focus on measuring learning after the learning session, but instead during the learning session. The study aims to answer the following two research questions:

- **RQ1:** Does learning take place during an unscripted exploration of the OpenSpace-exhibit at the science center Universeum?
- **RQ2:** If so, how does the learning take place during the exploration of the OpenSpace-exhibit?

1.2 Thesis outline

1. Introduction - In this chapter, the background of the study is presented alongside the study's aim and two research questions.

2. Background - This chapter begins with answering the question of how learning might be measured in this context before delving into previous research in similar studies and ending with a description of the studied OpenSpace-exhibit.

3. Theoretical framework - In this chapter, the theoretical framework of learning is presented. This is done by describing how learning may be understood in the context of this study and how learning might take place.

4. Methods - This chapter presents the methods used to examine the research questions. The chapter starts with an overview of the design of the study before presenting the data collection method and analysis methods.

5. Results - In this chapter, the results from data collection and analysis are presented. Starting with a presentation of participants' demographics, the result is then presented in both a qualitative manner - using selected quotes from data collection - and a quantitative manner - presenting the number of coding references per category.

6. Analysis - In this chapter, the results are analysed in themselves and by using the theoretical framework.

7. Discussion - In this chapter, the results are discussed in relation to previous research and there is a discussion of the thesis' limitations.

8. Conclusions - The final chapter presents the conclusions of the study and ends with a few suggestions for future research.

2

Background

The first question to ask when examining learning in any context is how to measure learning and thus also what learning is in the specific context. How learning can be measured will be expanded upon in this chapter. Drawing from both visual analytics and museum studies we formulate a way to measure learning in the moment by studying conversations between study participants. We then examine a few museum studies on learning conversations in more detail. Finally, we describe the OpenSpace-exhibit studied in this thesis to give the reader a sense of what type of learning could be expected from it. In the next chapter we will delve more deeply into how learning can be understood in this context by posing a theoretical framework of learning.

2.1 Measuring learning in exploratory visualization exhibits in museums

To be able to evaluate learning one needs to be aware of the type of learning that can be expected. In a formal learning environment, specific content of learning is expected and therefore tested via formal exams, tests or quizzes. However in an informal learning environment, such as a museum, there is no obligation to learn but the learner is free to gain any new knowledge, meaning that expectations on the content of learning can vary greatly and is difficult to test in a formal way. Designing a test to capture all possible insights would be difficult, and would also place formal expectations on an open exploration. To keep the informal learning environment, learning could instead be assessed via interviews after exploration, although this would only capture the perceived learning of the learner. A different way to assess learning can be found by focusing on learning in the moment, e.g. what learners think and say as they interact with new knowledge.

One example of assessing learning in the moment is found in Allen's (2002) examination of ”learning talk” among visitors in an exhibition at The Exploratorium, San Francisco. Taking her inspiration from the socio-cultural idea that learning is produced in the social setting she recorded visitors' conversations with each other as they moved through the exhibit. After collection, statements in these transcripts were coded according to the five main categories of Perceptual, Conceptual, Connecting, Strategic, and Affective talk and analysed by how frequent they occurred.

In contrast to the physical exhibition at The Exploratorium, the OpenSpace-exhibit is a digital visualization exhibit. Thus it is of relevance to look at how other similar systems - such as exploratory visual analysis systems - are examined. Battle and Heer (2019) identifies, for example, a quantitative methodology to examine interaction sequences performed in the visualization to try to find common interaction sequences that lead to insights. Battle and Heer also identifies a more qualitative methodology ”useful for identifying meaningful cognitive events” (Battle & Heer, 2019, p. 147). This type of evaluation is called ”insight-based evaluation”, which means that the system is evaluated according to what types of insights are generated by users during and open-ended use of the visualization.

One such insight-based evaluation method is presented by Saraiya et al. (2005) and is based on characterising each insight generated by a user of a visual analytics tool. The insights in the study were characterised through eight different aspects: the actual observation, time to reach the insight, domain value of the insight, if the insight contained a hypothesis, if the insight was due to a self-expressed question or was unexpected, if the insight was correct, if the insight was broad or deep and what category of insight (overview, pattern, group or detail) it belonged to. With this methodology, Saraiya et al. (2005) could quantify the insights and in the particular study evaluate which out of five different visual analytics tools performed the best.

An altered version of the method designed by Saraiya et al. (2005) is presented by Liu and Heer (2014). This method includes not only insights but other types of cognitive behaviour as well, such as asking questions. The seven categories of cognitive behaviour that Liu and Heer (2014) developed were: Observation, Generalization, Hypothesis, Question, Recall, Interface and Simulation. Further Liu and Heer (2014) restricted the evaluation to only characterize the insights according to these categories and disregarded characteristics such as domain value and time to reach the insight that was included by Saraiya et al. (2005).

Seeing as both exploratory visual analytics tools and museum exhibitions can be evaluated based on the cognitive behaviour that users or visitors express, it seems to be a promising evaluation method for an exploratory visual museum exhibit. This perspective on how to measure learning is the base for conducting this study and is further expanded upon in the method section of the report.

2.2 Previous research on learning talk in museums

In the following section, previous museum research which relates closely to this study is presented. Although conversations in museums have been studied in a few different ways, such as how long it takes to decode an exhibit (Ma et al., 2020) or what content visitors discuss (Scalfi et al., 2022; Tunnicliffe and Reiss, 2000), this section will only present the results of studies focusing on general learning talk categories which could potentially be generalised to a visualization exhibit and therefore comparable to the result of this study.

As previously mentioned, one example of studying learning talk in museums is the study by Allen (2002) which examined learning conversations of museum-goers by recording their conversations as they moved through an exhibition about frogs at The Exploratorium in San Francisco, USA. She developed a coding scheme for learning talk types consisting of five main categories: Perceptual, Conceptual, Connecting, Strategic, and Affective talk. The perceptual talk included identification, naming, pointing out a feature and quotations. The conceptual talk included simple and complex inferences, predictions and statements of metacognition. The connecting talk included explicit connections to either earlier life experience, previous knowledge or information gleaned from another exhibit (called an inter-exhibit connection). The strategic talk concerned metaperformance talk and talk about how to use the exhibit, and the affective talk contained expressions of pleasure, displeasure, or intrigue.

Allen (2002) then analysed the different types of learning talk by how frequently they occurred at the exhibits the participants stopped at in the frog exhibition. She found that learning talk occurred at 83% of the exhibits and the most common categories of talk were perceptual, affective, and conceptual whilst strategic and connecting talk were significantly less frequent. The most common sub-categories were identification and quotation at 44% and 43% of exhibits stopped at respectively, followed by complex inferencing, intrigue, pleasure, simple inferencing, and feature. The least common sub-categories were instead predictions and inter-exhibit connections at only 3% and 5% of exhibits stopped at respectively.

Another study, which used the coding scheme developed by Allen (2002) is the study of visitor learning at a national history museum in Korea done by Lee and Kim (2007). Their study yielded similar results to Allen with perceptual, conceptual and affective talk as the three most common type of talk at 38%, 24%, and 20% of all talk respectively. Connecting talk consisted of 15% of all utterances and Strategic talk of only 3%. The most common subcategories were feature, complex inferencing, intrigue, life-connection, identification, naming, and simple inferencing. The least common subcateogries were inter-exhibit connections, metaperformance, metacognition, prediction, and use.

A different coding scheme was developed in the study done by DeWitt and Hohenstein (2010) where student conversations were analysed both during a museum visit and a follow-up classroom session to compare the different settings. Their coding scheme consisted of eight types of talk: Explanation, Fit, Description, Read, Description-Visual, Content-superficial, Affective, and Attention. ”Explanation” contained explanatory or reasoning statements, ”Fit” contained talk about if something is relevant to the topic, ”Read” contained statements read aloud from labels, ”Description-Visual” contained talk of naming or labelling something you see, ”Affective” contained expressions of emotional reactions, and ”Attention” contained talk of drawing someone’s attention to an object. Lastly, ”Content-superficial” contained statements of engagement with the content on a superficial level while ”Description” contained statements of engagement with the content on a deeper level - for example describing, comparing or paraphrasing.

To begin with, the study of DeWitt and Hohenstein (2010) measured the amount of content-related talk compared to procedural talk and concluded that at the museum visit the average percentage of content-related talk was 72.8% compared to the follow-up classroom session where content-talk was only 45.2% of all talk on average and procedural talk was much more common. To expand this result in more detail, the average frequency of type of content-related talk at the museum visit was as follows: Content-superficial (24%), Description-visual (17.8%), Description (13.6%), Attention (12%), Read (9.8%), Affective (8.2%), Fit (6.2%), Explanation (2.6%), and Other (2.2%). Contrasting with the most common type of talk in the follow-up classroom session where "Content-superficial" accounted for 65.2% of content-related talk on average, this result hints at the different mode of learning the museum environment presents compared to the classroom.

2.3 Description of the OpenSpace-exhibit

The OpenSpace-exhibit is an exploratory visualization exhibit consisting of one screen with six main menus displayed in figures 2.1-6. Each main menu has a set of different sub-menus or tools to explore the current view including some text-based information to explain what is displayed. In each view, the visitor is also invited to explore the content by zooming and rotating.

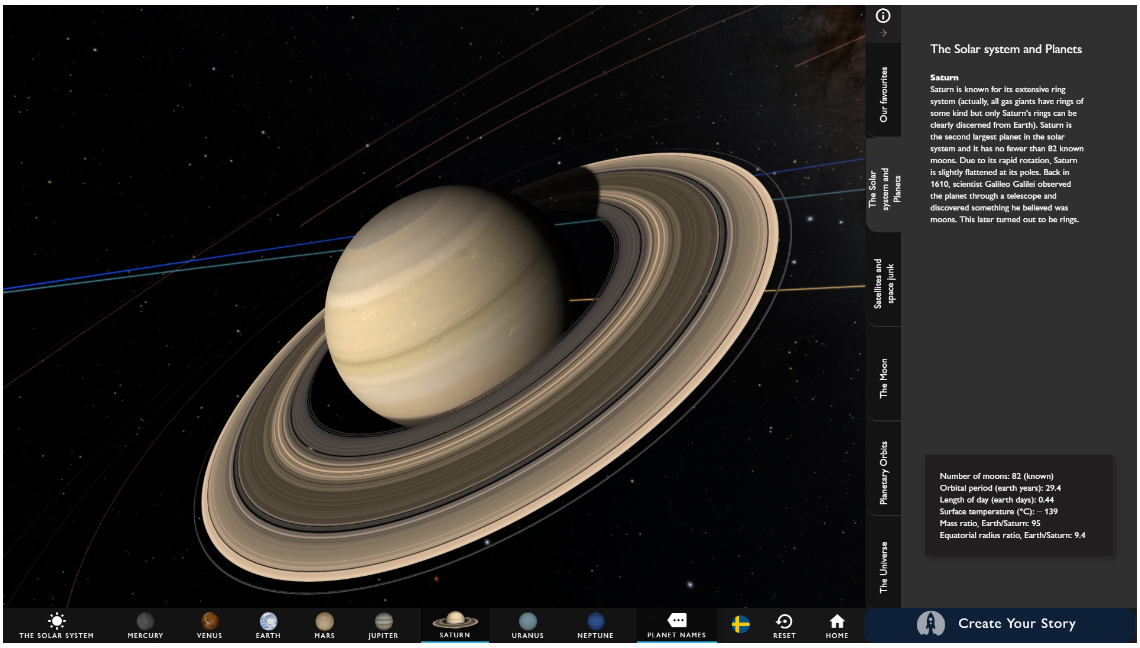

Figure 2.1: The Solar system and Planets. In this view you are able to explore the eight planets of our solar system by zooming and rotating as well as reading some facts concerning each planet. You can also view the solar system as a whole by clicking the button "The solar system".

The first menu concerns the solar system and planets and can be seen in figure 2.1. As seen in the figure, this view presents a zoomed-in perspective on each of the eight planets in our solar system with information on the right-hand side. Each planet can be selected from the sub-menu at the bottom of the screen, changing the view and the information on the right. Apart from general information, there is also a 'quick facts' box in the bottom right corner for each planet, containing information such as the number of moons and mass of the planet compared to Earth's mass. Lastly, in the bottom left corner is the sub-menu "The solar system" which provides a zoomed out picture of the whole solar system along with some general information, where you can also toggle planet's names on and off by pressing the button "Planet names".

The second menu shown in figure 2.2 concerns man-made objects orbiting the Earth. The menu contains four different types of man-made objects: geostationary satellites, the space station ISS, navigation satellites, and space junk. Each of the four is selectable in the sub-menu at the bottom of the screen allowing the user to display an item or not by toggling it on or off by pressing the corresponding button. Several items can be toggled on to be shown together, or none at all. The Earth is always displayed at the centre of the screen. On the right-hand side information is displayed for each type of satellite currently toggled on in the sub-menu. Additionally, this menu contains a time controller in the bottom part of the menu which allows the user to rewind, pause or fast-forward time at three different speeds by dragging the dial along a scale. The exact date and time in question is shown above the time controller.

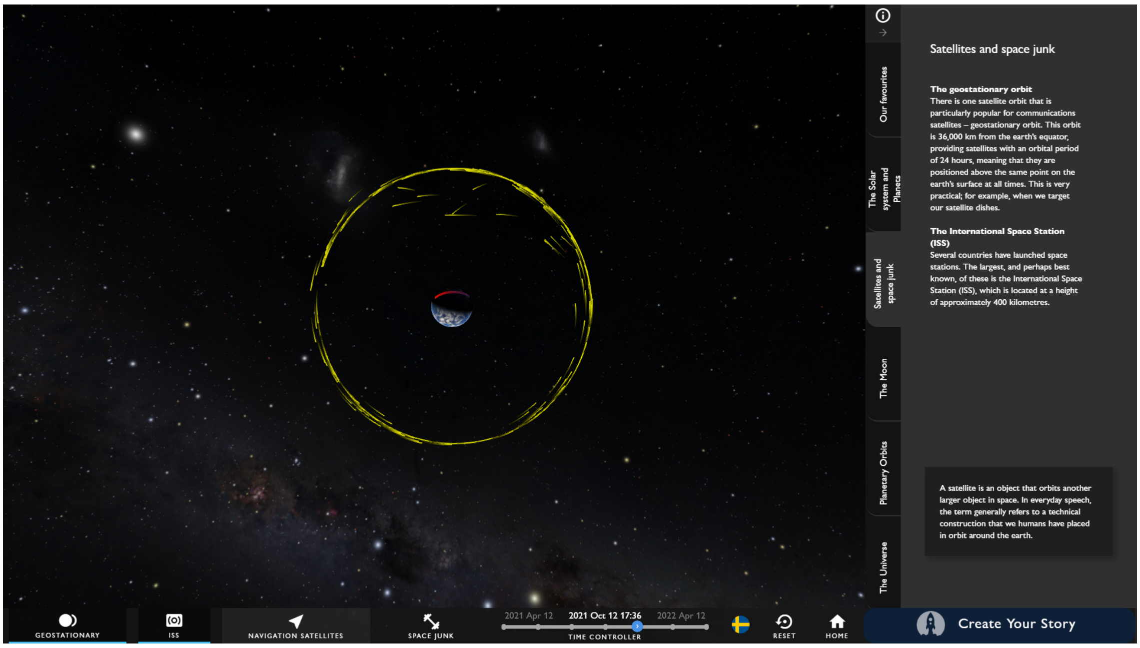

Figure 2.2: Satellites and Space junk. In this view, you are able to view four different types of man-made objects orbiting the Earth: geostationary satellites, the space station ISS, navigation satellites, and space junk. By clicking or un-clicking a button in the bottom menu the corresponding type of object is displayed around the Earth alongside information on the right-hand side. You can also rewind, pause or fast-forward the displayed time via the time controller in this view.

The third menu, seen in figure 2.3 concerns the Moon. The menu contains three sub-menus, accessed at the bottom of the screen, along with a time controller. The time controller allows the user to rewind, pause or fast-forward time at three different speeds by dragging the dial along a scale. The exact date and time in question is shown above the time controller. The first sub-menu, called "The Moon", focuses on the Moon itself. It provides a zoomed-in view of the Moon where the user can zoom and rotate, alongside information about the lunar surface on the right-hand side. The second sub-menu, called "The Moon's Orbit", is a zoomed-out perspective showing the Moon orbiting Earth where the user can zoom and rotate a view locked in on Earth, alongside information on the right-hand side about the Moon's orbit. The third and final sub-menu is called "The Moon's Phases" and can be seen in figure 2.3. This sub-menu provides a fixed perspective of the Moon from Earth's perspective and therefore does not allow the user to zoom and rotate, instead the user is invited to use only the time controller to explore how the view changes. This is explained in text along the bottom of the screen along with general information about the Moon's tidal locking on the right-hand side.

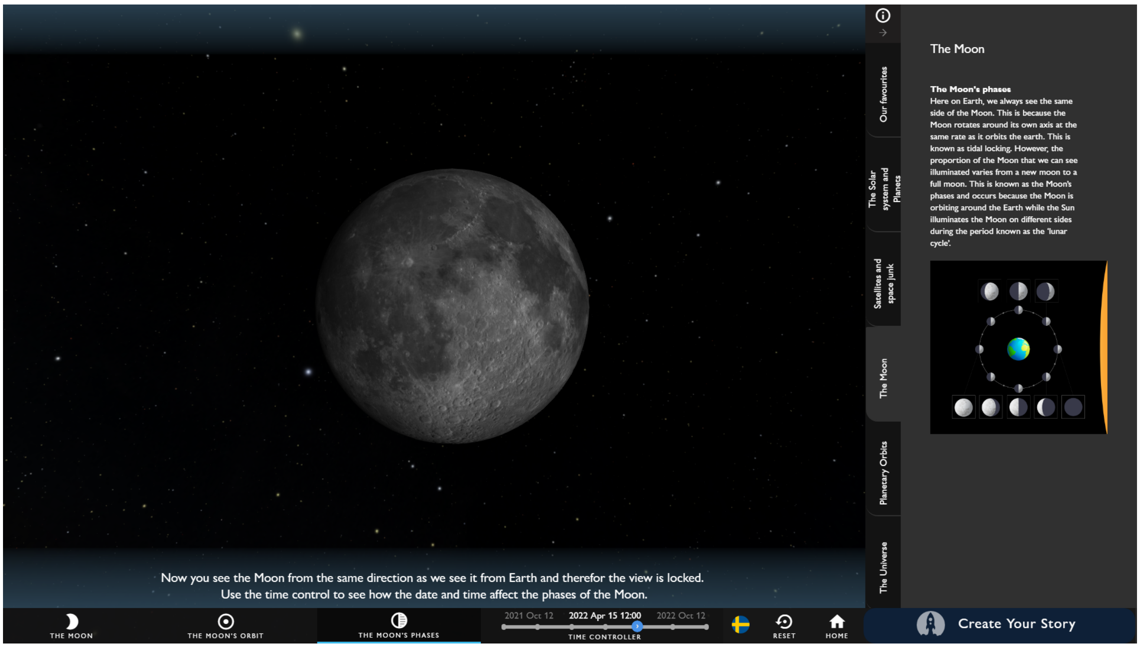

Figure 2.3: The Moon. In this view you are able to view three separate perspectives of the Moon: the first called "The Moon" allows you to zoom, rotate and control time alongside information regarding the lunar surface. The second one is called "The Moon's Orbit" and offers a zoomed-out perspective of the moon's orbit around the Earth, allowing you to control time, zoom and rotate a view locked in on the Earth alongside information about the orbit. Lastly, the third view, pictured above, is called "The Moon's phases" and presents a fixed view showing the Moon from Earth's perspective, allowing you only access to the time control for exploration alongside information about the Moon's tidal locking.

The fourth menu is called "Planetary Orbits" and can be seen in figure 2.4. This menu concerns the solar system as a whole and how the planets relate to each other. A short information text is displayed on the right-hand side. Similarly to other menus, it invites the user to explore by zooming, rotating or using the time controller which allows the user to rewind, pause or fast-forward time while displaying the current date above the scale. However, instead of sub-menus, this menu provides four tools at the bottom of the screen. The first one toggles whether the Sun is displayed as the centre of the screen or the Earth, and by clicking it the user can shift the locked perspective. The second one expands the planets to the same size or scale them to natural size, allowing the user to compare sizes or see the appearance of the different planets. The third one is called ”Measure distance” and is a pop-up window which allows the user to select two pairs of planets to display the distance between them. The fourth one toggles whether to display planet names or not. In figure 2.4 the sun is set in the centre, planets are expanded to the same size and the pop-up window is displayed in the top right corner measuring the distance between Earth and Venus, and Earth and Mars.

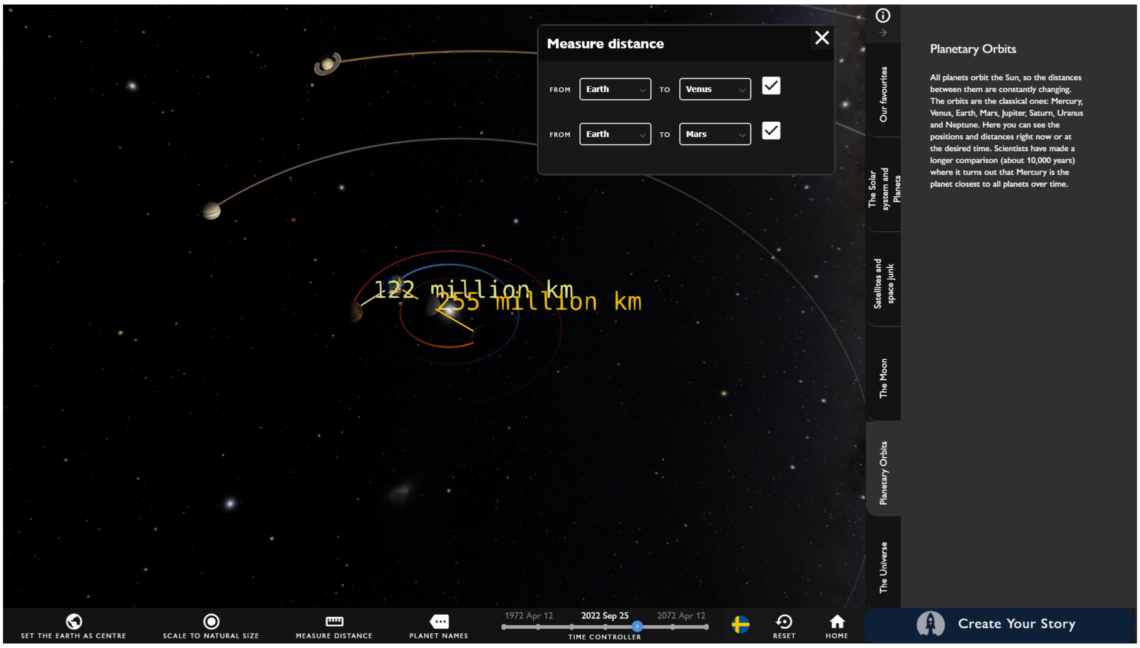

Figure 2.4: Planetary Orbits. In this view you are able to view the solar system with the sun in the center or with the earth in the center, view the solar system with planets scaled to the same size or with their natural size, measure the distance between different planets, show the planets’ names, and forward or rewind the displayed time. The tool to measure distance opens as a pop-up window displayed in the top right of the above figure.

