The Cosmic Perspective: Teaching Middle-School Children Astronomy Using Ego-Centric Virtual Reality

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Abstract

Virtual Reality (VR) has long been a promising medium for education, especially when an understanding of 3-dimensional relations is necessary for the learning outcome. Up until now, the use of VR has been reserved for research at universities and expensive custom training applications due to high equipment and maintenance cost. However, with the recent introduction of cheap, consumer-friendly head-mounted-displays (HMD) and motion tracking sensors the possibility of VR becoming a widespread educational tool is suddenly present. In this paper, we describe the evaluation of a VR application teaching astronomy to middle-school children using the consumer-grade VR equipment suitable for a classroom setting. The learning outcome and engagement is measured and recommendations for future applications are provided. We hope our research may provide a base of knowledge on how to make effective and engaging educational VR applications.

CR Categories: I.3 [Computer Graphics]: Three-Dimensional Graphics and Realism - VR; H.5 [Information Interfaces and Presentation]: Multimedia Information Systems - Artificial, augmented, and virtual realities

Keywords

VR, Virtual Environments, Education, E-learning, Science Education

1 Introduction

The past decades have revealed amazing discoveries in the field of astronomy. We have come to know the existence of thousands of exoplanets and have looked back into the earliest stages of the Universe. In our own Solar System we have discovered a host of new, small worlds and a few years ago we even put a 900 kg robotic rover on Mars. Despite all these amazing achievements and discoveries most children remain ignorant of even the most basic concepts of astronomy. For most children this ignorance continues into their adulthood. This is most unfortunate, not only because astronomy offers a true and deep understanding of our own origins and place in the cosmos, but also because astronomy is a gateway for the understanding of both science and technology. Our modern society depends heavily on science and technology and yet so few people understand anything about them. In a way, the reason for the lack of interest in astronomy is understandable. Most of the cosmos lies so well beyond human understanding and daily experiences, that it is hard to mentally model and understand the complexity, immensity and strangeness of the cosmos. The problem of teaching astronomy is made even worse by the difficulty of displaying the 3D nature of astronomy within a traditional classroom setting. Simply put, we need methods of letting people *experience* the universe so that they can more easily understand it the same way a zoo lets people experience exotic animals up close. A picture of a giraffe is one thing - standing next to it is quite another! Recent advances in Virtual Reality (VR) allows us to simulate cosmic journeys to anywhere we would like. With the amazing levels of computer graphics available today, this journey can be presented with near-photorealistic accuracy. Furthermore, with the introduction of the Oculus Rift, prices are now at a consumer friendly level, actually allowing for its use in schools and at home. VR thus presents a possible revolution in education and edutainment, but its success as more than a novelty will depend heavily upon its effectiveness as an educational tool. Even with the low price of the Oculus Rift, VR still represents an expense that needs educational justification. Development costs for educational applications will likely rival that of games in the video game industry and thus a demand for these applications must be present.

Previous research into VR as an educational platform has highlighted its usefulness in augmenting learning with ego-centric experiences and to visualize complex 3D structures. Some studies have already proven that 3D desktop applications improve the understanding of learning content that are inherently 3-dimensional such as astronomy and anatomy. However, research is needed to understand if these learning benefits also carry over to the highly immersive domain of VR. This paper describes a study of the educational benefits a VR application provides when teaching middle school children about size, distance and order of the planets within the Solar System. The study will also measure the level of engagement the children have towards the application. Finally, the study will provide recommendations for implementations of future educational VR applications.

This paper investigate research concerning the familiarity of astronomy to schoolchildren and adults as well as the research of VR as an educational tool. A preliminary study of a simple VR application is described which is followed by a larger study of a more complex application. Results are then processed and discussed before drawing conclusions concerning the study. Recommendation are then given for future work on the basis of the study.