The fifth menu, shown in figure 2.5, is called ”The Universe” and provides six sub-menus to explore the structure of the Universe, from the Earth out to the cosmic microwave background radiation. The six sub-menus, which can be selected from the bottom of the screen, are ”Earth”, ”Solar system”, ”Exoplanets”, ”Milky way”, ”Galaxies & Quasars”, and ”Cosmic microwave background”. The user can rotate and zoom in or out in each menu. Since each sub-menu shows a more zoomed out perspective the user can also zoom in or out between different sub-menus. When clicking on a sub-menu, information on what is currently displayed is shown on the right-hand side. This information only changes when the user clicks a sub-menu, not when the user zooms to a view corresponding to a different sub-menu.

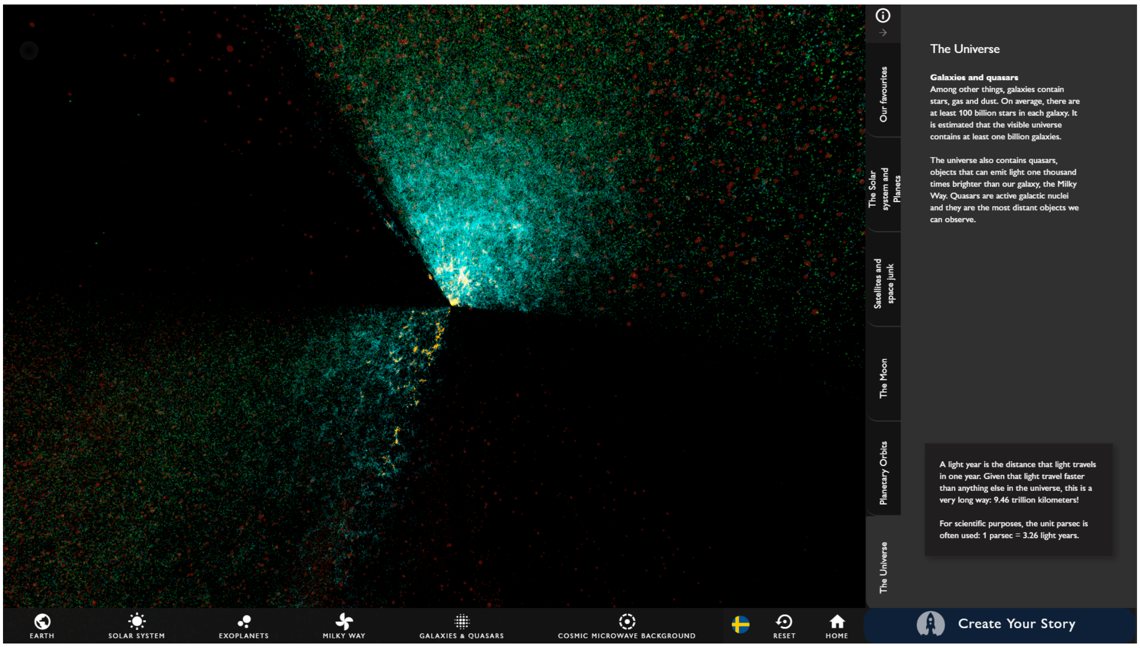

Figure 2.5: The Universe. In this view you are able to explore six differently zoomed in perspectives of the Universe, ranging from planet Earth to the cosmic microwave background radiation. The above view shows the second most zoomed out perspective "Galaxies & Quasars".

The final menu, "Our favourites", is different to the rest and is displayed in figure 2.6. Instead of showing new content, this menu collects selected content from the other menus and displays it in the form of questions. On the right-hand side, the user can choose between five different questions and is invited to explore the view on the left in search of an answer or click the button labelled "Tell me" to read the answer. The view on the left changes when the user selects a different question and corresponds to different places in the other five menus. The first question "The end of the Universe?" corresponds to the sub-menu concerning cosmic microwave background in the menu "The Universe". The second question "Is the sun in the centre?" corresponds to the menu "Planetary Orbits" where the user can toggle the Sun or the Earth to be displayed in the centre. The third question "Which planet is closest to earth?" also corresponds to the menu "Planetary Orbits" with the "Measure distance"-tool actively displaying the distance between Earth and Mercury, and Earth and Venus. The fourth question "Does the Moon have a far side?" corresponds to the sub-menu showing the Moon's orbit in the menu "The Moon". Finally, the fifth question "Is there other life in the Universe?" corresponds to the sub-menu "Exoplanets" in the menu "The Universe".

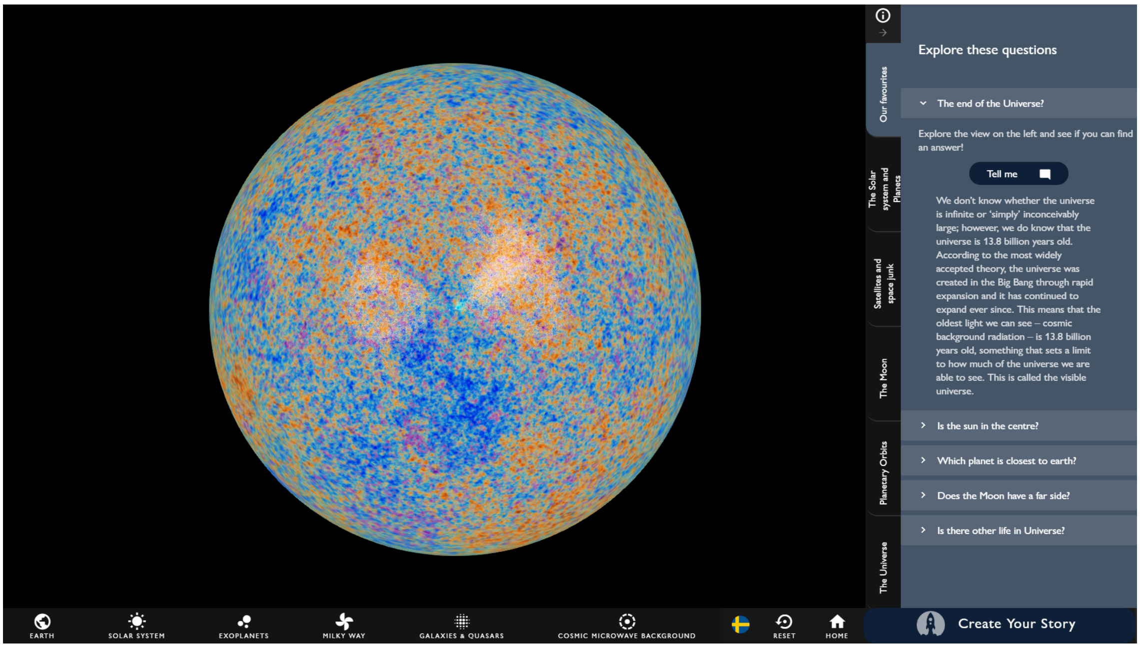

Figure 2.6: Our favourites. In this view you are able to explore five different questions and seek the answer in the view to the left, or read the answer by clicking "Tell me". The view to explore changes depending on the active question, and corresponds to one of the other five menus shown in figures 2.1-5.

3

Theoretical framework

In the following chapter, we will first describe how learning may be understood in the context of a dyad exploring the OpenSpace-exhibit. This will be done from a social constructivist perspective. Thereafter we will present a more specific theory describing how open exploratory learning may take place in the form of Kolb's experiential learning cycle.

3.1 Learning through exploring the OpenSpace-exhibit: Social Constructivism

Before we can describe social constructivism we need to consider constructivism as a whole. As described by Phillips (1995) the main aspect of constructivism is the question of whether knowledge is a human construct or if knowledge is something merely discovered by humans. This dimension may be seen as a continuum where different constructivist thinkers have different positions, though as Phillips states "... there is a point somewhere along this dimension where one ceases to *be* a constructivist." (Phillips, 1995, p. 7) Another dimension characterising constructivism, according to Phillips, is the continuum between focusing on the construction of knowledge in an individual or looking at the construction of human knowledge as a whole. The third dimension of constructivism, also described by Phillips, is that of individual or social activity. One may conclude that the construction of knowledge is seen as an active process, but there are different views regarding the activity. As stated by Phillips "... the activity can be described in terms of individual cognition or else in terms of social and political processes (or, of course, in terms of both)." (Phillips, 1995, p. 9).

Now that constructivism has been laid out very briefly, we may describe how we define learning in the context of exploring the OpenSpace-exhibit. In terms of Phillips's three dimensions we argue that (1) knowledge is mainly constructed by humans, implying that knowledge cannot simply be absorbed; (2) the construction of knowledge takes place in the individual's cognitive apparatus, implying that knowledge gained in one social setting is transferable to another setting; and (3) the construction of knowledge may be described in terms of social interactions. Thus it is the third (3) aspect that also puts the adjective social in front of constructivism.

Social interactions are however not limited only to interactions directly between human beings. Social interaction may also occur through different types of artefacts, such as images, books and tools. One may for example view a student reading a textbook as actually being an interaction between the author and the student. Lundgren et al. (2020) uses the term mediation to explain this. Mediation describes that humans use different tools and systems to be able to understand and act in the world around them and thus that these tools mediate knowledge. Vygotsky (1978) includes more physical as well as more abstract ”tools” in his definition of mediation: ”Vygotsky brilliantly extended this concept of mediation in human-environment interaction to the use of signs as well as tools. Like tool systems, sign systems (language, writing, number systems) are created by societies over the course of human history and change with the form of society and the level of its cultural development.” (Vygotsky, 1978, p. 7). As a concrete example, mental tools include numbers and arithmetic, which may be used as a tool to gain knowledge about trading, and physical tools include a shovel, which may be a central tool in learning how to dig a hole.

When it comes to the construction of knowledge, i.e. learning something, the social constructivist perspective implies that learning takes place when an individual is active in putting pieces of information together, which is done through interaction with other people or artefacts. This social interaction, especially the human-human interaction is expressed by Dewey stating that ”purposeful activity in social settings [is] the key to genuine learning” (Phillips & Soltis, 2009, p. 56). Though constructivism isn't purely about building structures of knowledge and connecting new information to the previously known, it's also about rebuilding existing structures of knowledge. This is described in the following statement:

> Constructivism not only emphasizes the essential role of the constructive process, it also allows one to emphasize that we are at least partially able to be aware of those constructions and then to modify them through our conscious reflection on that constructive process. (Confrey, 1990, p. 109)

One theory that tries to explain the dynamics of how this construction of knowledge by social interaction works is Vygotsky's well known *Zone of Proximal Development, ZPD*. In condensed form, ZPD states that there are three categories of knowledge with respect to an individual: a set of knowledge which is what a person may do unaided, a set of knowledge which is what a person may do with some sort of aid from a more knowledgeable other (the ZPD) and a set of knowledge which are what the individual is not able to do (Lundgren et al., 2020). To return to the example of digging a hole, the knowledge of how to dig a hole may be in a person's zone of proximal development. That person may not know how to dig a hole, as they haven't done it before. Though with some aid of another person who has previous experience, and the aid of the shovel-tool the person may learn how to.

This position of a social constructivist perspective on learning for the OpenSpace-exhibit may be further strengthened. As this study regards learning in a museum exhibit we may, as a final remark, note that constructivism is a common perspective on learning in museums. In a study by Phipps (2010) the author presents that the two most used perspectives on learning in museums are the constructivist perspective and the sociocultural perspective. As the social constructivist perspective is a constructivist perspective it may seem a justified perspective on learning for this study.

3.2 Experiential learning

One theory within the social constructivist umbrella is that of Experiential learning created by David Kolb. Drawing inspiration from the works of the two constructivists John Dewey and Jean Piaget, as well as psychologist Kurt Lewin, he defines learning as "the process whereby knowledge is created through the transformation of experience" (Kolb, 2014, p. 49). Something to note in this short quote is the similarity between Kolb's emphasis on knowledge being created with that of constructivists emphasising the construction of knowledge. This is done via transformation of experiences, emphasising the role the environment around the learner has in constructing new knowledge. Lastly, Kolb emphasises that learning is a process rather than a set of outcomes to be measured, and illustrates this in the form of a cycle.

The learning cycle in Experiential Learning involves four distinct modes of learning: Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC) and Active Experimentation (AE). This cycle is presented in figure 3.1. As can be seen in the figure these four modes of learning are related to one another in two dimensions of dialectical opposites: one concerns how to grasp experience via concrete experience or abstract conceptualization and the other concerns how to transform experience via reflective observation or active experimentation. Kolb continues: "Learning arises from the resolution of creative tension among these four learning modes. This process is portrayed as an idealized learning cycle or spiral where the learner 'touches all the bases' - experiencing (CE), reflecting (RO), thinking (AC), and acting (AE) - in a recursive process that is sensitive to the learning situation and what is being learned" (Kolb, 2014, p. 51).

To further explain the two dimensions we will look at them separately. Firstly, grasping experience can be done via either concrete experience or abstract conceptualization. Kolb (2014) explains this by the example of experiencing something through your senses compared to putting words to that experience. The first is perhaps a more 'pure' way of experiencing the world, but a quickly changing one, while the second introduces structure to a flow of sensory impressions which can never quite embody the whole experience but will allow for it to be communicated to others. The second dimension concerns how to transform experience via either action (AE) or reflection (RO). This means that you can either transform experience via reflecting on it and noting certain aspects of it for further inspection or you can transform experience via actively extending it in experimentation and trying something slightly different. Kolb (2014) uses the example of a rose lying on a table - an experience you can transform via noting its colour (RO) or picking it up (AE) and getting your finger pricked by one of its thorns.

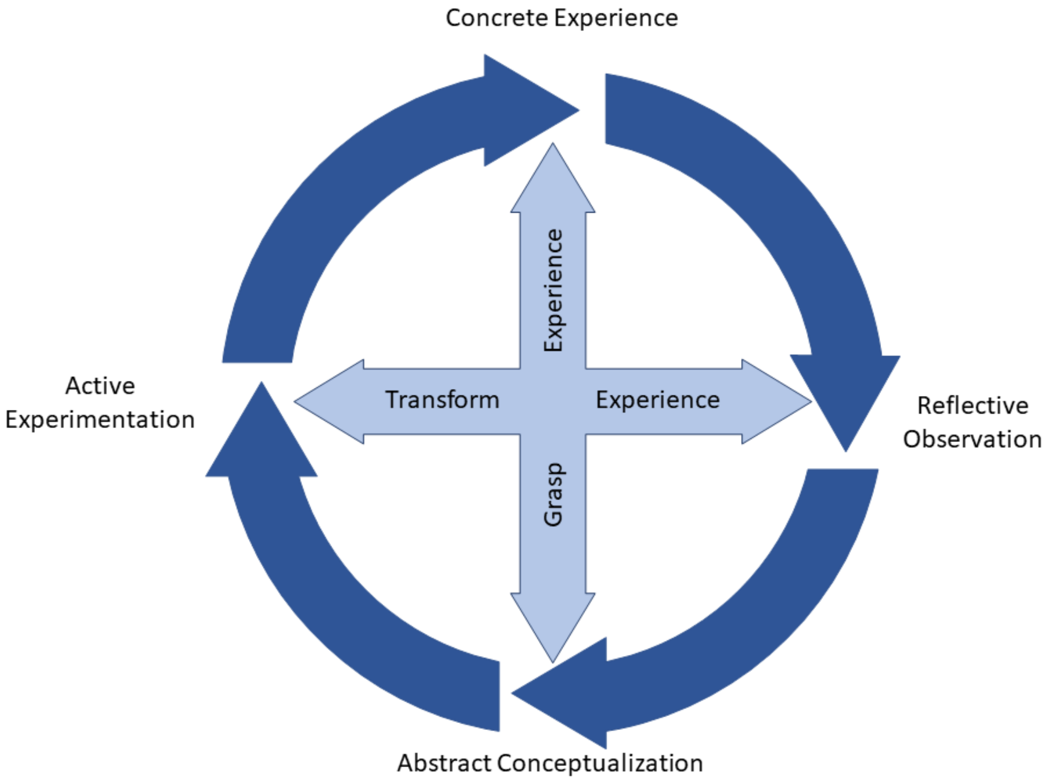

Figure 3.1: A graphic representation of Kolb's experiential learning cycle consisting of four modes of learning: Concrete Experience, Reflective Observation, Abstract Conceptualization and Active Experimentation. They are related to each other by the two dimensions of ways to grasp experience (vertical spectrum) or transform experience (horizontal spectrum).

Although described here in terms of grasping and transforming immediate experiences, Kolb (2014) argues that the learning cycle can be seen as an all-encompassing concept of learning - simply with varying degrees of extension in time and space from problem-solving and decision-making to development and adaption to environment. Coming back to the learning cycle again, Kolb (2014) reflects on the demands this puts on the learner in the following quote:

> [The learner] must be able to involve themselves fully, openly, and without bias in new experiences (CE). They must be able to reflect on and observe their experiences from many perspectives (RO). They must be able to create concepts that integrate their observations into logically sound theories (AC), and they must be able to use these theories to make decisions and solve problems (AE). (Kolb, 2014, p. 42)

To some extent, all these abilities are readily available to all learners and happen without thinking when we, for example, decide what to wear in the morning but can be developed to a more profound degree when it comes to for example scientific inquiry.

4
Methods

In the following chapter, the methods used in this study are presented. Starting with a description of how the study was designed then follows the data collection method and analysis methods. The study was designed in the form of a field experiment, using think-aloud protocols (Ma et al., 2020) to collect participants' conversations and analysed in two dimensions: type of talk and content of talk.

4.1 Design of study

The process of designing the study started with asking the question of how to actually measure learning. Since the aim of this study is to examine whether learning is taking place and if so also how learning is taking place in the OpenSpace-exhibit, we need a way to measure learning. The issue here is that what learning actually is and how to measure it is not a trivial question. The traditional way to measure learning in for example a school environment, is to measure what indications of learning can be demonstrated through a written, time-restricted test. In this study, we do not take this perspective and instead focus on what indications of learning can be extracted from participants' talk, as expanded upon in section 2.1. The aim of this study is to as well as possible, describe the possible learning which takes place in the OpenSpace-exhibit, not only during our study but during a regular visit as well. Thus we decided on the following governing design principle for the study: the study should as closely as possible mimic a regular visit to the exhibit. In doing so the study should strive to minimize the participants' feeling of being examined and make them feel as comfortable as possible. We will now expand upon the thoughts behind the construction of the study.

In an attempt to mimic an ordinary visit and capture typical visitor behaviour, the study was designed in the form of a field experiment. This meant conducting data collection on-site, during regular opening hours and by recruiting visitors as participants on-site instead of recruiting people from outside the science center. The form of the study as a field experiment may also be seen in contrast to conducting the study as an isolated laboratory experiment which would further decrease the resemblance to a typical visit. More specifically the data collection was chosen to be done during a school holiday to be able to more easily recruit participants to the study. The reason for this is that the science center is much busier during school holidays. The possibly different group of visitors on the holiday were assumed to not affect the results.

In a typical visit to the museum, a visitor does not get any guidance on how to interact with the exhibit or any specific tasks to solve. Thus to mimic an ordinary visit the study does not focus on any specific tasks but instead measure what the participants learn in an unguided exploration of the exhibit. To measure the learning of the participants in a way that makes it possible to describe how the learning takes place in the exhibit, minimize the disturbance of their museum visit and minimize participants' feeling of being monitored or evaluated we chose to measure the learning through *think-aloud protocols*. This may be seen in contrast to methods to evaluate learning via pre-tests and post-tests, which is further from an ordinary visit and might more strongly make a visitor feel like they are being evaluated and monitored. A think-aloud protocol consists of the participants expressing their thoughts aloud during the exploration of some exhibit or exhibition, while also being recorded. The recording is then saved for later analysis. The data collection method of recording and analysing visitor conversations has been used in several previous museum studies (Ma et al., 2020; Allen, 2002; Lee and Kim, 2007; DeWitt and Hohenstein, 2010; Tunnicliffe and Reiss, 2000; Scalfi et al., 2022). We use the term *think-aloud protocols* from Ma et al. (2020). To further be able to motivate if learning takes place or not during an exploration of the exhibit, the study also includes a finishing question asked after the participants' exploration of the exhibit.

Before the participants are asked to start exploring the exhibit they need to be introduced to the study. The introduction consists of telling the participant what is studied, why it is studied and how the study is done. We decided to do an oral presentation of this information alongside a printed information sheet that the participants can take with them after their participation.

More practical details regarding the collection of the spoken thoughts of participants include audio recording and collection of consent. To be able to record the participants, we decided to use a clip-on microphone attached to their shirt or held in their hand. In order to collect informed consent to participate in the study, the participants are given an information sheet regarding the study and are asked to give their consent in an online questionnaire. The questionnaire also log their age to make sure the study cover a broad range of different visitors. To ensure that the participants would be able to withdraw their consent the information sheet also contain an anonymous id-number, which is mapped to the corresponding audio recording.

To test and improve the design of the study we conducted a pre-study to explicitly test whether to study only pairs of participants or include both pairs and single participants. The idea, gained from Ma et al. (2020), to examine dyads was because the talk is supposed to flow more naturally when exploring in pairs. We also wanted to train ourselves in leading the study and be able to test for unexpected problems before the main collection of data.

The pre-study confirmed the suggestion of talk flowing more naturally with pairs of participants rather than a single participant. The pre-study also showed that it wasn't obvious to all participants how to interact with the interface, at least not in the context of being part of a study. Since interface design wasn't the primary focus of the study we do not want the participants to be hindered in their exploration due to interface issues. Therefore, to not hinder the participants due to interface issues, the study leaders introduce the interface to the participants and the study leaders are allowed to interfere when there is an obvious interface issue.

The first part of the pre-study also made us realise that it would be very difficult to afterwards interpret what the participants were talking about if we cannot see what they explore on the screen. We therefore decided to video record the screen while the final participants in the pre-study explored the exhibit. This was done by using a mobile phone held in place by a selfie stick and taped to the side of the exhibit screen so that it hovered over the screen. To keep the participants anonymous we also made sure the video recording only covered the screen so that only the participants' hands would be visible apart from the screen. Thus the data collection also includes video recording the screen while the participants interact with the exhibit.

After the pre-study had been completed, data collection began. We decided to collect data from participants until saturation of data had been reached, i.e. until participants are repeating roughly the same sentiments. This is to be able to state that we would have captured the typical visitor's behaviour.