2 Related Work

Much research has shown that children often have inconsistent and fragmented knowledge of astronomical concepts, such as the cause of Earth's seasonal change (Barnett et al, 2005) or the relationship between the Earth, Moon and Sun (Bryce & Blown, 2012) (Blown & Bryce, 2007). This poor knowledge of basic astronomy continues well into adulthood and even effects many elementary school teachers (Trumper, 2003) (Barnett et al, 2005). Research has suggested the difficulty of obtaining a coherent and scientifically correct cosmological framework is due to the 3D nature of astronomy which is difficult to correctly represent by 2D representations such as books and pictures (Barnett et al., 2005). Recommendations for future astronomy teaching include observation of celestial phenomena and the use of 3D models (Bryce & Blown, 2012) due to the 3D nature of astronomy. However, direct observation of astronomical phenomena, e.g. via telescopes or days-long tracking of celestial objects, can be time-consuming, tedious and only provide a look at the Universe from the single vantage point which is Earth. Furthermore, the dependence on the often poor cosmological knowledge of elementary school teachers (Trumper, 2003) provides a weak foundation for astronomy teaching.

The VR application in this study can provide a simulated observational platform on which to view the 3D relationships of the celestial bodies within the Solar System. Research into the use of VR as a learning tool has also revealed other possible benefits. One proposed benefit is that of individualized learning in which the student freely explores the educational content in a closed-loop feedback system (Wickens, 1992). This is supported by a study providing positive results of medical students learning the anatomy of the ear using an interactive 3D model (Nicholson et al., 2006). VR provides the possibility of an ego-centric experience which can interactively shift and manipulate the vantage point of the observer which research indicate lead to a better understanding of astronomical concepts (Barab et al., 2000) (Barnett et al., 2005). The application in this study uses a spaceship as frame of reference and clue for the user on how to travel and change vantage point. However, a recent study found that interactive navigation might not support learning positively (Ragan et al., 2012), but if the application in this study can, by the virtue of being interactive, keep users engaged for longer sessions, the learning outcome might be positively affected nonetheless. Furthermore, educational content which require a 3-dimensional understanding, like anatomy or astronomy, would likely benefit more from the interactive, 3-dimentional nature of VR. VR can provide a natural interaction paradigm which reduces unnecessary cognitive load which is proven to inhibit learning (Sweller et al., 1990). By utilizing the Microsoft Kinect the application in this paper implements such a natural user interface in order to relieve cognitive load. However, the effort of closed-loop interaction seems to be important for long term retention *if* the interaction facilitate cognitive links within the learning material (Wickens, 1992). Intentionally making travel time within the virtual world depend on distances between celestial bodies will be a good example of naturally communicating these distances to the user at the expense of convenience and efficiency.

VR provides a paradigm shift by augmenting learning with experience (Psotka, 1995). In an educational setting adhering to the learning theory of constructionism, VR has proved to be an effective tool by providing experience of natural phenomena (Schneider & Ohadi, 1997). These experiences can be very convincing since VR delivers *presence* unlike any other medium. Sight, hearing and motion are all enveloped in the experience resulting in a complete immersion of the perceptual system which can lead to stronger feelings and emotional effects (Lombard & Ditton, 1997). The kind of immersion and presence that VR provides have proved to be beneficial for understanding and performing tasks in a volumetric representation of a 3D space (Laha et al., 2012). Finally, presence is when you feel like your are *in* the virtual world and not just presented to it. It can only truly be understood by experiencing it (Abrash, 2014). The final application used in this study attempts to utilize this potentially strong degree of presence found in VR in order to give users the experience of traveling to planets and moons in the Solar System.

3 Preliminary Study

In preparation for the development of the final VR application, a simpler VR application was developed named the Planet Room. This Planet Room consists of a virtual room containing all the eight major planets and the Sun. All the planets and the Sun are modeled in correct relative sizes to each other and with realistic graphics and high resolution textures. The application uses both the Oculus Rift and the Microsoft Kinect in order to allow the user limited, natural movement within the virtual world. The four terrestrial planets are placed right in front of the user and the four gas giants are placed further away. The Sun is outside the room as it is much too large to fit inside. The room has no walls, but Greek pillars instead which are intended to provide a sense of depth and aesthetics. The planets are placed on small pedestals which all have the same size such that they can be used for size comparison with the planets. The application did not use sound or music.

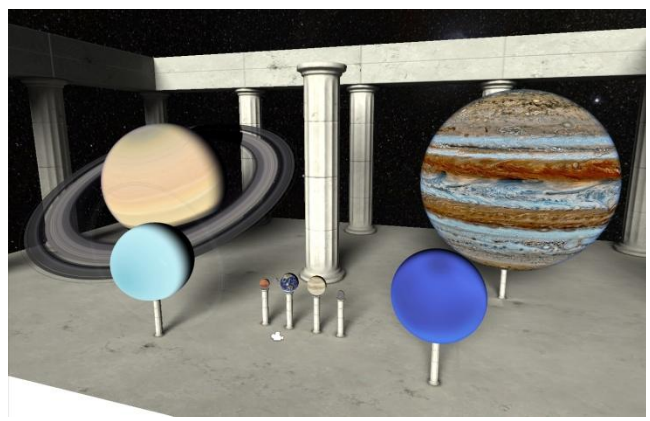

Figure 1: *The Planet Room. The user stands in front of the four terrestrial planets facing away from the Sun*

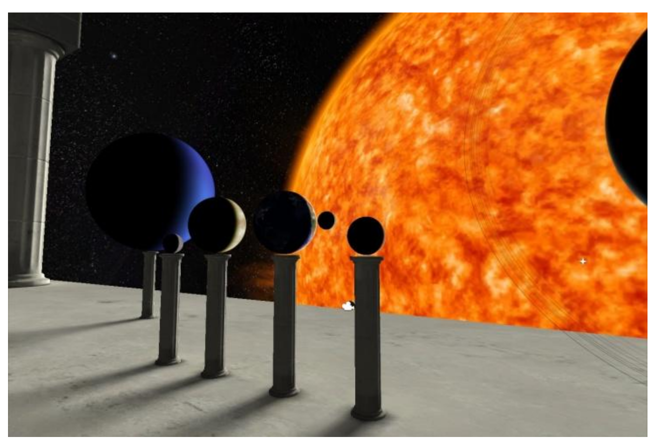

Figure 2: *The Sun placed outside the Planet Room*

The purpose of the Planet Room was to conduct a less structured evaluation of the interaction between an astronomy VR application and the target audience which in this study are children around the age of 12. More specifically, we wanted to evaluate the possibility of children at that age gaining knowledge of the size of the eight planets and the Sun though the use of the Planet Room. Of interest is also how quickly the children adapt to the virtual world, their reaction, feelings and general interest in using the application. The evaluation also evaluated whether the methodology was suitable for further use.

Six children were asked to try the application in pairs. In order to measure the learning outcome, the children were asked to draw, on a whiteboard, the planets of the Solar System and the Sun in correct relative sizes to each other. This process was conducted both before and after the children tried the application to measure if the sizes were more correctly represented. After both children had tried the application and drawn the planets a short, semi-structured interview was conducted to know the children's reactions and feelings about the application and whether they found it interesting. Due to the small sample size, no statistical analysis was conducted.

Most of the children found the application very exciting especially regarding the perceptual immersion. Some of the children showed very investigative behavior and exploited the possibility to move freely around to look at the terrestrial planets from different angles. The fun factor was mostly ranked high in the post-test interview. However, most importantly all of the children showed improvements in their understanding of the relative sizes of the planets and the Sun. Also, all three pairs of children drew more planets after the test session than before. Figure 3 and Figure 4 shows the drawings of one of the pairs of children.