4.2 Collection of data

In order to capture typical visitor interaction with the visualization exhibit, we conducted the study over the course of six days where visitors inside the Vislab exhibition were asked to participate in a study. After an introduction to the study and a short questionnaire, the participants were asked to explore the exhibit whilst thinking aloud. This was recorded for later analysis. When the visitors had finished exploring we asked a final question about what stuck with them from the interaction before thanking them for their participation. The process is expanded on in more detail under the corresponding headings.

4.2.1 Recruitment of participants

Participants were recruited in dyads (two and two) during regular opening hours of the science center in order to capture ordinary visitors. Data gathering was conducted during a school holiday as it is one of the more busy weeks of the year, and thus makes the data collection more time efficient. As long as the exhibit was unoccupied participants were actively recruited by approaching anyone inside the exhibition who seemed to meet our criteria. The criteria were: being in a group of two or more people, speaking Swedish or English with ease and not in charge of children younger than around 10 years old, as these were considered too young to participate due to the target group of the exhibition being 13+. Furthermore, because we required legal guardian consent from participants younger than 15 years old, any children or youths were asked their age and if their legal guardian was present to collect said consent before being allowed to participate.

After recruitment, the participants were introduced to the study's aim and method. Consent to participate in the study was collected via an online questionnaire which also gathered the participants' age as background information. Each participant was also given information about the study and our contact details in written form to take home, see Appendix A, in order to make sure that consent could be withdrawn at any time if the participants so wished. In order to keep the participants anonymous, each dyad was given a unique identification number, e.g. dyad (pair) number 13 was labelled ”P-13” in the questionnaire, on their participant slip and in the recordings of their exploration.

4.2.2 Exploration of the exhibit

In order to study the thought process occurring during the exploration of the exhibit, think-aloud protocols (Ma et al., 2020) were used. This method means asking the participants to think aloud as they interact with the exhibit. The interaction was recorded with both video and audio and later transcribed for analysis.

Before the participants were asked to initiate their interaction with the exhibit the researchers did a two-minute demonstration of the exhibit's interface. The demonstration first introduced the core functions of interaction, i.e. how to zoom in/out and rotate the current view. Secondly, they were shown the menu part of the interface. This meant showing them that there are different types of sub-menus, information texts, fact-boxes and tools. Lastly, the participants were instructed on two distinctive parts of the interface. The first one was the time-control tool (seen in figure 2.3) which allows the user to forward or rewind the displayed date and time. The second one was the menu ”Our favourites” (seen in figure 2.6) which, instead of displaying information, shows questions with matching answers from the creators of the exhibit.

Participants were asked to interact with the exhibit for as long as they wanted and to let us know when they were finished. They were told that they could spend how much or how little time they liked. The participants were also made aware of the fact that they themselves were not under any sort of examination, as the study aims to examine what knowledge the exhibit enables the visitors to acquire. Whilst the participants explored the exhibit a researcher was present to prompt participants to speak when falling silent or ask for clarification. If participants expressed in some non-articulate way that some cognitive behaviour had taken place but did not elaborate, e.g. by looking surprised or by exclaiming “wow”, the researcher could interrupt and ask for clarification. The researcher also helped the participants with interface-related issues, e.g. if wondering what the names of the planets were, the researchers would point to the button that displayed the names. This was to further reduce the risk of participants being hindered in their exploration due to interface issues.

When participants had finished exploring, they were asked a concluding question about what they considered interesting while exploring the visualization exhibit or if there was something that they felt they would take away from the exploration. This was included in the recording, after which point the recording was stopped and saved for further analysis expanded on in the next section.

4.3 Analysis

Using both the audio and video recordings, the participants' interaction with the visualization exhibit were transcribed and saved in think-aloud protocols for analysis. Each statement was coded in two ways: by what type of cognitive behaviour their talk classified as and by what subject content they concerned. A statement could span in length from a few words to several minutes worth of talk as long as the topic of conversation did not change. The categorisation by type of talk was based on the seven categories of cognitive behaviour from Liu and Heer (2014) but using an inductive and iterative approach changed into fifteen categories clustered in three groups: those concerning learning, the system or experiences. The categorisation by content was done with the aid of the existing topical menus in the exhibit.

4.3.1 Transcription

The saved audio and video recordings were both used in the process of transcribing the interaction. Each statement by a participant was marked with a given timestamp from the audio recording and with which participant was speaking (Speaker 1 or Speaker 2). Microsoft 365 Word's online transcription software "Transcribe" was used to save some time in this process but thoroughly checked and edited afterwards. Furthermore, the video recordings were used to insert actions done by users that the audio recordings did not pick up. These included for example pointing to an object on the screen whilst referring to it as 'this' or 'that'. To be able to read what they are referring to, a square bracket was inserted to indicate the object pointed to. Also, any user action which radically altered what was displayed on the screen or which the participants commented on was inserted, such as pressing a menu button or zooming quickly in or out, or changing the speed of the time controller. Since this alters the content displayed on the screen these were placed in square brackets in the spoken text to know when this change occurred. Lastly, any statement that could not be made out from either the audio or video recordings was marked as *inaudible* to mark that something was spoken, but either too softly or mumbled to be interpreted.

4.3.2 Categorisation by type

Categorisation by type of thought expressed out loud was based on the categories created by Liu and Heer (2014). The study by Liu and Heer is based on the methodology designed by Saraiya et al. (2005), which was designed as a tool to evaluate statistical visualization tools by their effectiveness in generating insights. The method was later adopted and modified by Liu and Heer to better suit a broader evaluation by extending the focus from insights to 'cognitive behaviours'. For example, Liu and Heer added the category *Questions*, which might not be considered an insight per se, but a relevant category as a stepping stone toward gaining insight. In sum, the following seven categories are adopted by Liu and Heer: Observation, Generalisation, Hypothesis, Recall, Question, Simulation, and Interface.

Using these initial seven categories as a baseline for analysis the pre-study transcripts were analysed to get a 'feel' for the categories and to add any needed additional categories. In this process, the goal was to include all talk in some category, even though the main interest was still learning talk. The coding was then performed in close collaboration between the two coders to ensure consistency - multiple transcripts were coded by both and then compared and discussed, and any uncertainties were discussed between the coders. In this process, the categories were further developed and more precisely defined which led to a sum total of 15 categories of type. In order to confirm consistency, the categories were examined one by one in collaboration and any deviations were moved to the correct category. The overarching goal when fine tuning the coding was to find the core activity in each statement and code it as such - this means that if a statement could be seen to fit more than one category the core component of that statement was given priority.

As this process involved adding categories which did not relate to learning, a final step was taken that grouped together type-categories related to learning, those related to the visualization system and those related to experience. The result was the following 15 categories with corresponding definitions.

Type-categories of learning:

- Observation - included from Liu and Heer (2014), Observation contains any description of observed phenomena in own words, including any associations.

- Comparison - adapted from Liu and Heer's (2014) "Generalisation", Comparison contains all statements which include a comparison between two or more observations without strictly needing to be a generalising statement.

- Shallow Question & Answer - adapted from Liu and Heer's (2014) "Question" and "Hypothesis", Shallow Question & Answer refers to a subject related question generated by one of the participants or the system, including any shallow search for an answer or shallow answer generated by a participant or the system. Shallow means that the question either isn't attempted to be answered, is given a brief answer such as "Yes." or the answer is only given by the system (i.e. not answered by the participants).

- Deep Question & Answer - also adapted from Liu and Heer's (2014) "Question" and "Hypothesis", Deep Question & Answer refers to a subject related question generated by one of the participants or the system, including any deep search for answer or deep answer generated by a participant. Deep means that the search for an answer or the answer itself goes beyond what is directly presented in the system.

- Recall - included from Liu and Heer (2014), Recall contains any reference to earlier subject knowledge either by sharing information not in the system or expressing a contrast or confirmation to earlier knowledge.

- Mental visualization - adapted from Liu and Heer's (2014) "Simulation", Mental visualization contains all expressions of internal visualization of something not visualized in the exhibit.

- Quotation - reading text aloud from the exhibit.

- Interpretation of Written Information - summarising or reflecting on any text in the exhibit by putting it into own words.

- Interpretation of Visual Information - an expression of interpretation of what is seen on the screen either in questioning what the objects are or identifying said objects using the participants' own subject knowledge.

- Exploration - an expression of testing the system's boundaries and functionalities in search of a specific object or view, including any attempts to find the object or view.

Type-categories related to the visualization system:

- Interface - included from Liu and Heer (2014) but considered less relevant for learning, Interface contains any comments relating to the interface of the system such as any limitations discovered.

- Instruction - instructions given by the study leaders to help participants find the sought after function in the interface.

- Orientation - an expression of confusion or questioning of the navigation or functionality of the system, including arriving at an understanding.

- Planning - talk about the structuring of the exploratory activity.

Lastly, type-categories relating to experience only included one category:

- Indication of experience - affect words indicating a positive or negative experience which are detached from any other type of talk.

Comparing these to the categories of Liu and Heer (2014) a few categories were added which could be seen to be more distinctive of museum exhibits - Interpretation of written and visual information, "Exploration" and "Quotation" - and a few more system talk categories as well as an experience category to capture the affective talk.

4.3.3 Categorisation by subject content

Categorisation by subject content was done with the aid of content menus in the visualization exhibit, with the exception of the menu "Our favourites" which consisted of questions regarding content within three of the other five menus. The transcriptions were therefore coded to the corresponding subject, ending up with the following five categories:

- The Solar system and Planets - content about the appearance, characteristics and scientific history of the eight planets in the solar system.
- Satellites and space junk - content about satellites around the Earth with human origin.
- The Moon - content regarding the Moon, its orbit and phases.
- Planetary Orbits - content regarding the position, the relative position and distance between planets in the solar system at a specific time.
- The Universe - content regarding the general structure of the universe including the cosmic microwave background radiation, galaxies, quasars, the Milky Way, exoplanets and the solar system as a single object (i.e. content such as the size of the solar system or its position in the Milky Way).

The appearance of the Earth could be explored from multiple content menus but all such exploration was coded as belonging to ”The Solar system and Planets” as that is the main menu related to the appearance of planets in the solar system.

5

Results

The result of the study is presented in the following chapter. First demographic information of study participants is presented before a qualitative and thereafter quantitative presentation of the collected data. The qualitative section presents selected quotes from the study to illustrate the different learning type-categories. The quantitative section presents the number of coding references organised by group of type-categories, before examining in more detail the learning and system type-categories separately. Thereafter, content categories and the cross-section of type and content are presented. Finally, the perceived learning of the participants is presented in the form of illustrative quotes from the finishing question in the study.

5.1 Demographics of participants

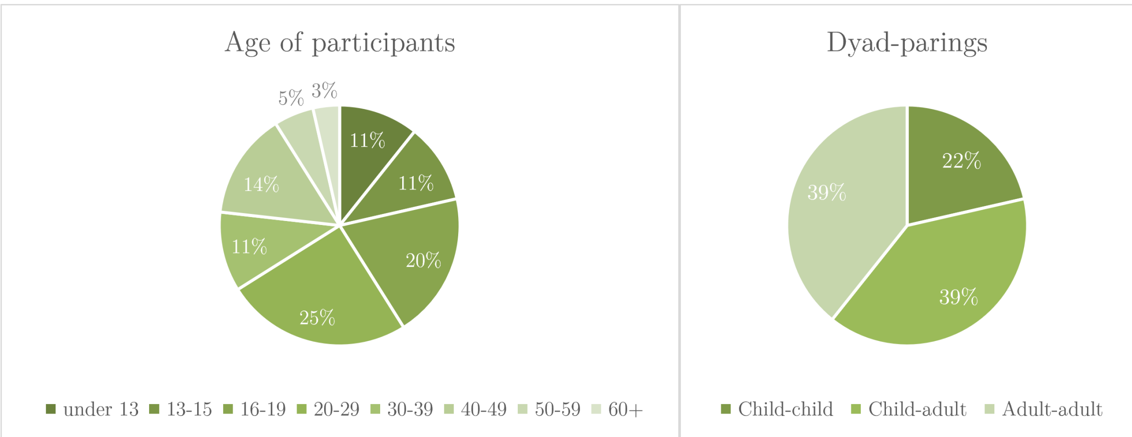

Figure 5.1: Two pie charts showing the demographic information of participants in the study. The chart on the left displays the age groups of all participants ranging from under 13 to over 60. The chart on the right displays the pairing of participants in dyads of only adults, only children or child-adult dyads. Please note that 'child' is defined as a participant up to the age of 19.

In total, 26 dyads were recruited to take part in the study. The demographic information about these participants can be seen in figure 5.1 where the age range of the participants are presented in one pie chart and the pairing distribution of the dyads in child-adult, child-child or adult-adult are presented in a separate pie chart.

However, note that 'child' is defined as anyone up to the age of 19. In this figure, one may note that there is a wide spread of participants' ages, but that 16-19 and 20-29 years old are the biggest sections, representing 45% of all participants, and 50-59 and 60+ years old are the smallest sections. We can also observe that there were more child-adult and adult-adult dyads, but still a significant amount of child-child dyads.

5.2 Qualitative illustration of type-categories

In the following section, quotes from the ten different learning type-categories are presented to illustrate typical quotes in each category.

5.2.1 Shallow Question & Answer

The "Shallow Question & Answer"-category contains questions that get a shallow answer or no answer at all. An example of a question that doesn't get an answer is the following:

> Speaker 2: Isn't the Universe constantly expanding? But isn't it infinite. That confuses me.
> Speaker 1: Yeah, I don't know, actually. I haven't gotten that far.
> [authors' translation from Swedish, original in Appendix B] (1)

Another example of such a question is the following, regarding the white areas of Mars:

> Speaker 1: It's kind of cool. I wonder what that is? [zooming in on a white area near one of the poles]. Is just a plume or something? (2)

A third example of a shallow question-answer is the following, where a brief answer is given regarding the International space station:

> Speaker 2: What is ISS? The international space station.
> Speaker 1: Now there is a red one, the red one wait there. It's speeding. What does it do?
> Speaker 2: It's a space station.
> [authors' translation from Swedish, original in Appendix B] (3)

5.2.2 Interpretation of Visual Information

The category called "Interpretation of Visual Information" contains the participants' talk which indicates that they try to understand what they see or do not understand what they see, i.e. the visually represented information. One such example of participants who do not understand what is shown is presented in the following quote regarding the dots representing galaxies and quasars (see figure 2.5):

> Speaker 2: But, why are there different colours? [about the ”Galaxies and quasars”-view]
> Speaker 1: I don’t know.
> Speaker 2: What are they supposed to represent, stars or sun-?
> [authors’ translation from Swedish, original in Appendix B] (4)

Another example of participants trying to understand what they see is when looking at the surface of the Earth:

> Speaker 2: Gives a little wei*. What is this eh wait. What is this country thing something?
> Speaker 1: That’s Africa right?
> [authors’ translation from Swedish, original in Appendix B] (5)

A final example of participants interpreting what they see is the following, where participants not only wonder about what they see but also identifies what it is:

> Speaker 1: [Clicks on ”Moon’s orbit”-view] So is this like, the earth?
> Speaker 1: I think that’s the earth. [Zooms in on Earth in the ”Moon’s orbit”-view] (6)

5.2.3 Observation

The theme ”Observation” contains talk concerning the description of what the participants see when using the exhibit. A first example is associating the appearance of Mercury with the appearance of the moon:

> Speaker 2: [Zooms in on Mercury] Oh, how pretty.
> Speaker 1: Oh, looks like the moon.
> [authors’ translation from Swedish, original in Appendix B] (7)

A second example of a participant describing what they see is the following, regarding Venus:

> Speaker 2: [Clicks the Venus-button] It kinda looks like a very dry Earth.
> [authors’ translation from Swedish, original in Appendix B] (8)

A third example of a participant describing what they see regards the amount of space junk orbiting Earth.

Speaker 2: What the hell?[...] We thought that Earth was polluted.
Speaker 1: There is a lot. (9)

5.2.4 Recall

The category called ”Recall” includes statements from people that indicate that what they say has a clear connection to a, to them, earlier known fact. For example recalling the fact that Pluto isn't classified as a planet anymore when observing that it isn't possible to look at Pluto, as seen in the following statement:

Speaker 1: Also sad. No, no more Pluto.
Speaker 2: No more Pluto. RIP Pluto. (10)

Another example of ”Recall” is that participants quite suddenly state a fact that isn't related to what was previously talked about:

Speaker 2: Light actually isn't the fastest that... it. Darkness is a lot faster than light. (11)
[authors' translation from Swedish, original in Appendix B]

There are also examples of the information that the participants get from the exhibit is in contrast to what they already know, as seen in the following example about the position of the solar system in the Milky Way:

Speaker 1: Did you know that it was located quite far out in the Milky Way?
Speaker 2: No.
Speaker 1: It really is located in the outskirts. (12)
Speaker 2: I had no idea about that.
[authors' translation from Swedish, original in Appendix B]

5.2.5 Deep Question & Answer

The ”Deep Question & Answer”-category contains statements where the participants' talk goes beyond what is stated in the exhibit and mere descriptions of what is seen. A lot of the statements in the ”Deep Question & Answer”-category are quite long. To promote the readability of the results here we've chosen to only present some of the shorter examples.

A first example is the participants looking to confirm the answer provided by the system in the "Our favourites"-menu by using the exhibit:

> Speaker 2: [Clicks "Which planet is closest to earth"] Which planet is closest? Mars. [Clicks "Tell me"] It depends on the date. That make sense. So if we move forward [Fast forwards on the time control]. Sometimes it will be other planets. (13)

Another example is a participant showing a deep understanding of what is seen and a quite deep idea about why it could be that way:

> Speaker 1: Oh, it's like a whole wave here. [About the cone formation in the exoplanet-view]
> Speaker 2: Is that the only direction we've looked, you think?
> [authors' translation from Swedish, original in Appendix B] (14)

The cone formation spoken of in quote 14 may be seen in Appendix C, figure C.27.

Another example is participants' reasoning about the system-generated question "Is there life in the Universe?"

> Speaker 1: [Clicks "Is there life in the Universe?"] Explore the view on the *inaudible*. The first planet orbiting another star than our own sun was discovered in 1995. Ah, it's exoplanets. [Clicks "Galaxies and quasars"] Oh my God, that's all, like galaxies and such.
> Speaker 2: Yeah, there's not a chance that we're alone.
> Speaker 1: No, right? If you think like that this is the solar system, and you come down like this. [Zooms in from galaxies to the solar system] It's sooo small. The little solar system. Then we come to exoplanets. The Milky Way alone is like. [Looks at the Milky Way view] If we think about that all of these are solar systems, every little dot - there isn't a chance - are like solar systems.
> Speaker 2: We are far too egoistic if we think that we're the only ones.
> [authors' translation from Swedish, original in Appendix B] (15)

5.2.6 Interpretation of Written Information

The type-category "Interpretation of Written Information" consists of the participants' talk containing an indication of the participants trying to understand the written information in the exhibit. An example is the following quote where participants read about the surface temperature on Jupiter:

Speaker 2: What's the temperature? Cold.
Speaker 1: Very cold. (16)

Another example of interpretation is when the participant read information and then tries to understand the information visually, as in the following example, when looking at the lunar surface:

Speaker 1: Aha! They think that certain areas have been filled with water. These... in the past. The dark areas.
Speaker 2: How about these? [points at the dark areas on the lunar surface]
Speaker 1: Yeah, could it be those, perhaps?
[authors' translation from Swedish, original in Appendix B] (17)

5.2.7 Exploration

The "Exploration"-type concerns talk about the participants in some way trying to figure out what is possible to see while exploring the exhibit. One example of this is participants exploring the surface of the earth, trying to find where they live:

Speaker 2: Find where we're living!
Speaker 1: I think we can't zoom that much. Maybe? (18)
Speaker 1: Eyy, I think it's right there. [Points at some location]

Another example of exploration is one dyad trying to see if it's possible to see the centre of the Milky Way:

Speaker 2: Oh, can we actually head to the center?
Speaker 1: I mean, it's not like we're going to get great. Pictures of the center but yeah. (19)
Speaker 2: That's true, that's true.

5.2.8 Quotation

The "Quotation"-type consists of talk when the participants read aloud what is written in the exhibit, without any further indications of interpretation. As an example when reading about the Earth:

Speaker 2: I see. Oh it's just 1 1 [looking at the "quick facts" about earth year and day]. (20)
Speaker 2: Number of moons: 1.

Another example is reading the full info text aloud, in this example about the planet Mercury:

> Now lets see. Mercury is the planet closest to the sun. It is the smallest of the eight planets in the solar system, with a heavily cratered surface much like the moon. Mercury has virtually no atmosphere and its surface temperature varies greatly, from -183 degrees on the dark side to 427 degrees on the sunlit side. The planet has been known for at least 3,400 years, when it was described by the Babylonians.
> [original quote in Swedish (see Appendix B), translated by the system since the original quote was practically verbatim of the displayed text - see Appendix C: Figure C.8 for the exact text displayed in the system in Swedish and C.9 for English] (21)

5.2.9 Comparison

The ”Comparison”-category contains talk where different aspects are connected and compared by the participants. For example, comparing the rotational speed of planets:

> Speaker 1: Woah! Mercury is so much. Faster than Earth.
> Speaker 2: Yeah because it has- it is. [indicates Mercury’s orbit around the sun]
> [authors’ translation from Swedish, original in Appendix B] (22)

5.2.10 Mental Visualization

The ”Mental Visualization”-category contains talk indicating that the participants visualize information in their own mind, i.e. not through the use of the exhibit. An example of this concerns the moon’s phases.

> Speaker 1: Then we should just see like if you split it in half, you see that surface. [illustrates on the screen by ”splitting” the moon in the plane of the screen]
> Speaker 2: Yeah. And then it’s full moon, right? That’s how it is.
> [authors’ translation from Swedish, original in Appendix B] (23)

5.3 Quantitative illustration of type and content themes

In the following section, the quantitative part of the results are presented in graphs and tables. In figure 5.2 type of talk by number of coding references is presented in a treemap chart. Following the groups of type-categories discussed in section 4.3.2, the number of coding references pertaining to learning talk are 565, which are 72% of the total number of coding references. System talk has 183 references, meaning 23% of the total number of references, and experience talk has only 37 references or 5% of the total.