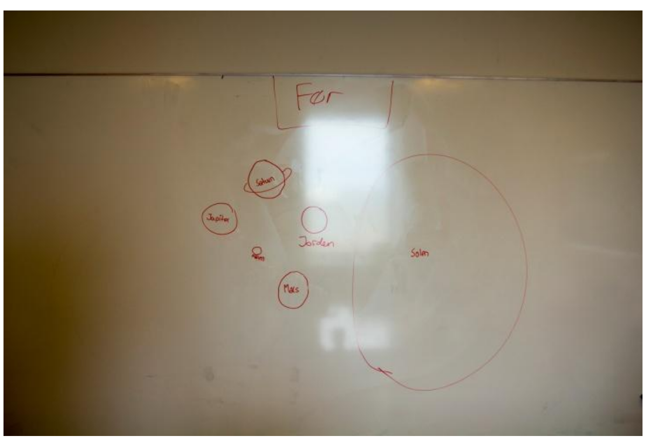

Figure 3: *Before-drawing of the planets and the Sun. Only four planets are drawn and at nearly the same size*

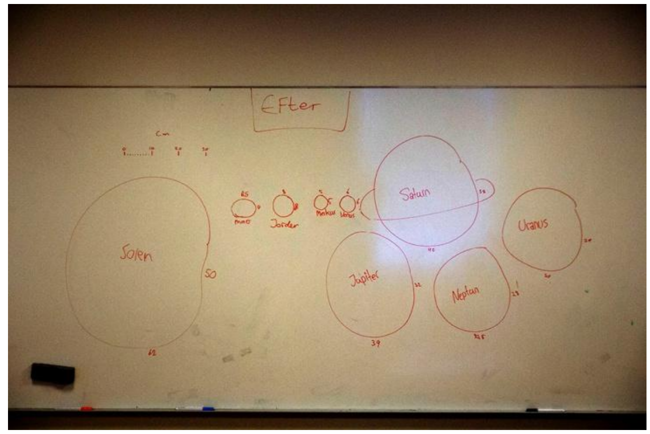

Figure 4: *After-drawing. All the planets are drawn and at much more correct scales than before*

The preliminary study indicates that VR could be a viable tool for teaching astronomy to middle school children. It also demonstrates that children at that age have an interest in VR and have positive reactions towards the technology. However, the test is limited by the small sample size and the fact that only size and known planets could be evaluated. Since the children were grouped in pairs, it was not possible to isolate each child's knowledge about the Solar System both before and after the test.

4 Evaluation

4.1 The VR Application

The preliminary study indicated that VR could be a promising tool in teaching astronomy to middle school children. The next iteration of the VR application will introduce more learning parameters namely relative *distance* between the planets and their *order*. A more realistic depiction of the Solar System will also be introduced. The planets will still be in correct relative sizes and their largest moons will now be included as well. The distances between the planets and their moons will be realistic in relation to the size of the planet and the distance between the planets will use mechanics within the application to give the impression of realistic distances, since planets cannot be clearly seen from other planets. The planets will not orbit the Sun and the Moons will not orbit their parent planet. This is supposed to make it easier for the user to comprehend the order of the orbiting bodies. The VR application will take advantage of the ego-centric perspective that VR offers and place the user inside a virtual spaceship which can travel at about 1 AU per second. This means that the user can travel from the Sun to Neptune in about 30 seconds. Travel time will be linear to support the notion of distance. This notion will be further supported by displaying the user's position among the planets while traveling (see Figure 5). A transparent "warp" tunnel will be used when traveling between planets both as an aesthetic effect and to illustrate motion. The solar lens flare will also diminish or increase with distance to the Sun.

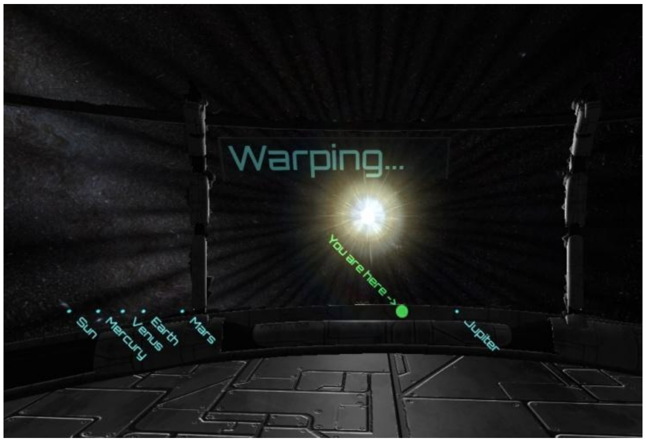

Figure 5: *The users position amongst the planets is shown when traveling between planets. The distances are relatively correct adding to the sense of scale*