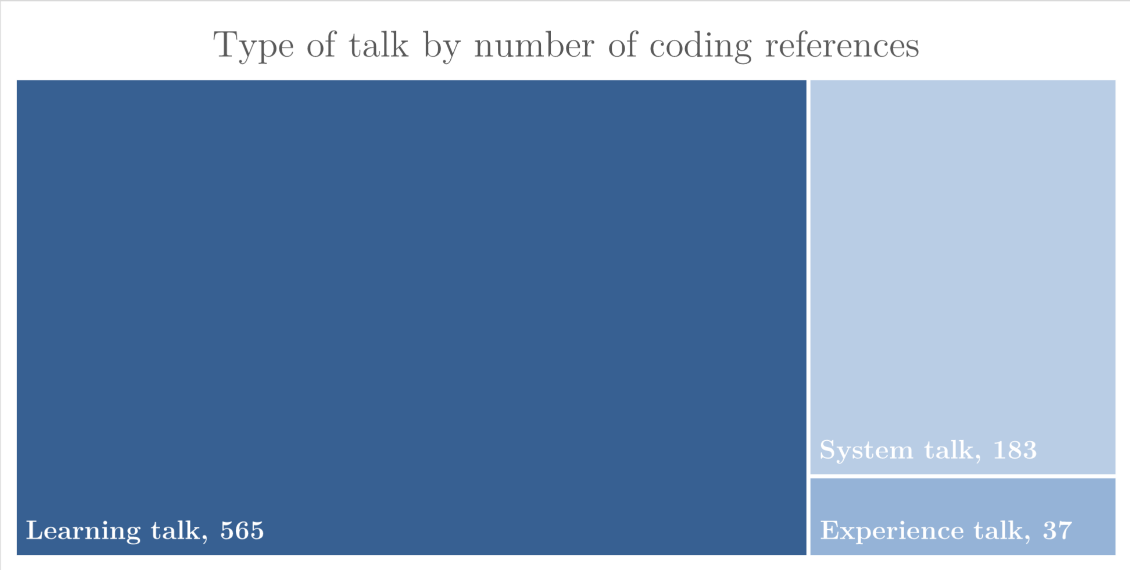

Figure 5.2: The tree map chart illustrates type of visitor talk by number of coding references. The most common type is learning talk at 565 references (72%), followed by system talk at 183 references (23%) and experience talk at 37 references (5%).

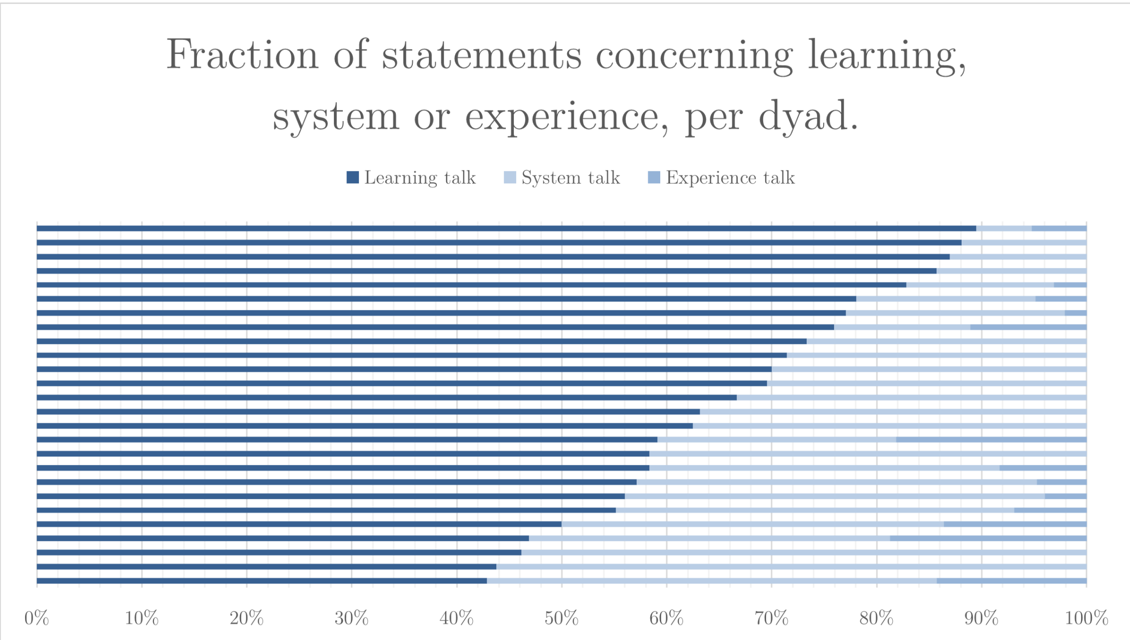

Figure 5.3: The fraction of learning, system and experience talk, presented per dyad. Note that the fraction of learning talk spans the range of 40-90% of statements uttered by a dyad.

A more detailed view of the individual dyads' talk is presented in figure 5.3 displaying the fraction of statements concerning learning, system or experience per dyad. One may note that the fraction of learning talk spans the range of 40–90%.

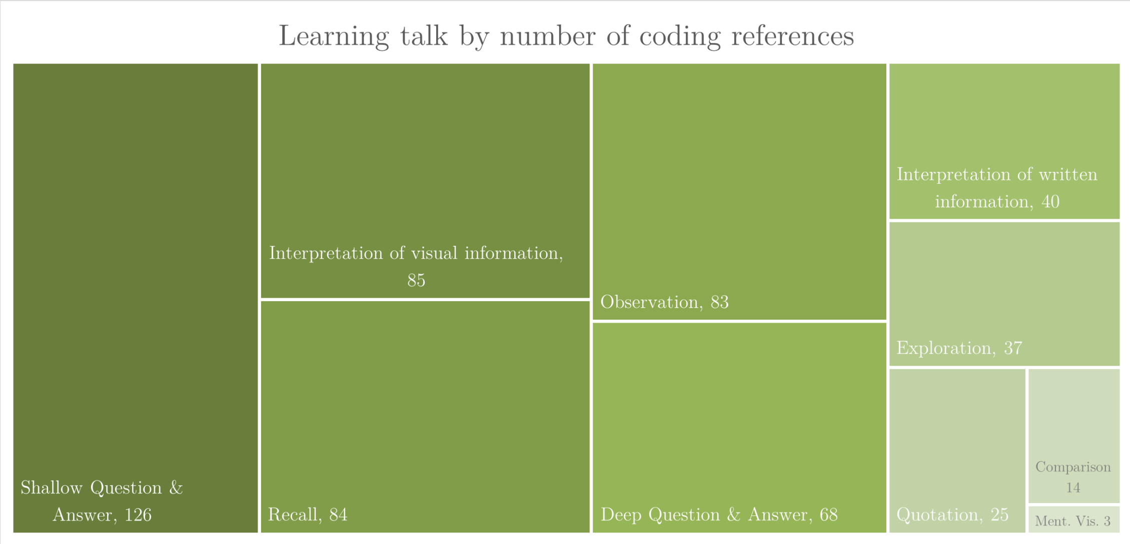

Figure 5.4: The tree map chart above illustrates the most common types of learning talk. Bigger box and darker colour indicates more references. Note the five most common types of learning talk are "Shallow Question & Answer", "Interpretation of Visual Information", "Recall", "Observation" and "Deep Question & Answer".

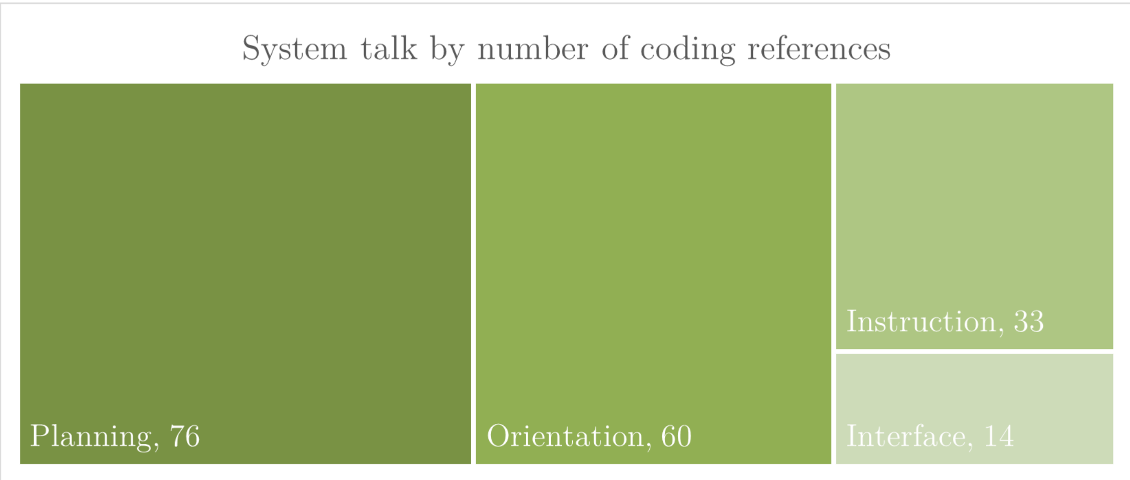

Figure 5.5: The tree map chart above illustrates the most common types of system talk. Bigger box and darker colour indicates more references. Note the very few references of "Interface" compared to most common category "Planning".

To further expand on the different type-categories, figure 5.4 presents the ten different type-categories related to learning in a treemap chart by number of coding references and figure 5.5 presents the four different type-categories related to the system in the same type of chart. In figure 5.4 we can see that the five largest categories "Shallow Question & Answer", "Interpretation of Visual Information", "Recall", "Observation" and "Deep Question & Answer" make up for 75% of all learning talk. The biggest category of system talk, as seen in figure 5.5, was "Planning" with 76 references, and the smallest "Interface" with only 14 references.

The results from categorisation by subject content can be seen in figure 5.6. This treemap chart displays the number of statements regarding learning per subject content category. Note that this chart therefore does not include references of system talk or experience talk but only learning talk. From this we can see that the most common subject content category is "The Solar System and Planets" at 200 references, followed by "The Universe" at 139 references.

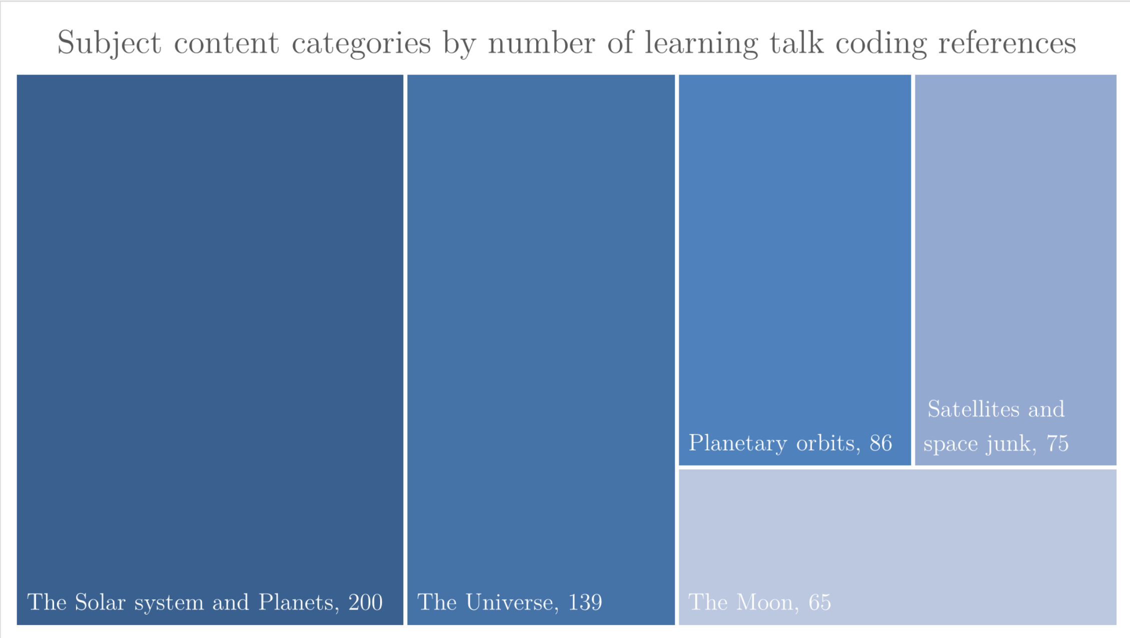

Figure 5.6: The treemap chart above illustrates the most common subject content categories by number of coding references. A bigger box and darker colour indicate more references. Note that the two most common subject content categories are "The Solar System and Planets" and "The Universe" which together make up for 60% of all coding references. The last three subject content categories "Planetary Orbits", "Satellites and space junk" and "The Moon" each contain around 10–15% of all coding references.

Putting together the result of figure 5.4 and figure 5.6, we present the result of intersecting learning type-categories and subject content categories in the matrix seen in figure 5.7. Note that the table can be analysed from left to right - to find what content categories are most common within a specific type of learning talk - or from top to bottom - to find what types of learning talk are most common within a specific content category. For example, an analysis from top to bottom yields the result that "Shallow Question & Answer" were the most common type of learning talk within the content category "Satellites and space junk" and an analysis from left to right can tell us that "The Universe" was the most common content category within the type-category "Interpretation of Visual Information". As seen in the figure the most frequent combination of content and type were ”Recall” within the content category ”The Solar system and Planets” at 46 references.

In figure 5.7 one may also observe four other notable traits. Firstly, ”The Solar system and Planets” stands out in having more references of ”Recall” and ”Observation” than other content categories. Secondly, one may also note that ”The Solar system and Planets” and ”Satellites and space junk” have relatively few statements of the ”Deep Question & Answer”-type. Thirdly, one may also observe that ”The Solar system and Planets” as well as ”The Universe” and ”The Moon” has a lot of statements of the ”Interpretation of Visual Information”-type. Lastly, one may also observe that relative to the total number of statements regarding a content category (i.e. row 11) the ”Satellites and space junk” is the category with the highest fraction of ”Shallow Question & Answer”.

	A : Planets	**B : Universe**	**C : Orbits**	**D : Satellites**	**E : Moon**	**F:Sum**
1 : Shallow Q. & A.	32	36	25	26	7	126
2 : Interp. Visual	20	37	5	9	14	85
3 : Recall	46	12	8	10	8	84
4 : Observation	41	13	7	15	7	83
5 : Deep Q. & A.	10	21	24	3	10	68
6 : Interp. Written	16	7	5	5	7	40
7 : Exploration	18	9	3	1	6	37
8 : Quotation	12	4	1	4	4	25
9 : Comparison	5	0	7	2	0	14
10 : Ment. Vis.	0	0	1	0	2	3
11: Sum	200	139	86	75	65	

Figure 5.7: The table above illustrates the counts of intersecting type of talk and content treated. Furthest to the right is the sum total of each row and at the bottom is the sum total of each column. First one may observe that ”The Solar system and Planets” stands out in having more references of ”Recall” and ”Observation”. Secondly, one may also note that ”The Solar system and Planets” and ”Satellites and space junk” have relatively few statements of the ”Deep Question & Answer”-type. Thirdly, one may also observe that ”The Solar system and Planets” as well as ”The Universe” and ”The Moon” have a lot of statements of the ”Interpretation of Visual Information”-type. Lastly, one may also observe that relative to the total number of statements regarding a content category (i.e. row 11) the ”Satellites and space junk” is the category with the highest fraction of ”Shallow Question & Answer”.

5.4 Perceived learning

After each dyad had finished exploring the visualization exhibit they were asked if there was anything in particular which stuck with them from the short exploration - anything that caught their interest, or something they will take away from the exploration. The answers to this question were coded into two main categories: content-related comments and system-related comments. Out of 26 dyads in total, 19 answers contained at least one content-related comment, 15 contained at least one system-related comment and 9 contained both. This leaves one dyad who did not share any comments on their experience and therefore were coded at neither.

Content-related comments typically revisited a content that had caught the dyad's interest during the exploration such as this quote where the dyad had been fascinated by the "Satellites and space junk"-tab:

> Speaker 1: I like the satellite and space junk one, it's like all of them were going in a line around the equator, and then some of them are just everywhere and then they were like space junk everywhere. Very close by.
> Speaker 2: Space junk was everywhere. It was very close by. I was surprised. It's scary. What if it falls on us? (24)

Or comments relating to content the participants wished had been part of the exhibit, such as this quote, lamenting the lack of information on what chemicals make the planets take on specific colours:

> Speaker 1: What I'm missing is actually why it is these colours that I see? It said on Mars that it was iron oxide. But it doesn't say on the others.
> [authors' translation from Swedish, original in Appendix B] (25)

Lastly many dyads commented on the size or distances in space as their take-home point, which was coded as content-related comments.

> Speaker 2: Space is cool in every way because it's so incomprehensible somehow. That's why it's so co-. It is, yeah, fun with space, I think. What do you think?
> Speaker 1: Yeah, I think it is, yeah, cool.
> Speaker 2: Yeah, yeah, so that, absolutely. And then when you get a bit of distance from it all, when you see everything around, with stars and moons and all that stuff. When you realise how big it is. So that is something I will take away. It's not exactly like you travel there on one tank of diesel really. [laughter]
> [authors' translation from Swedish, original in Appendix B] (26)

System-related comments usually either commented on the features of zooming, rotating or visualizing catching their interest or on the features of the amount of information, the system-generated questions and reasoning.

In one such quote on the feature of visualization a participant commented on the "Exoplanets"-view, where, if you rotated the view, had a clear cone shape going off in one direction (see figure C.27 in Appendix C). The participant in the following quote expands on how that, mixed with their previous knowledge on the Hubble deep field shot, taught them something new:

> Speaker 1: For me, it's the the 3D part of it that I really like.
> Speaker 2: 3D part
> Speaker 1: Because, you can always see like for example, the Hubble deep field. Cool, that's a picture of like how much dense this is, but being able to rotate that and seeing ”oh it's visually this slice that goes off into forever versus this is the ball we normally look at” and then you really get much more of a perspective of how far we can look in this one spot. Like how much more can we discover if we had time to sweep across everything? (27)
> Speaker 2: Exact!
> Speaker 1: And it's, it's really cool getting that perspective because I thought it was. I thought we already looked out that far everywhere and this was just longer exposure versus we actually never really looked out that far anywhere else. It's, it's really cool. It you know it it gives more context being able play with it and look at things.

The next quote illustrates instead the comments on the information to read and the questions to answer when a participant reflects on that process:

> Speaker 2: It was fun to be able to, both do stuff on the screen and to be able to read there. And first, and stand around and guess a little and discuss your way to an answer and then you also get the answer if you want. I thought was really good. (28)
> [authors' translation from Swedish, original in Appendix B]

6

Analysis

In the following chapter, the result is analysed, both in itself and in relation to the theoretical frameworks of social constructivism and experiential learning. The analysis is divided into two sections corresponding to the two research questions ”Does learning take place?” and ”If so, how does the learning take place?”.

6.1 RQ1: Does learning take place?

First we want to investigate if learning actually takes place while visitors explore the OpenSpace-exhibit. The results in Figure 5.2 show that what participants talk about mainly concerns learning, rather than talk about the system or the experience. Figure 5.3 shows that the dyad which had the lowest fraction of learning talk actually had as much as 40%. From this data, it may seem as though learning generally is taking place and to a quite high degree as well. So we may begin by concluding that in general, the dyads do make quite a lot of statements that regard learning. Though we may ask: How may we argue that the type of talk categorised as ”learning talk” actually concerns learning? Figure 5.4 presents the frequency of the different types of learning talk and we will now analyse the five most common learning type-categories - ”Shallow Question & Answer”, ”Interpretation of Visual Information”, ”Recall”, ”Observation”, and ”Deep Question & Answer” - through the lens of social constructivism presented in section 3.1.

To begin with, a core part of a constructivist perspective on learning is that the learner is active in constructing their knowledge which often is built upon existing knowledge. The two type-categories ”Observation” and ”Interpretation of Visual Information” can be seen as active connection to existing knowledge. This may be exemplified by quote 7 regarding an observation that connects the appearance of Mercury to the appearance of the Moon. It can also be seen in quote 4 where the colours in the ”Galaxies and quasars”-view is interpreted by trying to connect it to the dyads existing knowledge of objects in space such as stars and suns.

Constructivism isn’t only about building upon existing structures of knowledge. As mentioned in section 3.1 it also claims that we may be aware of those structures and correct them if they are wrong. The experiences of such contrasts are gathered in the type-category called ”Recall” and may be seen for example in quote 12 where there is a contrast about where in the Milky Way the dyad thought the Solar System was located.

Continuing on to the two ”question & answer”-type-categories. These two categories may be understood with the help of the Vygotskian *Zone of Proximal Development (ZPD)* in the context of the triad of the the two participants and the exhibit itself. As expanded on in section 3.1, ZPD describes learning taking place by expanding what can be done or understood alone through the aid of a more knowledgeable other. In the case of the triad, one of the participants may get aid from both the other participant and the system. As an example, one participant may ask a question which may be attempted to be answered by either the system or the other participant. The formulation of that question from the first participant may then give rise to other types of insights that the second participant may not have gained alone. On the other hand, the first participant asking the question may not know or be able to figure out the answer to their question alone and thus may be able to gain new knowledge through the help of the second participant or the system. This means that both formulating and answering questions may be done by either the system or the individual participants and thus enabling learning in the individuals.

The learning in the triad may also be viewed from the perspective of mediation. Similarly to the ’reading of textbook’-example mentioned in section 3.1, we may actually view the exhibit as partly being a tool to be able to act on such a large scale as space and to be able to construct knowledge about space. This is apparent in the case of quote 15 where the possibility to zoom out in the Universe is used as a tool to be able to reason about the existence of non-human life in the Universe. The use of the exhibit as a tool to act and understand is not only something we may observe that the participants talk about, it is also something that the participants themselves perceive. One may note this perceived learning-enabling feature of the exhibit in quote 27 where a dyad talks about the exhibit giving a perspective on how far we can look.

A final aspect of social constructivism is the social part, that learning takes place through social processes. One may note that when the participants explore the exhibit, their collaboration is a social interaction. There is also in the far perspective a social interaction between the participants and the developers and designers of the exhibit. An illustrative example of this can be seen in quote 15 where the reasoning about life in the Universe is a conversation between the participants while using the exhibit. As with the tool-mediated learning the learning through social processes is also perceived by the participants. In quote 28 the participant points out the sequence of guessing, discussing and reading answer as an enjoyable experience. Thus the participant at least implicitly points out the discussion-aspect as a part of the learning process when exploring the exhibit.

One could argue however that learning talk in itself is not enough to ascertain that learning has taken place. Considering the strong tendency of learning talk during the study, it is striking to examine the perceived learning by study participants where 7 out of 26 dyads make no content-related comment. Since this final question was formulated very openly it might be that participants were unsure of what to comment on and therefore not quite reliable as a measuring tool for learning. Instead, perhaps we should argue that the high concentration of learning talk indicates that it is likely that learning took place or at least that the possibility of learning taking place is high. For example, a participant noting a feature of a planet and recalling a previously known fact might lead to new insight if the observation and recalled facts stand in contrast to one another or it could be a confirmation of something to further strengthen the existing knowledge.

A limiting factor of the study, though the aim has been to minimize it, is that we actually do not know how the participants would behave during a typical visit. The quite high fraction of system talk, despite the participants receiving an introduction to the system, sparks the following question: How would the dyads with a high fraction of system talk in this study have behaved if we didn't study them, and thus also did not introduce the interface to them? A possible situation that could occur is that if a dyad approaches the exhibit and the interaction with the interface does not 'click' fast enough, the dyad would probably leave the exhibit and move on to another one, thus not learning anything from the exhibit. Then theoretically if the same dyads participating in the study would have been unknowingly measured, and we could record the fraction of learning, system and experience talk, a few of the dyads would probably not have learned anything at all since they would struggle too much with the interface. The consequence of this argument would be that an introduction, or something similar, probably would be a necessity for some visitors.

To analyse the effect of the quite high fraction of system talk in the study we will look more closely at the categories defined as system talk, as presented in figure 5.5. The most common type-category within system talk was "Planning", which refers to talk of structuring of the exploratory activity such as "let's click here". Although this is an important part of the communication between dyads in exploration, it was deemed to not be evidence for learning the contents of the system in this study. The second and third most common type-categories, "Orientation" and "Instruction", are fairly similar. "Orientation" concerns statements of confusion and thereafter understanding of the system's functionality or navigation, and "Instruction" concerns statements where study leaders interfere to help find the sought after functionality of the system. The difference between the two categories is that in "Orientation", study participants solve their confusion on their own whilst in "Instruction" the study-leaders intervene. While also not being seen as evidence for learning the contents of the system, these can additionally be seen to be evidence of hindrances to learning, and are therefore important to minimize. Lastly, "Interface" - any talk commenting on the interface - only contained 14 references, which could be interpreted to mean that the system did not contain any obvious interface issues that bothered people in their exploration. Thus we may conclude that the quite high fraction of system talk might not be as detrimental to learning as first seemed, since the biggest category "Planning" rather is evidence of good communication, but it does contain the fairly large categories of "Orientation" and "Instruction" which indicate stumbling blocks in a free exploration of the exhibit.

In sum, we may argue that the type-categories classified as learning talk do concern learning. Our results also show that learning talk takes place to a high degree, even among those participants with the least fraction of learning talk. However, the participants with a high fraction system-talk raise some concern regarding how they would act in an unsupervised exploration since that has not been studied.

6.2 RQ2: How does the learning take place?

The learning observed at the OpenSpace-exhibit in this study can be described in terms of the type-categories defined in section 4.3.2. In figure 5.4 we can note the five most common type-categories of learning are ”Shallow Question & Answer”, ”Interpretation of Visual Information”, ”Recall”, ”Observation”, and ”Deep question & Answer”. To describe the observed learning we can therefore say that it to a great extent concern asking and answering questions, interacting with the visual information of the exhibit and connecting information gathered to previous knowledge.

In this section, we will first analyse the results in themselves and note some interesting intersections between type-categories and content-categories, and pose some explanations as to why the learning may have taken place in this way. Lastly, we compare our findings with the learning cycle of Kolb (2014).

6.2.1 Discussion of results

An initial and general description of how the learning takes place during the exploration of the exhibit may be done by taking a closer look at figure 5.4 and 5.6. In figure 5.4 we may note that the five largest categories of learning talk regard asking and answering questions of varying depth, making connections to previous knowledge and grasping the visual information. In figure 5.6 we see that the categories which regard the planets and the Universe were the content most talked about whereas content about the Moon was the least talked about. From these results one may describe a typical visitor as spending a lot of time asking or answering questions and making associations to previous knowledge, but that a significant amount of focus is put on the visual aspects. We may also see that the typical visitor talks mostly about subjects that could be described as to be familiar but not well known. By this, it is meant that ”The Solar system and Planets” is a subject content category familiar from school, but that there is more to learn, whereas one may believe that they already know most content there is to know about the Moon. To get a more detailed perspective on how the learning takes place we will make some remarks on the results of intersecting learning activities and content in figure 5.7.

The first is the observation that within the category of ”Deep Question & Answer” the two content-categories ”The Solar system and Planets” and ”Satellites and space junk” stand out as having relatively few references compared to the total number of references in their respective content-category. This should be viewed in light of the system. As mentioned in section 2.3 the OpenSpace-exhibit consists not only of the five menus used in our content categorisation but by a sixth menu - ”Our favourites” - containing questions posed by the system for the visitor to answer. These questions correspond to content within the three categories that have a high relative number of ”Deep Question & Answer” but no system generated question correspond to ”The Solar system and Planets” or ”Satellites and space junk”. This could explain the relatively low frequency of ”question & answer” type-categories within these content categories. However, they do contain a considerable amount of ”Shallow Question & Answer”. This leads us to the conclusion that the menu ”Our favourites” containing questions with corresponding answers may be seen to promote reasoning beyond the obvious and perhaps invites the explorer of the exhibit to linger for a moment to ponder before moving on to the next thing in the exhibit. This conclusion may also be strengthened by the fact that similar results has been observed by Graesser et al. (1996). Their study, examining an interactive software containing many different types of questions and corresponding answers, showed that participants interacted with causal reasoning questions (similar to our ”Deep Questions & Answer”) to a greater extent when given a causal reasoning objective for exploring the software compared to a free exploration condition. Concluding that: ”They need to be given a learning objective that requires causal reasoning before they ask causal questions” (Graesser et al., 1996, p. 23).

Continuing to reflect on questions and answers, the category with the highest relative frequency of references of ”Shallow Question & Answer” is ”Satellites and space junk”. While it is not a surprising fact, it prompts the question about what makes it different from the other content categories, and - if shallow questions are what is sought after - what design principles underlie the design of the menu and should be replicated in future exhibits? One answer to this question could be that whilst most people are familiar enough with satellites being man-made objects orbiting our planet, few are familiar with different types of satellites and their respective function and position - which was the main focus of this content category. This could probably lead to the behaviour displayed here which is that participants knew enough to formulate a question rather than interpret visual information, but not enough to ponder it any further than what was visualized in the system. This can be seen in quote 3 where a question is prompted about the function of the space station ISS but no further answer is given than that of the system: ”It’s a space station”.

Another observation to be made from the results is that the content categories which had the highest frequencies of ”Interpretation of Visual Information” were ”The Solar system and Planets”, ”The Universe” and ”The Moon”. To explain this finding we need to go back to the definition of the category ”Interpretation of Visual Information” which is talk concerning an attempt to understand the visually represented information. This means that a high frequency of ”Interpretation of Visual Information” might indicate that the visualized information in the corresponding content category requires quite a lot of interpretation to be understood. This can be seen in example from the content category ”The Universe” where the view of galaxies and quasars - which consisted of coloured dots spread out in a cone-shaped pattern - evoked confusion as can be seen in quote 4.

The fourth and last observation we want to draw attention to is the substantially frequent type-categories of ”Recall” and ”Observation” within the content category ”The Solar system and Planets”. As can be seen in figure 5.7, these are the highest number of references in any intersection of categories and are therefore of interest. One possible explanation for the large number of recalls and observations in this content category could be because this content is familiar to most people. This content category contains the Earth - which is familiar to all visitors - as well as our closest planets - which is something studied in school at quite a young age and therefore familiar to many people. This could explain the high frequency of the type-category ”Recall” which are statements relating to previous knowledge. It is harder to pinpoint why the type-category ”Observation” should be so prevalent in ”The Solar system and Planets” but one possible explanation is that a familiar object - in this case a planet - invites further observations about it - such as ”the planet has many moons” - whilst a more unfamiliar object would be harder to make observations about since there is not yet a terminology established to describe it further.

6.2.2 Mapping type-categories to Kolb's learning cycle

Another way to describe how learning takes place while the visitors interact with the OpenSpace-exhibit is by mapping the type-categories developed in this study to Kolb's experiential learning cycle. As presented in section 3.2 experiential learning according to Kolb's learning cycle consist of cycling through the stages of ”Concrete experience”, ”Reflective observation”, ”Abstract conceptualization” and ”Active experimentation”. A mapping of our type-categories to Kolb's learning cycle is presented in figure 6.1 which will be expanded on below.

To begin, we may argue that a lot of the type-categories contain statements which begin in what Kolb calls a ”Concrete experience”. One may understand this in the case of the ”Observation” and ”Quotation”-types as the participants initially having a concrete experience of the visual or the written information, respectively. Then in the case of ”Observation”, the participants reflect over and describe a certain aspect of what is observed. In the case of ”Interpretation of Visual Information” and ”Interpretation of Written Information” the statements may also be understood as starting in a concrete experience of either text or of visual information, where some aspect of the information either is, or is attempted to be, comprehended, organised and put into an existing mental structure. This varying degree of success in comprehending the information may be illustrated by comparing quote 4 and 17. In quote 4 the participants notice and reflect on the different colour representations of galaxies and quasars (which may also be seen in Figure 2.5), whereas in quote 17 the dyad reads about dark areas of the Moon earlier thought to be oceans, reflects about this and manages to bring order to that information by connecting it to the visible dark areas of the lunar surface. One may also note that the types ”Comparison” and ”Mental Visualization”, although infrequently appearing as seen in figure 5.4, also starts with a concrete experience. A comparison is a connection between two different reflections on concrete experiences and a mental visualization is a distinct way of reflecting upon a concrete experience to be able to comprehend and create

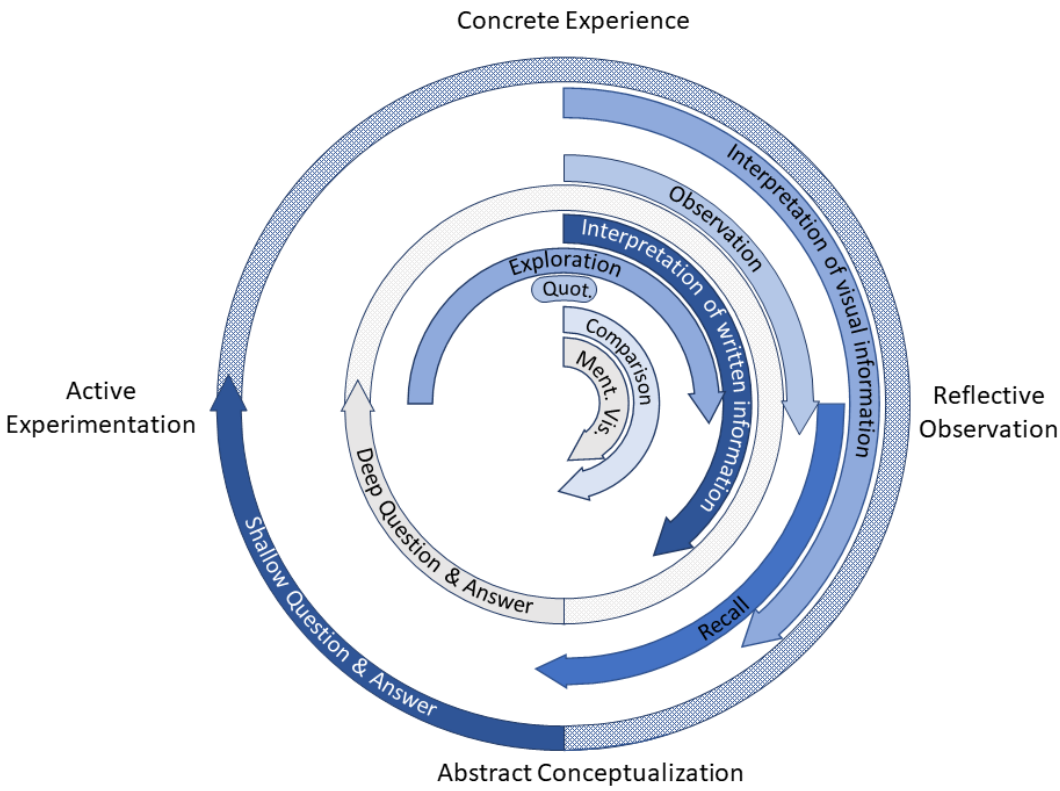

Figure 6.1: The ten learning type-categories mapped onto Kolb's experiential learning cycle. Each type-category may span several modes of learning in the cycle which is illustrated by an extended arrow covering the concerned modes. The most common type-categories are illustrated furthest from the center of the circle, and the least common type-categories are illustrated closer to the center. Note that the two categories Shallow and Deep Question & Answer do concern moving from "Abstract Conceptualization" to "Active Experimentation" but might concern the other modes as well, which is indicated by a patterned extension of their arrows. Also, note that "Quotation" does not extend in any direction but only concerns the "Concrete Experience"-mode.

order in the information. In summary, the statements of the type-categories now presented may be understood to begin with a concrete experience. In total these statements do amount to a large fraction of all statements, but as we will see this is not true for all statements or type-categories.

The two categories of "question and answer" are a first example of categories that don't always start with a concrete experience. The common aspect of these two categories in the context of Kolb's learning cycle is that they concern "Abstract conceptualization" where comprehension and order are built and at least to some degree concern "Active experimentation" where the understanding is tested. As an illustration one may compare quote 1 and quote 14. In quote 1 one participant, based on a mental model of the Universe, wonders whether it is infinite or constantly expanding and thus may be seen to indicate a desire to test their current model. In quote 14, which do start in a ”Concrete experience”, the dyad notice and reflect on a formation in the exoplanet-view, tries to bring some order and comprehension into the experience by naming it a ’wave’ and then indicate a desire to test the understanding of that formation by asking if that is the only way that we’ve looked. By quote 1 and quote 14 we may exemplify that the ”question and answer”-types may begin in different parts of the learning cycle, in either an ”Abstract conceptualization” of the Universe or a ”Concrete experience” of currently found exoplanets, but will all concern ”Abstract conceptualization” and at least to some degree ”Active experimentation”.

One more category that does not - at least not as clearly - start in a concrete experience is ”Recall”. In quote 11 the participant reflects on light being the fastest thing in the universe, and tries to bring order to the conceptualization of what is fastest by concluding that darkness is the fastest. There was no statement of a concrete experience which indicated anything about the speed of light or darkness previous to the recall.

Another category that doesn’t start with an experience is the category ”Exploration”. As this category contains statements of the dyad trying to find the limits of the exhibit and what is possible to observe, the statements of this category may be seen to start in an ”Active experimentation” and possibly end in a ”Reflective observation”. This may be understood through quote 18 where the dyad tests if it is possible to find where they are living while exploring the Earth and then finds it.

In regard to Kolb’s experiential learning cycle, we may thus give one description of how learning in the OpenSpace-exhibit takes place. As can be seen in figure 6.1 the type-categories of learning map onto all different modes of the learning cycle but does not include any full cycle. As Kolb states: ”Learning usually does not happen in one big cycle but in numerous small cycles or partial cycles” (Kolb, 2014, p.57). These cycles or partial cycles may also be seen to often begin in concrete experiences, but there is also a notable amount of statements that do not result from concrete experiences.

7

Discussion

In this chapter the learning talk categories, the frequency of the respective categories and the fraction of learning talk are compared to the results of previous studies. The chapter ends with a discussion of the generalisability of the results to other situations and the applicability of the methodology in other contexts.

7.1 Similarities and contrasts to previous research

This section will examine what role our research have in the subject area. How does the categories and their frequencies, which describe how learning in the exhibit takes place, compare to previous studies on visitor conversations in museums that concern learning? To begin with, most studies have developed their own coding scheme, as we have, and we therefore need to start this section by comparing our type-categories to other categorisations. We will focus on the categorisation done by Allen (2002) who uses five categories of learning talk: Perceptual, Conceptual, Connecting, Strategic, and Affective talk. The perceptual talk includes identification, naming, pointing out a feature and quotation - most closely related to our type-categories ”Observation”, which points out features, and ”Quotation”. The conceptual talk includes simple and complex inferences, predictions and statements of metacognition - these relate to our two ”question & answer”-categories as well as ”Comparison” and ”Interpretation of Written Information”, who all includes some simple or complex inferences. The connecting talk includes explicit connections to either earlier life-experience, previous knowledge or information gleaned from another exhibit - comparing well with our type-category ”Recall”, which contains all connections to previous knowledge. Lastly, the strategic talk concerns talk about how to use the exhibit, which we marked as system talk, and the affective talk contains expressions of pleasure, displeasure or surprise/intrigue, which we marked as experience talk.

Comparing our result to that of Allen (2002) we can see many similarities between the three most common categories of talk in their study (Perceptual, Affective, and Conceptual) and our five most common type-categories (”Shallow Question & Answer”, ”Interpretation of Visual Information”, ”Recall”, ”Observation”, and ”Deep Question & Answer”). As mentioned in the previous segment, their conceptual category is very similar to our two ”question & answer”-categories and their perceptual category holds similarities with our ”Observation”-category. The biggest difference, however, is Allen’s large affective category (around 55%), comparing to our category of experience talk making up only 5% of all talk at the exhibit. One reason for this could be that we only coded experience talk if it was not connected to any other type of talk and therefore should expect a lower count. An example of this can be seen in quote 9 where one participant exclaim ”what the hell?” when observing the quantity of space junk, which is coded together with the observation rather than a separate experience-talk code.

DeWitt and Hohenstein (2010) developed a different coding scheme to study learning talk by students on a field trip to a museum with eight categories of type of talk: Explanation, Fit, Description, Read, Description-Visual, Content-superficial, Affective, and Attention. Their two most common categories were Content-superficial and Description-Visual which can be compared to two of our five most common categories. Content-superficial contains engaging with the content at a shallow or unreflected level, which could be compared to our most frequent type-category ”Shallow Question & Answer” which contains questions and answers that does not go beyond the content of the display. Additionally, Description-Visual can be compared to our fourth most frequent category ”Observation” as it contains naming or describing what is observed.

Coming back to the result of Allen (2002) we notice the low presence of connecting talk in their study, which is the category closest related to our third largest category ”Recall”. Is there something about our exhibit which elicits more recalls to previous knowledge compared to the frog exhibition studied by Allen (2002)? Similarly a study on visitor conversations done by Lee and Kim (2007), using the same categorisation as Allen (2002), reported perceptual, conceptual and affective talk as their top three categories and note their own surprise over the lack of connecting talk at only 15%. However, if we compare our 84 references of ”Recall” to the total number of learning talk references, ”Recall” similarly makes up for about 15% of all learning talk. This prompts the question if the bigger categories of perceptual and conceptual talk simply are that much bigger because they are a merge of several different categories in our coding scheme.

A final comparison is on our results regarding if learning takes place. Our results of learning talk being frequent is consistent with that of earlier research. Our average of 72% learning talk (seen in figure 5.2) compares well to the 72.8% average of content-related talk in the study by DeWitt and Hohenstein (2010) and is slightly less than the 83% of learning talk in the study by Allen (2002).

In summary, we can see many similarities between the most common type-categories of our study with that of previous museum studies, which strengthens the validity of our description of how learning takes place. We also see similar results regarding the extent of learning talk compared to other types of talk. The most notable difference was the high frequency of affective talk in the studies by Allen (2002) and Lee and Kim (2007), which could be explained by our strict definition of experience-talk only encompassing affective talk not connected with any other type of talk.

7.2 Limitations

In this section we discuss different aspects on the limitations of the study. First we discuss to what extent the results of this study could be generalised to other contexts. Thereafter we discuss the applicability and adaptability of the developed method for further studies in this field.

7.2.1 Generalisability of results

One may in accordance with section 6.1 state that learning takes place in the time and context of the study, but how much may these results be generalised?

To start with, one aspect that strengthens the generalisability is that there was a wide distribution of age and type of dyad-pairings. As seen in figure 5.1, most age-categories contain around 10–20% of all participants. Notably, the age-categories aren't equally spaced, though one may argue that there is a faster rate of development in children than in adults and that it therefore is justified to have more tightly spaced categories for children. As seen in figure 5.1 the dyad composition, i.e. if the dyad consisted of only children, only adults or one of each, was also fairly well distributed. Notably though, there was a smaller amount of child-child dyads which probably is due to our requirement of consent from a legal guardian if they were under the age of 15. Therefore we argue that these results are applicable to all types of visitors that explore the OpenSpace-exhibit.

One aspect which may affect generalisability is that the participants were introduced to the interface of the exhibit before they got to explore it by themselves. Therefore we can't be sure how non-introduced dyads would behave at the exhibit. As mentioned in section 4.1, the motivation for the introduction was for the participants to not be hindered in their exploration due to interface issues. Thus one could see that the introduction merely reduced the time that it otherwise would take for the participants to figure out how the system worked. If that is the case, and the dyad had not been introduced, the exploration-session of each dyad would probably have consisted of more system talk regarding how to use the interface.

Another aspect of generalisability is how dependent the results are on the fact that the participants were exploring the exhibit in pairs. One may wonder how well these results translate to the situation of one visitor exploring the exhibit alone or the situation of a group of three or more visitors exploring the exhibit. Since the results in figure 5.4 indicate talk that may be seen as quite dependent on human-human interaction the results may not be that generalisable to a single explorer. By this, it is meant that asking a question, describing what you see or restating a known fact may be quite characteristic of a conversation and not of solitary exploration. It could be seen as probably more infrequent to ask yourself explicit questions, describe to yourself what you see or restate to yourself that you remember that darkness is faster than light as in quote 11.

One more issue that might influence the generalisability of our results is the fact that the participants were aware they were taking part in a scientific study. Knowing that someone is observing them might make them perform better than they would normally do, this is known as the Hawthorne effect (McCambridge et al., 2014). What indicated this effect in our study is the fact that some participants expressed some sort of feeling of wanting to stop earlier than they did because they wanted to do well, as well as those who misunderstood our role and made comments about how well-made the exhibit was that they thought we had produced. The issue at hand is not whether to inform participants, since their informed consent is vital, but rather how to inform them and how to be present as study leader during the exploration. We chose a very short introduction to not take up more time than necessary and to maximise exploration time, but this might have led to some miscommunications as expressed above. We also chose to be very present during the exploration, by standing on the opposite of the exhibit to the participants. This was to be able to help or instruct participants when they got stuck but it might have had the negative effect of an imposing presence, making it hard to not focus on the fact that it was a study. Although notably, only very few participants interacted with us study leaders during the exploration in the form of asking a question or giving a statement directed exclusively to us.

7.2.2 Applicability of methodology

We may also pose the question of how applicable the methodology is to other types of exhibits. There shouldn't be a problem in analysing the spoken thoughts of participants in other types of exhibits, as this had been done in previous studies not concerning visualization exhibits. Though in regard to the categories there are some hindering aspects to examining other types of exhibits. The least applicable aspect is that of the content-categories corresponding closely to the content menus in the OpenSpace-exhibit. These have very limited applicability as these categories only apply to an exhibit with very similar content to this exact exhibit.

More interesting are the type-categories. Can these be used more generally than just the exhibit studied? To some extent, we believe, yes. The learning talk regarding asking or answering questions, recalling previous knowledge, observing and comparing should be present at most museum exhibitions. However, the more specific categories of interpretation of visual as well as written information might only be applicable in a similar exhibit as the one studied, where a lot of information is presented both in textual and visual form. If an exhibit is leaning toward being only visual or textual these categories perhaps should be joined to one. One could also argue that the shallow and deep "questions & answers"-categories are very similar and can be seen to both be part of a more general category of asking and answering questions. For an exhibit which prompts fewer questions, these categories may not have been separated but instead kept as one category.

As a whole, the type-categories may be seen to be quite specific to visualization-exhibits that are interactive and somewhat exploratory in nature. As an example, the category "Interpretation of Visual Information" is dependent of there being a lot of visual information. Similarly, the "question and answer"-types may be seen to be dependent on there either being questions provided by the exhibit or the exhibit triggering questions from the visitors. Finally, the exploratory category ”Exploration” requires visitors’ close acquaintance with some part of the content of the exhibits, such as most visitors have with Earth in the exhibit about space, and might not be applicable in an exhibit about quarks since that content area is unknown to most.

Another limitation in our methodology is the choice to only examine dyads of visitors. As the size of groups exploring different exhibits at museums varies greatly from one to several people this is a significant limitation to the generalisability of our results, discussed above. Could the same method be used to examine the learning of a single visitor at the exhibit? Perhaps a visitor could be prompted to speak their thoughts out loud in a similar manner, but would probably express themselves differently than in regular conversation.

8

Conclusions

The starting point of this study was Universeum's aim of testing if the visualization lab could accelerate learning. Therefore this study aimed to examine if, and in that case, how learning takes place when visitors explore the OpenSpace-exhibit at Universeum's Vislab-exhibition. We may conclude that, with a constructivist perspective, learning does take place, though to a greatly varying degree between different visitors. We may also conclude that the way that the learning takes place, to a great extent concern asking and answering questions, interacting with the visual information of the exhibit and connecting information gathered to previous knowledge. Another aspect of the learning is that it to a greater extent regard subject content that may be seen to be familiar and intriguing, compared to less familiar or mundane content. By this description of how learning takes place in the OpenSpace-exhibit this study has contributed to two overlapping gaps in the current research. Firstly, it has contributed to expand the research of museum exhibit evaluation through the analysis of learning talk to include digital visualization exhibits. Secondly, it has filled the gap of research on digital visualization exhibits by describing the learning that can be observed during the use of the exhibit rather than after an interaction with the exhibit.

This study can therefore be seen to be the first step toward a description of learning at visualization exhibits which holds great potential to be developed further. There are a few different routes we see that future research could take in this venture. Firstly, the most obvious extension of this study would be to examine other visualization exhibits with the developed categorisation as a baseline to test whether the categorisation is applicable or try to develop a more generalised categorisation. Secondly, one or a few of the discussed categories could be examined in more depth to understand it more fully - for example the categories of ”question & answer” could be further examined to find what type of questions are asked, what type of answer is provided and how the dyad moves from question to answer. Finally, a third possible route to expand the model would be to study sequences of learning talk to examine how learning takes place in a sequential pattern and possibly strengthen the comparison to the learning cycle of Kolb (2014) if evidence of more full cycles emerge.

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A

Participant information sheet

Study of learning in Vislabs space exhibit

What is the study about?
The study wishes to examine if the space exhibit can produce any new insight or knowledge for visitors at Universeum, and if so, how this new knowledge is produced. The study thereby examines the exhibit and not you. Nothing you do is either wrong or right.

Why study this?
The aim for these visualization exhibits is to produce learning opportunities for visitors. We want to examine if that aim is fulfilled and if so, how this learning takes place.

How the study is conducted:
If you wish to participate we will ask you to answer 5 short questions about your interest in space, your faith in your own knowledge about space, age, gender and education. After these questions you are free to explore the space exhibit for as long as you like. During this exploration you are encouraged to think aloud about what you see and think, which will be recorded using a microphone. We will also record the screen from above to see how you are interacting with the screen (only the screen and your hands will be visible). These recordings will then be analysed and compared to other visitors´ and only shared between us, our supervisor and examiner.

Withdrawal of consent
At the start of the questionnaire there's a tick box to collect your informed consent to participate in the study. You are free to withdraw this consent at any moment by contacting us and stating your unique ID-number.

Your ID-number is:

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Contact details:
Maria Söderberg,
marisod@student.chalmers.se
Isak Pettersson,
isakpe@student.chalmers.se

B

Original quotes in Swedish

Original quote, in Swedish, quote 1:

> Talare 2: Expanderar inte universum hela tiden? Men det är oändligt stort. Det förvirrar mig.
> Talare 1: Ja, jag vet inte, faktiskt. I haven't gotten that far.

Original quote, in Swedish, quote 3:

> Talare 2: Vad är ISS? Den internationella rymdsstationen.
> Talare 1: Nu kom det en sån här röd, den röda vänta där. Den speedar. Vad gör den då?
> Talare 2: Det är en rymdstation.

Original quote, in Swedish, quote 4:

> Talare 2: Men, varför är det olika färger? [om "Galaxer och kvasarer"-vyn]
> Talare 1: Jag vet inte.
> Talare 2: Vad ska det symbolisera, stjärnor eller sol-?

Original quote, in Swedish, quote 5:

> Talare 2: Ger en liten konst* Vad är det här för eh vänta. Vad är det här för land sak vad är det här för någonting?
> Talare 1: Det är väl Afrika?

Original quote, in Swedish, quote 7:

> Talare 2: [Zoomar in på Merkuris] Oj, va fin.
> Talare 1: Oj, ser ut som månen.

Original quote, in Swedish, quote 8:

> Talare 2: [Klickar på Venus-knappen] Det ser typ ut som en väldigt torr jord.

Original quote, in Swedish, quote 11:

Talare 2: Ljuset är faktiskt inte är det snabbaste som... det. Mörkret är mycket snabbare än ljuset.

Original quote, in Swedish, quote 12:

Talare 1: Visste du att det var längre ut? Asså en bra bit ut.
Talare 2: Vad sa du?
Talare 1: Visste du att det låg en bra bit ut i vintergatan?
Talare 2: Nej.
Talare 1: Det ligger ju verkligen i utkanten.
Talare 2: Det hade jag ingen aning om.

Original quote, in Swedish, quote 14:

Talare 1: Oj, det är ju en hel våg här. [Om den konformationen i exoplaneter-vyn]
Talare 2: Har man bara kollat åt ett håll då eller?

Original quote, in Swedish, quote 15:

Talare 1: [Klickar på ”Finns det liv i universum?”] Utforska vyn till *ohörbart*. 1995 hittades den första planeten runt en annan stjärna än vår sol. Jaha det är exoplaneter.
Talare 1: [Klickar på ”Galaxer och kvasarer”] Oh my God, det är allt, såhär galaxer och sånt.
Talare 2: Ja det finns ju inte en chans att vi är ensamma.
Talare 1: Nej, eller hur? Om man tänker att liksom det här är solsystemet, ocå kommer man ner såhär. [Zoomar in från galaxer till solsytemet] Det är sååå litet. Det lilla solsystemet. Sen kommer man till exoplaneter. Bara vintergatan är ju liksom. [Tittar på vintergatan-vyn] Om man tänker att alla dessa är solsytem liksom, varenda liten prick. Det är ju inte en chans.
Talare 1: Är solsystem liksom.
Talare 2: Vi är alldeles för egoistiska om vi tror att vi är dom enda.

Original quote, in Swedish, quote 17:

Talare 1: Aha! Man tror att vissa områden har varit fyllda med vatten.
Talare 1: De här... förr i tiden.
Talare 1: De mörka områdena.
Talare 2: De här då? [pekar på de mörka områdena på månen]
Talare 1: Ja kan det vara de då, kanske?

Original quote, in Swedish, quote 21:

Talare 1: Nu ska vi se. Merkurius är den planet som ligger närmast solen. Den är minst av solsytemets åtta planeter och dess yta påminner om månen med många kratrar. Merkurius saknar i princip atmosfär och dess temperatur varierar kraftigt från minus 183 grader på planetens skuggsida till 427 grader på solsidan. Planeten har varit känd länge. Redan för 3400 år sedan skrev babylonierna om den.

Original quote, in Swedish, quote 22:

Talare 1: Woah! Alltså Merkurius går så mycket. Snabbare är Jorden.
Talare 2: Jo för den har ju - den är ju närmre. [ritar ut Merkurius omloppsbana runt solen]

Original quote, in Swedish, quote 23:

Talare 1: Då borde vi bara se liksom om man delar den på mitten, ser man den ytan. [visar på skärmen genom att ”dela” månen i skärmens plan]
Talare 2: Ja. Och då är det fullmåne då? Så är det.

Original quote, in Swedish, quote 25:

Talare 1: Men jag, jo, det jag-, det jag saknar det är faktiskt varför är det de färgerna jag ser? Det stod på Mars att det var järnoxid. Men det står ikke på de andra.

Original quote, in Swedish, quote 26:

Talare 2: Men rymden är ju häftig på alla sätt och vis för det är så ogreppbart på något sätt. Därför så är det ju co-. Det är ju, ja, kul med rymden, tycker jag. Vad tycker du?
Talare 1: Ja. Tycker den är, ja, cool.
Talare 2: Ja ja, så att, absolut.
Talare 2: Och sen när man får lite distans på det hela, när man ser allting runtomkring, med stjärnor och månar och allting sånt. När man inser hur stort det är. Så det kommer man ju ta med sig.
Talare 2: Det är ju inte riktigt att man åker dit på en tank diesel direkt.

Original quote, in Swedish, quote 28:

Talare 2: Det var kul att kunna, både hålla på på skärmen och så kunna läsa där. Och först, och just stå gissa lite och så diskutera sig fram och sen får man svaret om man vill också. Tyckte jag var jättebra.

C

The OpenSpace-exhibit

In this chapter the OpenSpace-exhibit is documented. Each view is presented in the English version, though Swedish is available as an option.

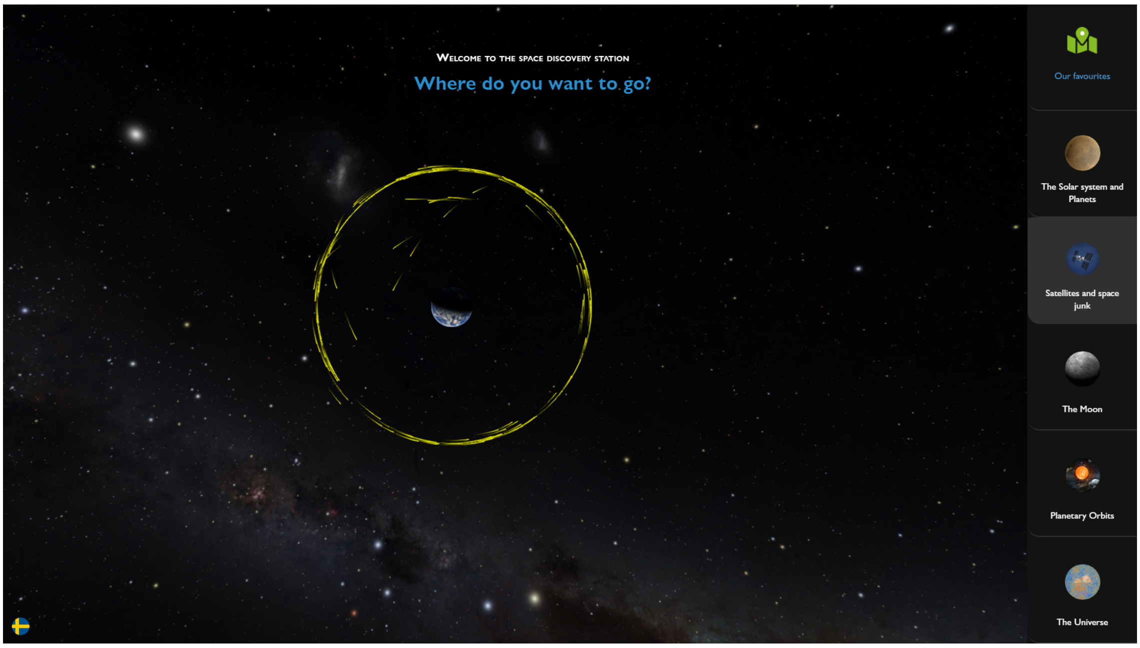

Figure C.1: The home screen.

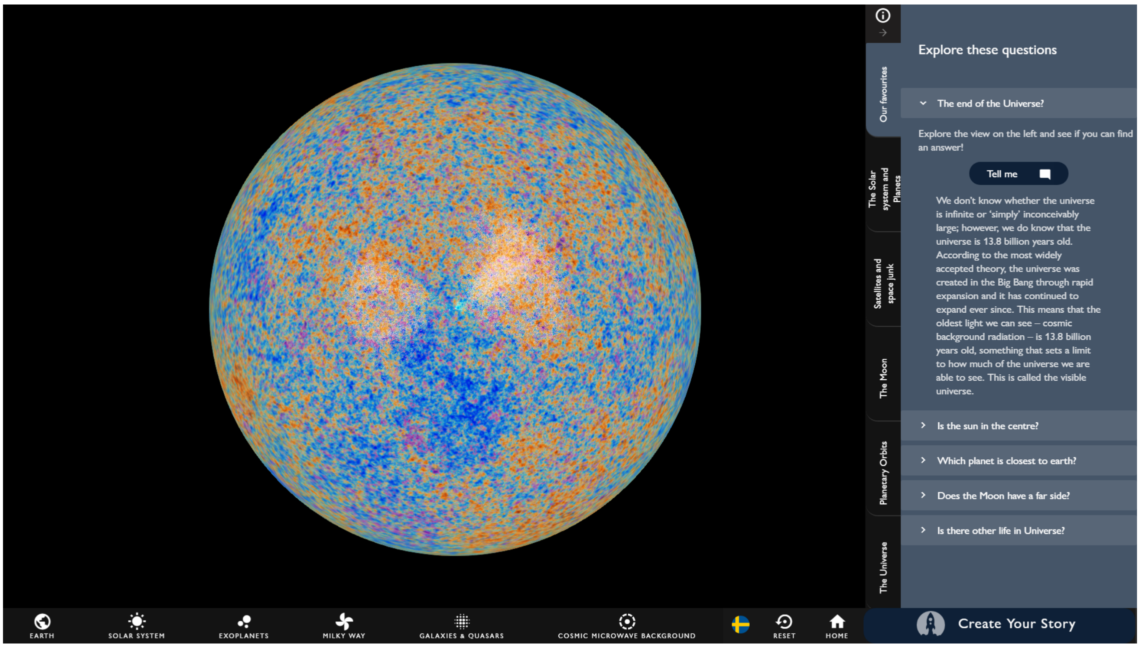

Figure C.2: Our favourites: The end of the Universe?

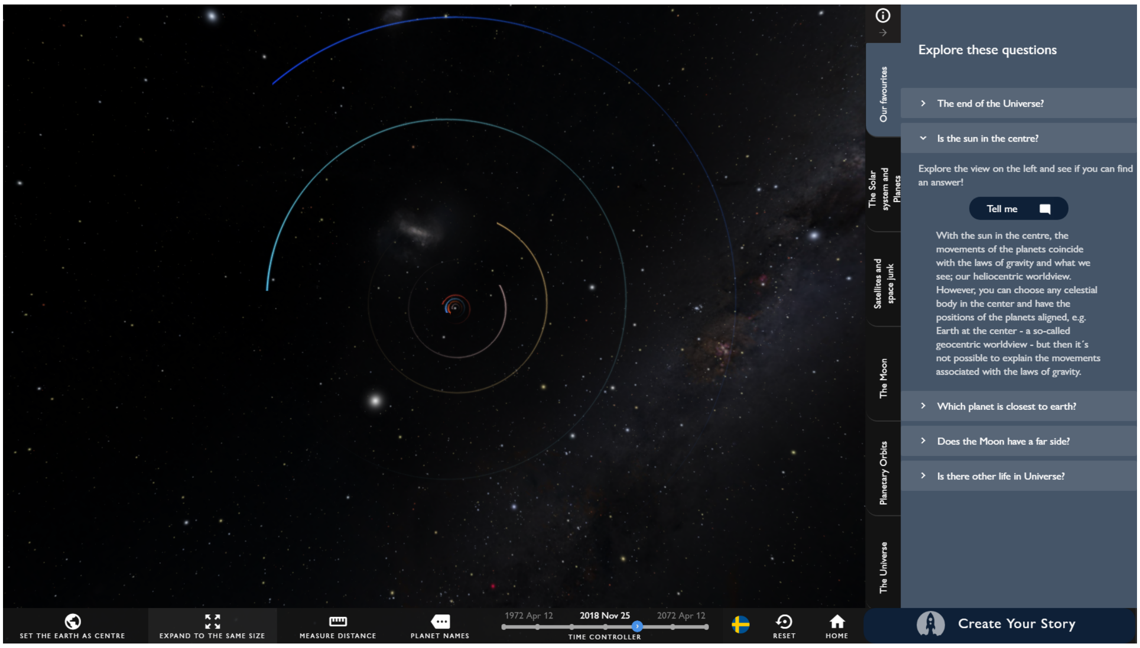

Figure C.3: Our favourites: Is the sun in the center?

Figure C.4: Our favourites: Which planet is closest to earth?

Figure C.5: Our favourites: Does the Moon have a far side?

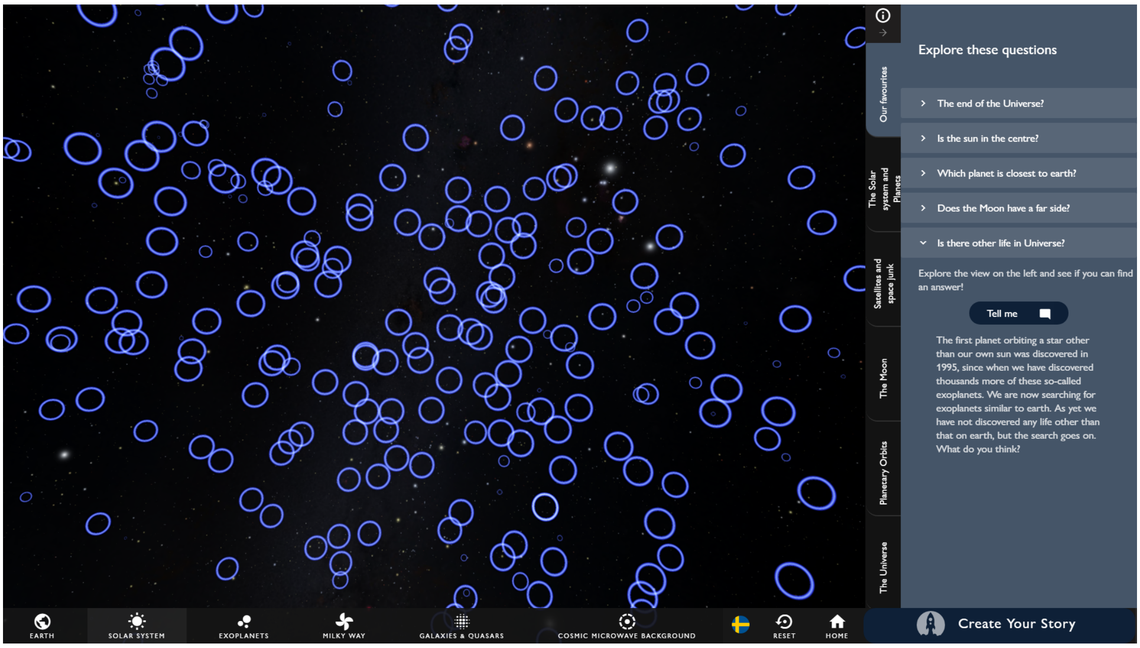

Figure C.6: Our favourites: Is there other life in Universe?

Figure C.7: The Solar system and Planets: The Solar System

Figure C.8: The Solar system and Planets: Mercury. In Swedish

Figure C.9: The Solar system and Planets: Mercury. In English

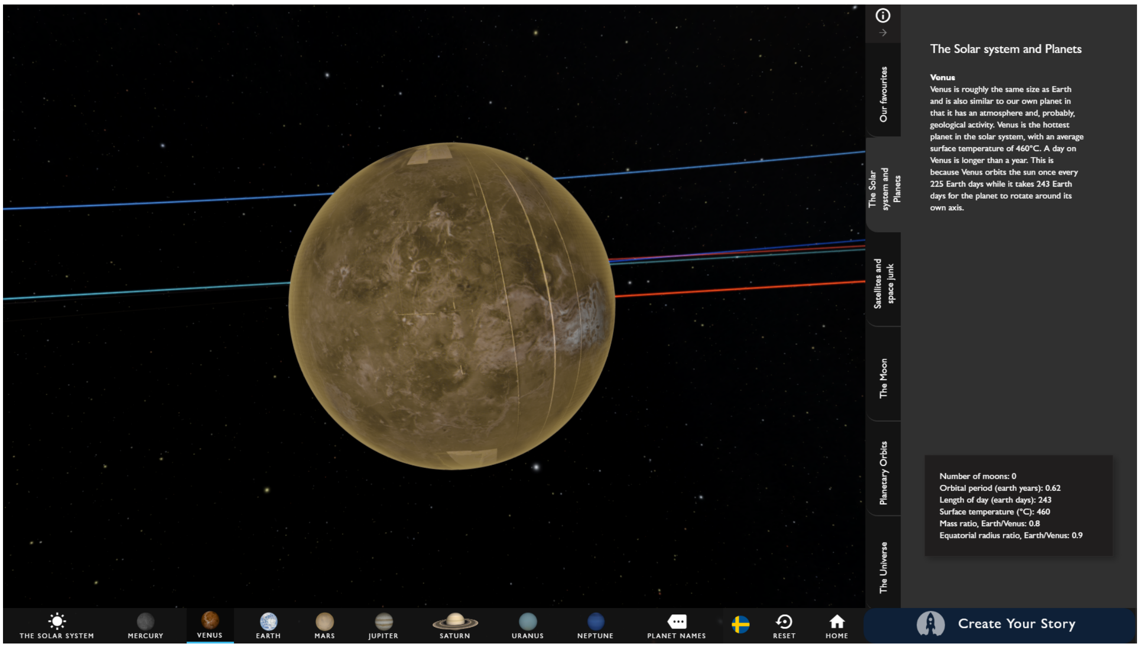

Figure C.10: The Solar system and Planets: Venus

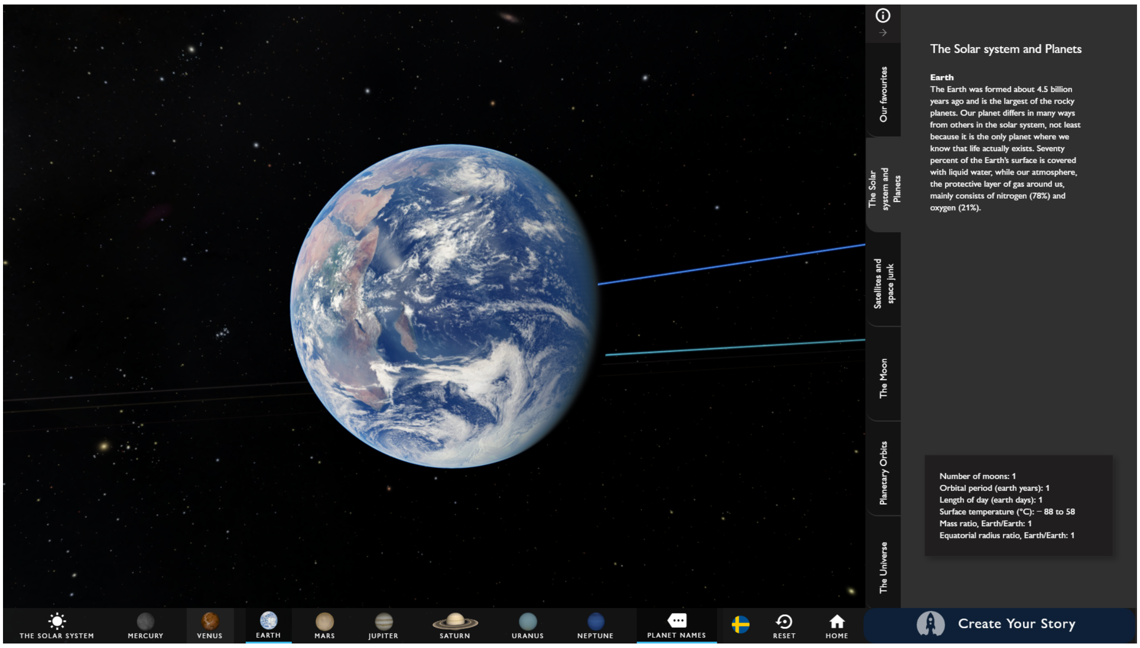

Figure C.11: The Solar system and Planets: Earth

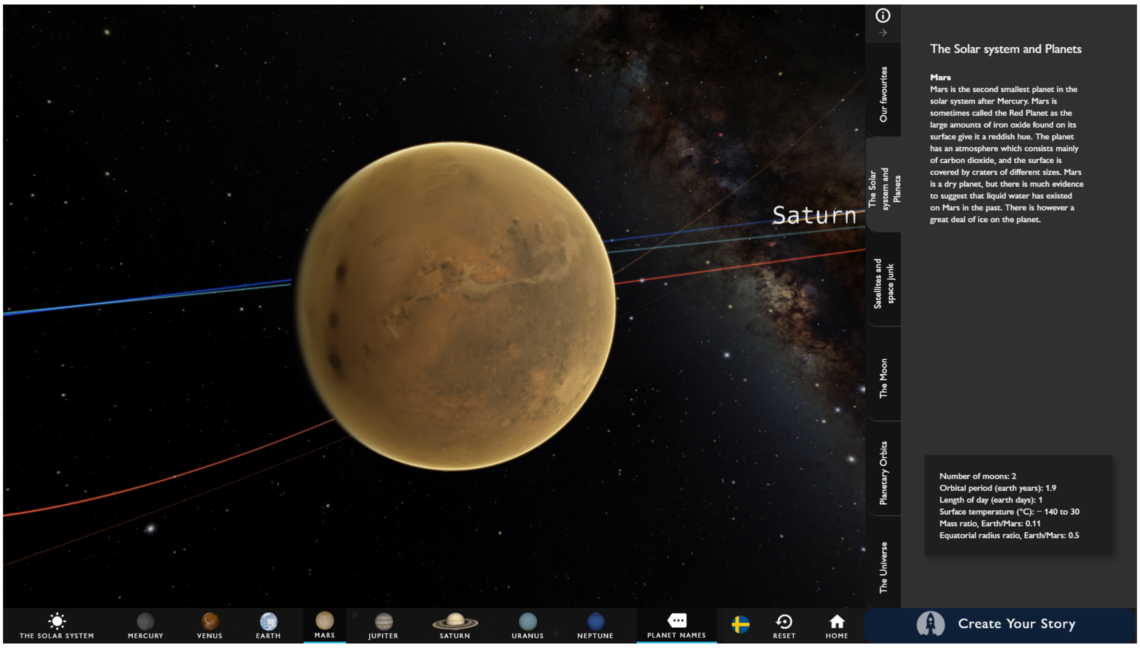

Figure C.12: The Solar system and Planets: Mars

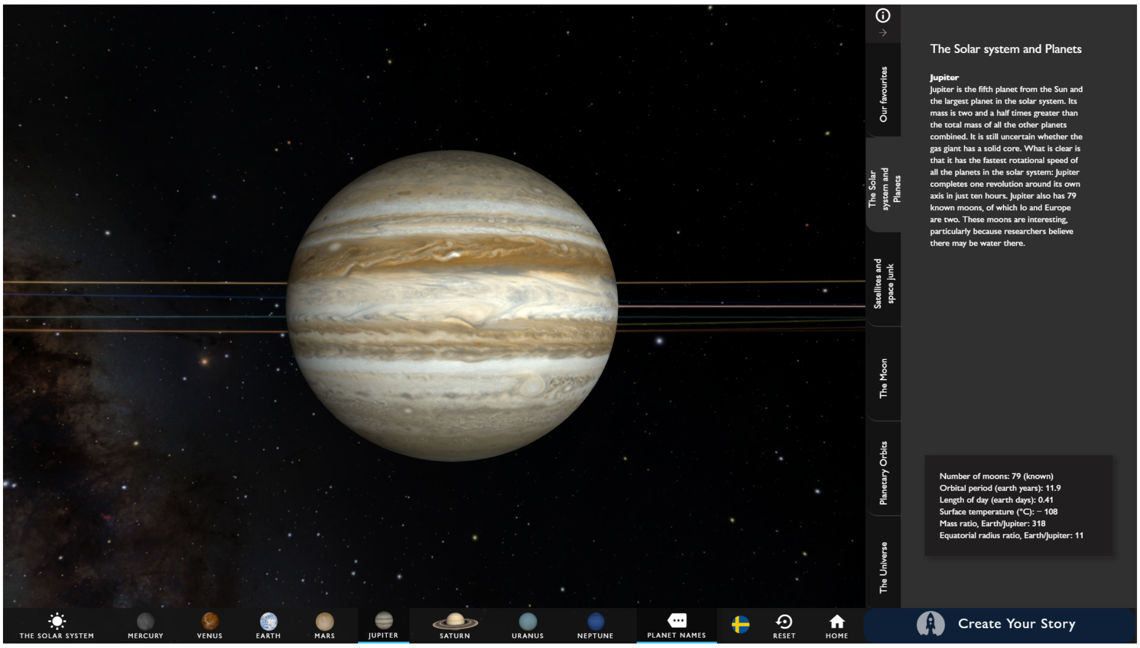

Figure C.13: The Solar system and Planets: Jupiter

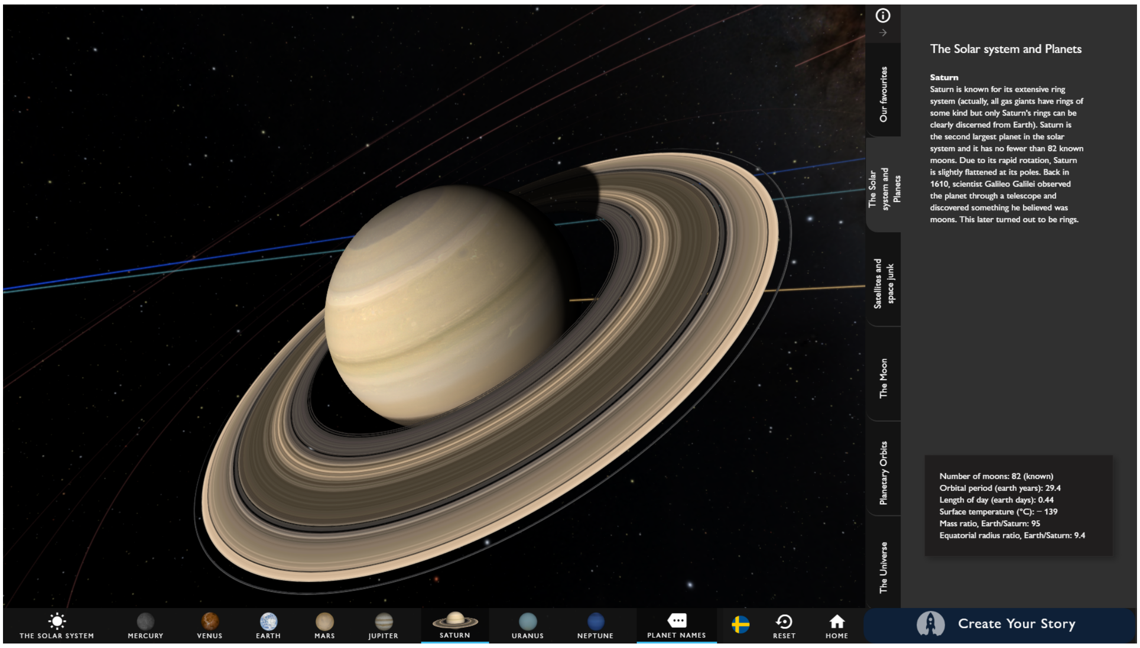

Figure C.14: The Solar system and Planets: Saturn

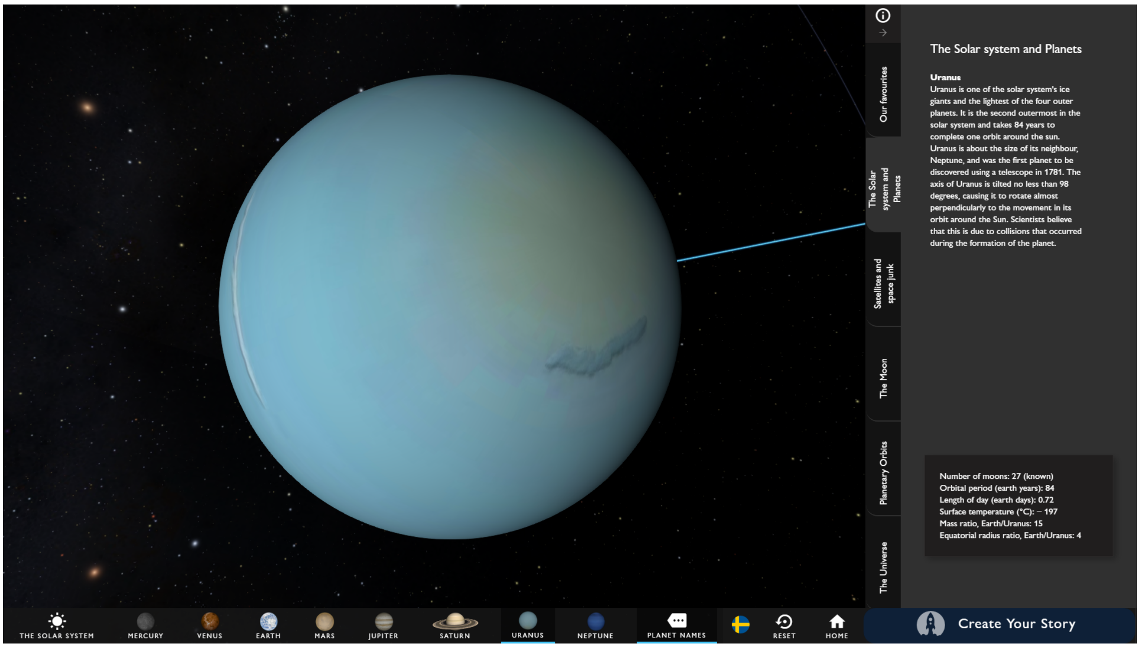

Figure C.15: The Solar system and Planets: Uranus

Figure C.16: The Solar system and Planets: Neptune

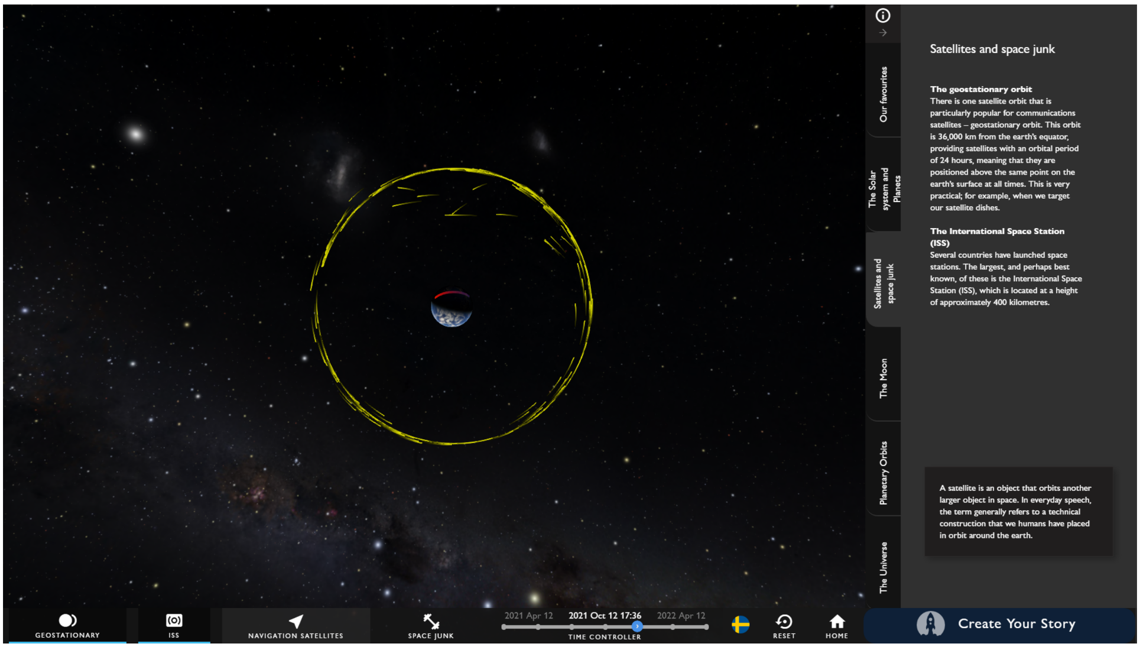

Figure C.17: Satellites and space junk: Geostationary satellites, ISS

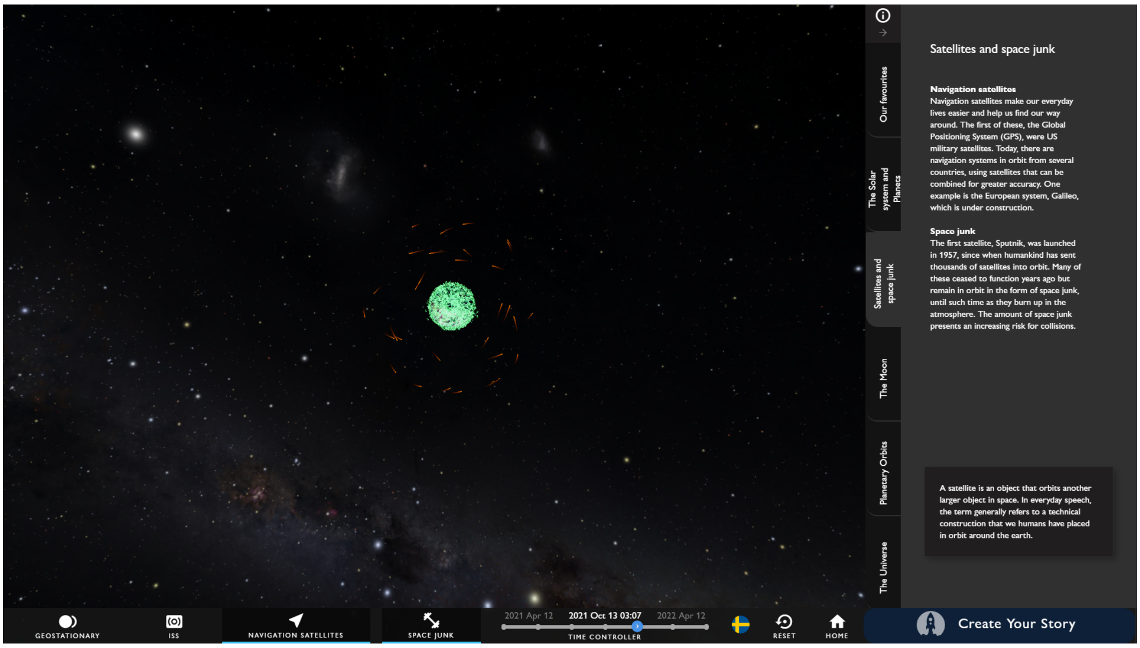

Figure C.18: Satellites: Navigation satellites, Space junk

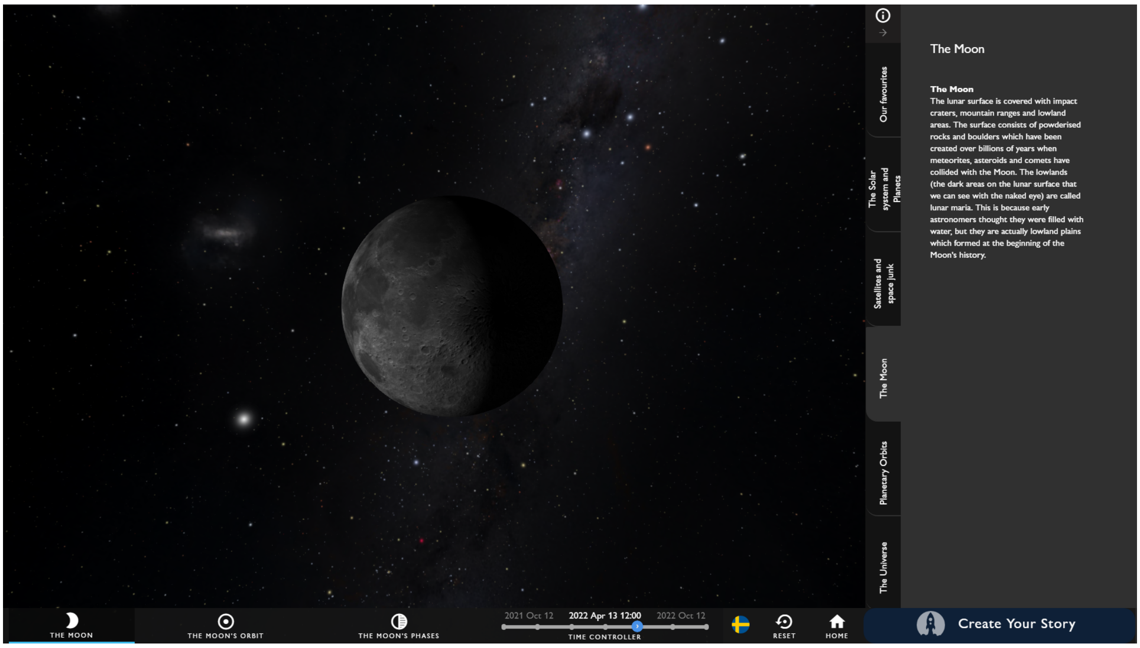

Figure C.19: The Moon: The Moon

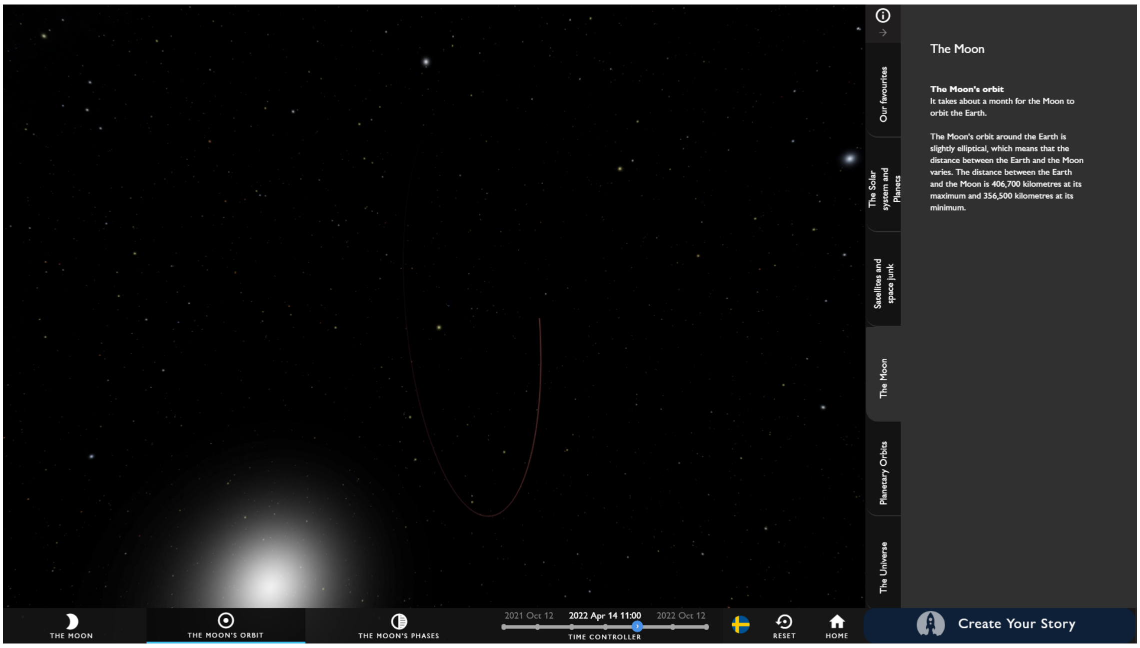

Figure C.20: The Moon: The Moon's orbit

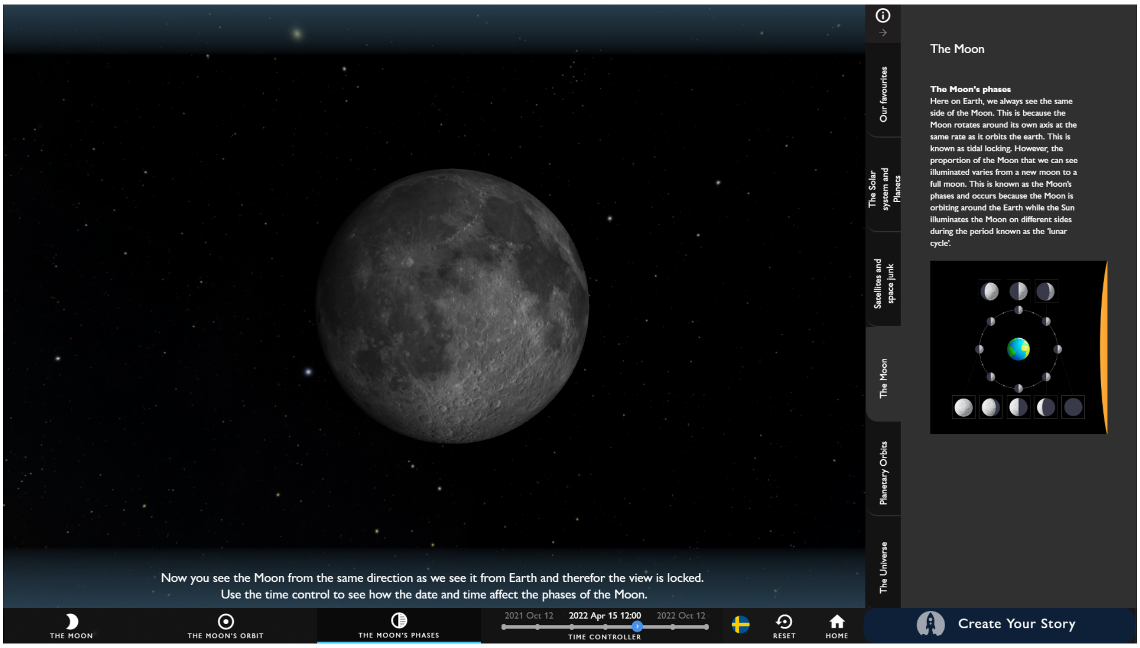

Figure C.21: The Moon: The Moon's phases

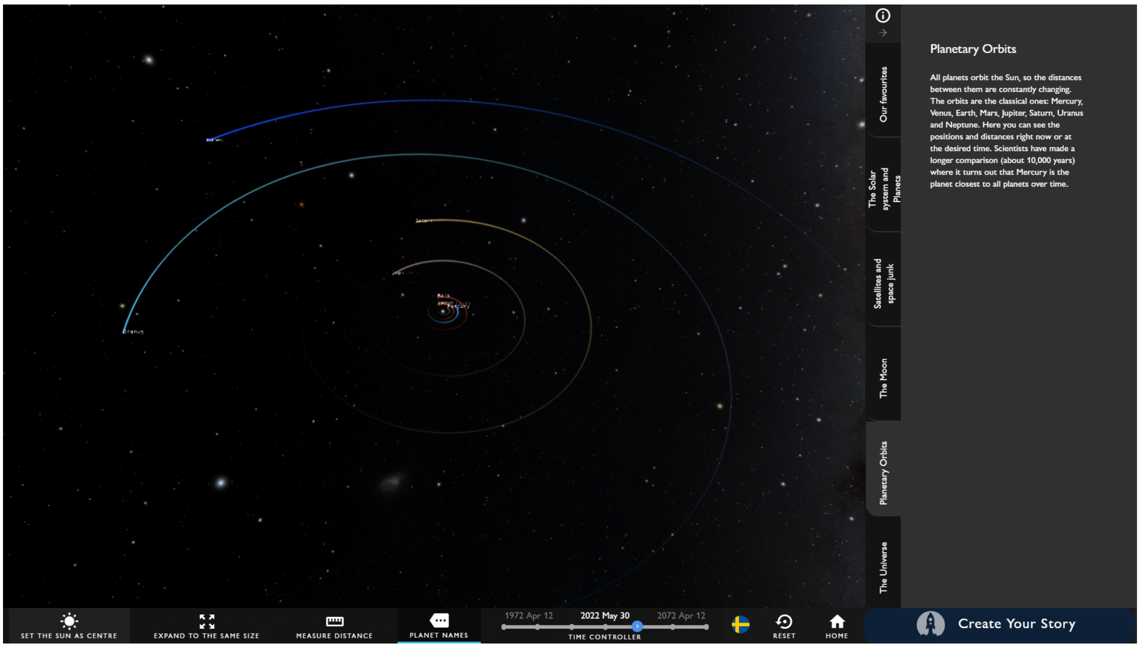

Figure C.22: Planetary Orbits: The Earth in the center, planets scaled to natural size, distance not shown, planet names shown

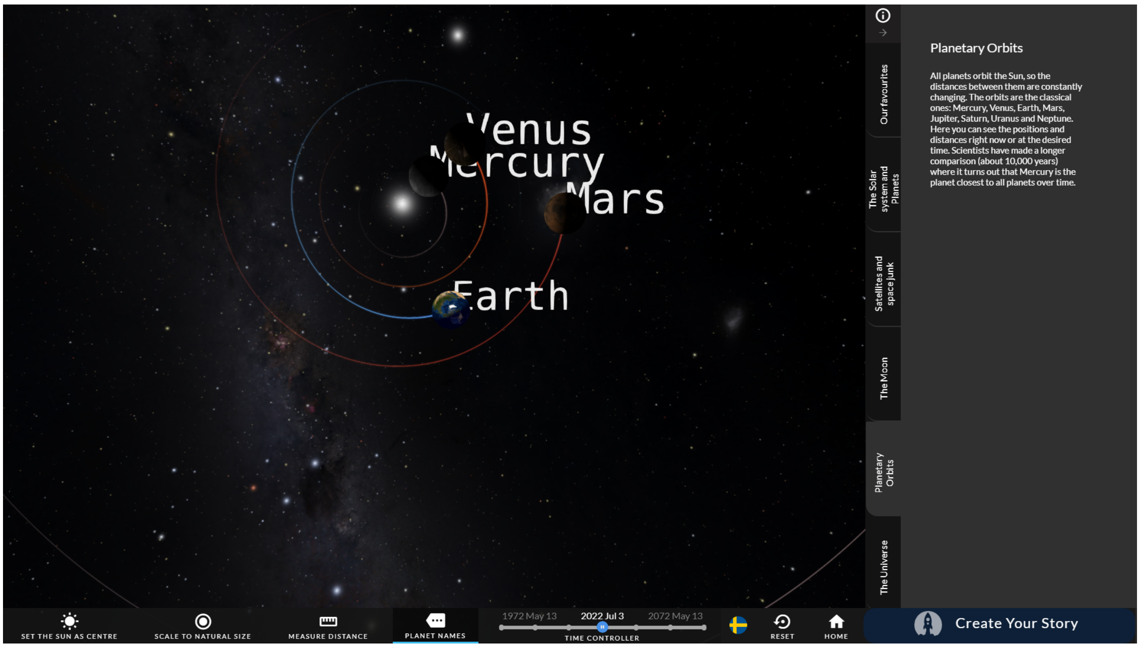

Figure C.23: Planetary Orbits: Earth in the center, planets scaled to same size, distance not shown, planet names shown

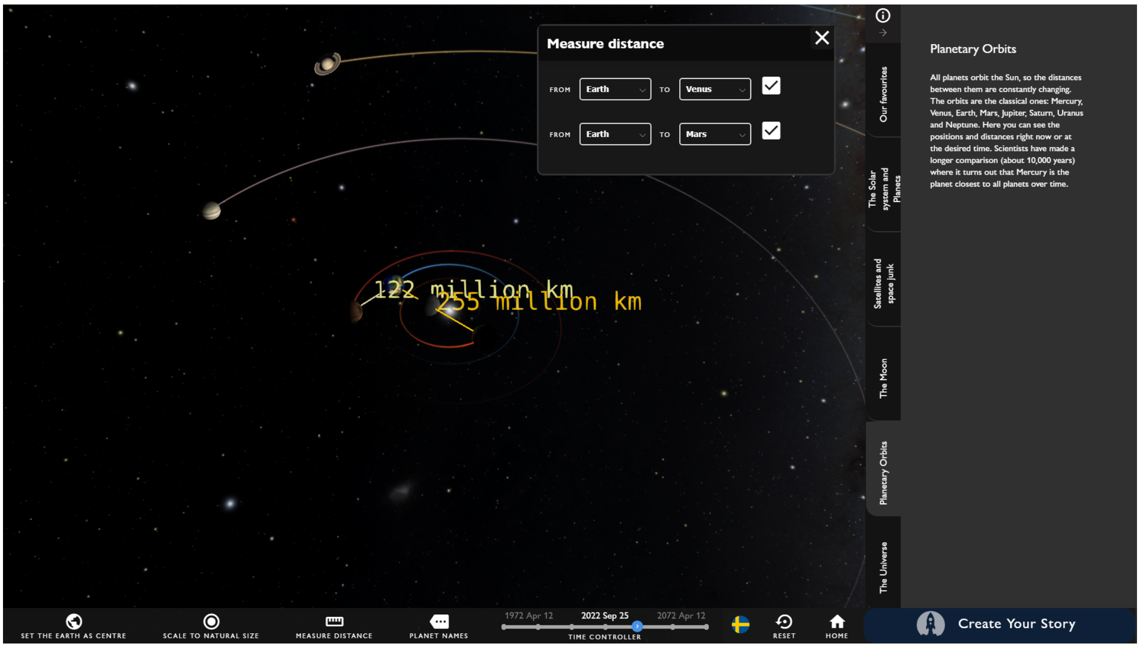

Figure C.24: Planetary Orbits: Sun in the center, planets scaled to same size, distance shown, planet names not shown

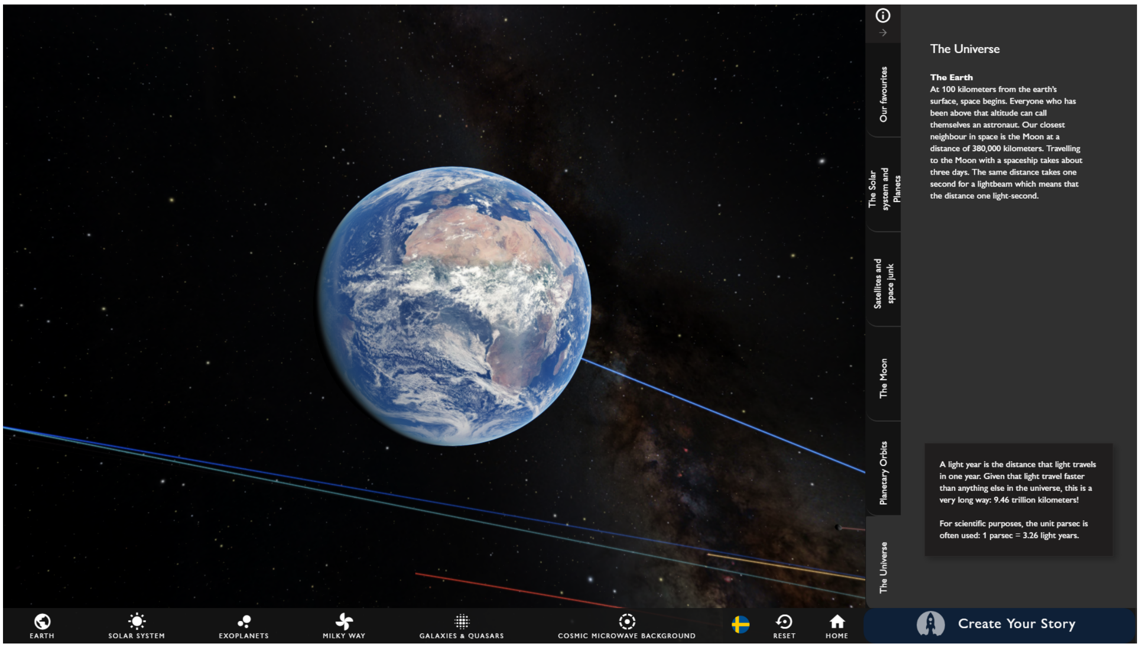

Figure C.25: The Universe: The Earth

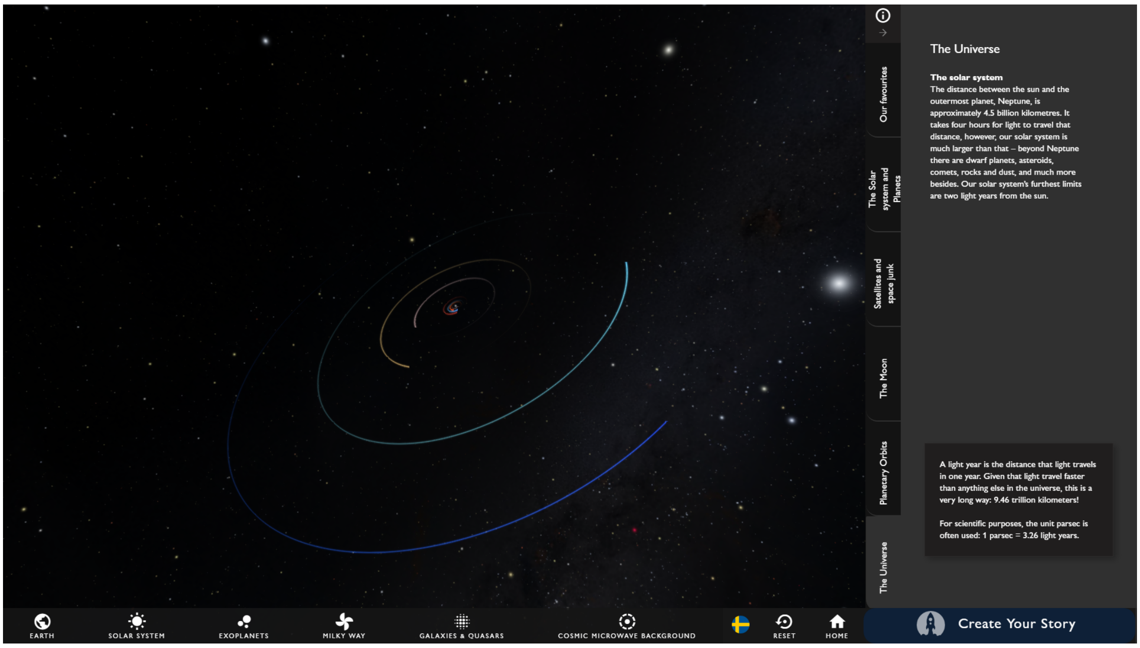

Figure C.26: The Universe: The solar system

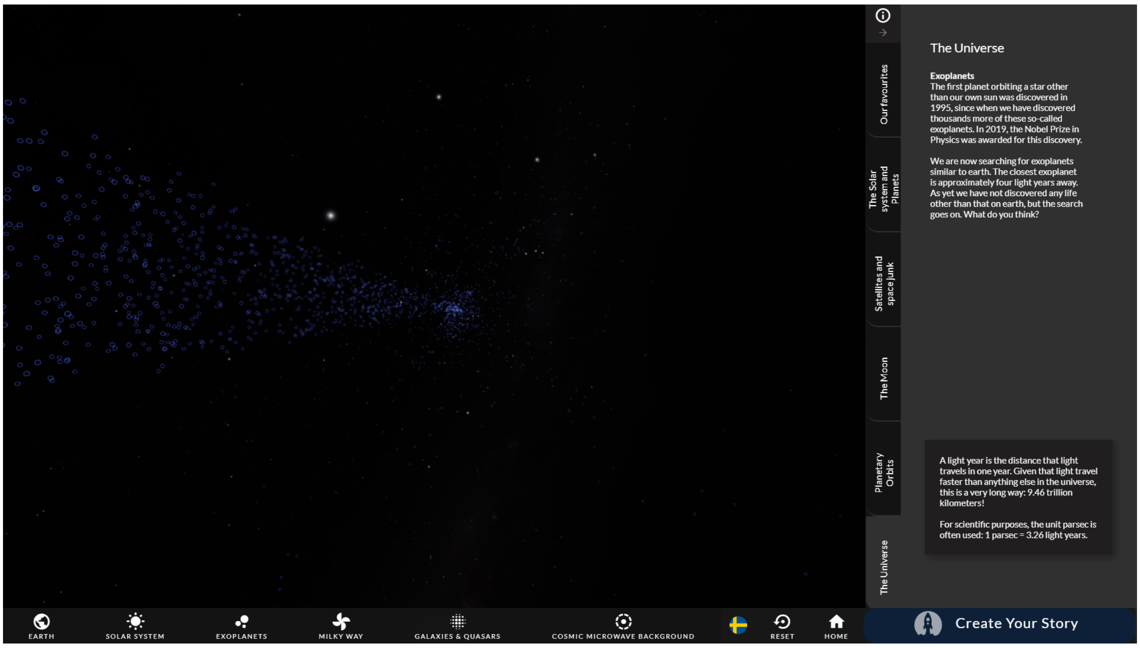

Figure C.27: The Universe: Exoplanets

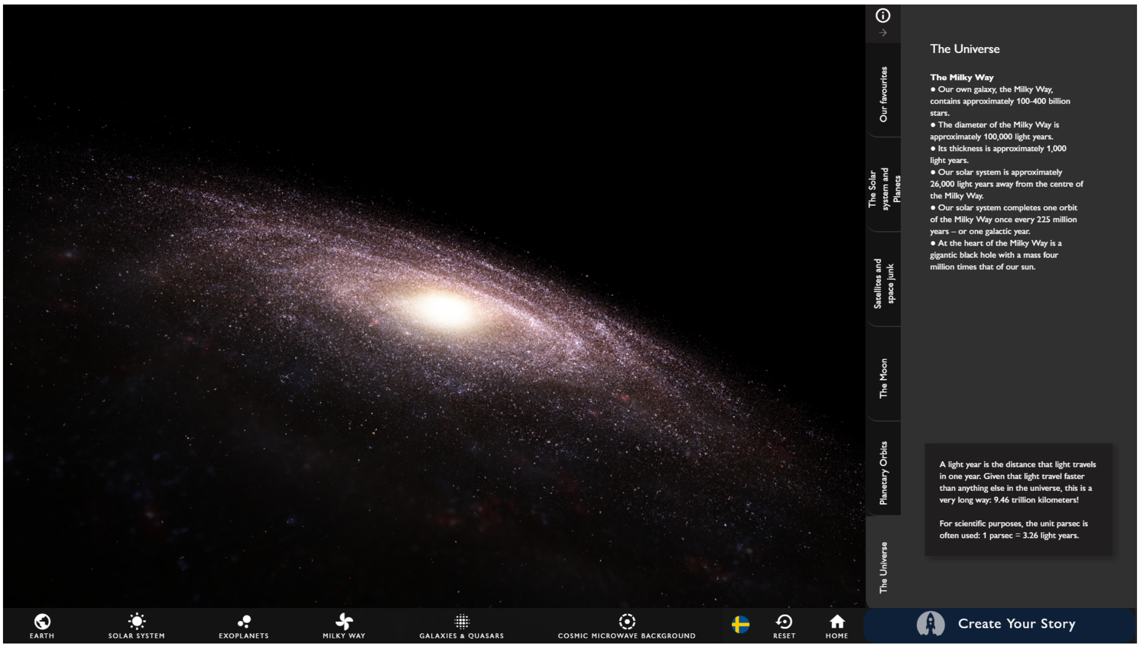

Figure C.28: The Universe: The Milky Way

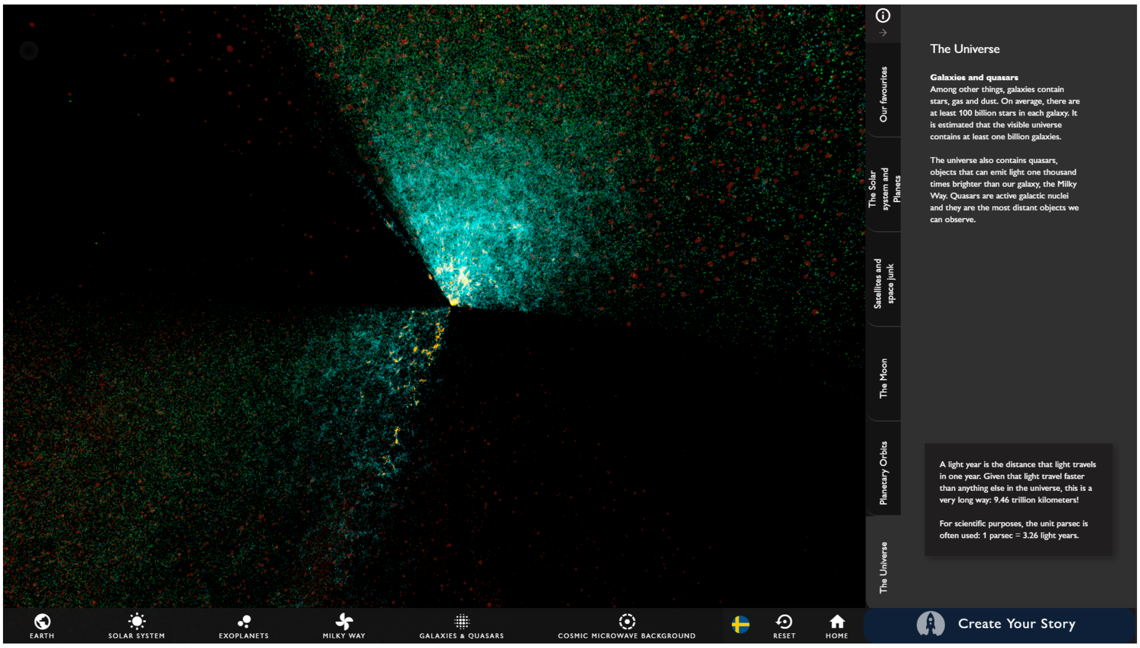

Figure C.29: The Universe: Galaxies and quasars

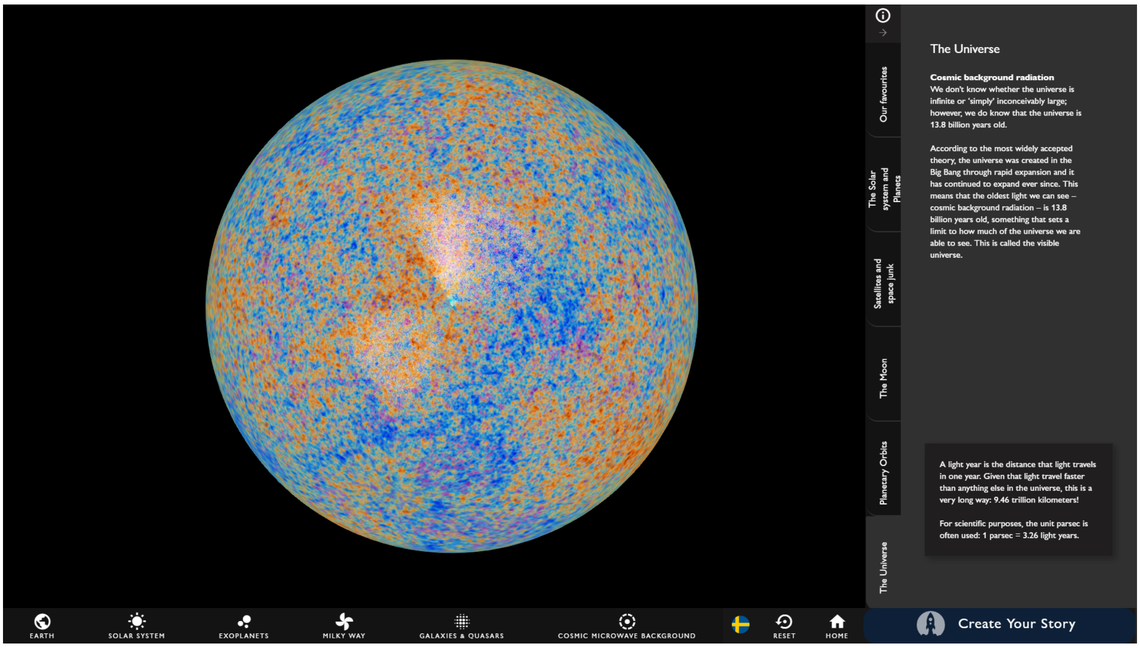

Figure C.30: The Universe: Cosmic microwave background

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