On the virtual spaceship the user is presented with an interactive, 3D model of all the planets in the solar system including their moons. Like the application in the preliminary study, this application also uses the Microsoft Kinect to track the position of the users head, but in this application the user's hands are also tracked in order to allow the user to interact with the 3D user interface. The user's hands are represented by spheres for hand-eye-coordination. The user can travel to a destination by directly touching the name of that destination. This simple form of 3D user interface ensures the most natural and intuitive control, but can be prone to errors if the user accidently moves his hands into the interface. The planets in the 3D interface are presented in realistic relative scales since the preliminary study indicated that this was an effective way of visualizing size in VR. The largest moons of the current planetary system can also be selected as destinations.

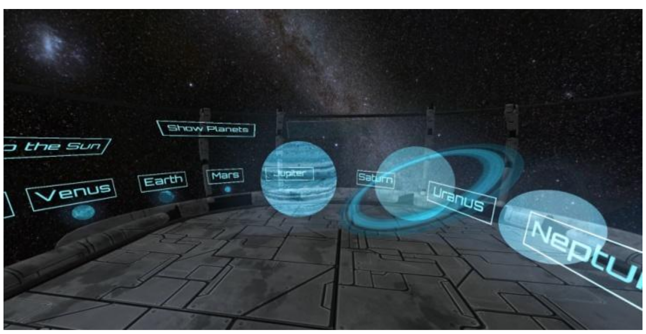

Figure 6: *The holographic representation of the planets. The planet nametags function as destination selectors*

The user can move around the spaceship platform to investigate the planet holograms close up and from different angles. Meanwhile, the platform acts as a natural barrier to discourage the user from walking outside the tracking zone of the Kinect. Sound is also added. A sound is played as a feedback whenever a holographic button is pressed. This is important since there is no tactile feedback. The warp tunnel also generates rumbling to increase the feeling of travel. A music soundtrack is also added in order to constantly envelop the user's auditory sense and enhance presence.

4.2 Experiment Design

The experiment will test two response variables for the VR application. These response variables will depend upon other variables which are measured during the experiment.

A) Motivation for learning: Is the application engaging? If so, then it is more likely that the children using the application will want to continue the experience for longer sessions and with greater joy and thus have more time to learn about the subject.

B) Is the application an effective tool when teaching astronomy to children? Do the children actually *learn* something about astronomy by using the application? If so, they should be able to answer certain questions about astronomy more correctly after the experiment than before.

The novelty factor could be a huge influence on this experiment. Since VR equipment is only available to developers and professionals, it is most likely that none of the children has experienced VR before. This means that the children will encounter a radically different medium which can result in the *medium itself* stealing a lot of their attention. The novelty factor will be addressed in the Discussion section of this thesis.

4.2.1 Hypothesis

Hypothesis A.1) Middle school children feel a strong degree of engagement towards astronomy teaching when presented in an interactive virtual environment

Hypothesis A.2) Middle school children feel a strong degree of engagement towards the interactive VR application

Hypothesis A.1 will require the children to be engaged in the actual *content* of the VR application and not just the VR medium itself. Parameters will need to be defined for distinguishing engagement in content from engagement purely in the medium.

Hypothesis A.2 will only require engagement in the VR medium itself in order to be accepted.

Hypothesis B.1) Middle school children are able to significantly improve their knowledge about the *order* of the eight major planets in our solar system.

Hypothesis B.2) Middle school children are able to significantly improve their knowledge about the *size* of the eight major planets in our solar system.

Hypothesis B.3) Middle school children are able to significantly improve their knowledge about the *distance from the Sun* of the eight major planets in our solar system.

The experiment could be conducted by comparing the VR application to other traditional means such as books, movies or traditional lectures. The reason why the experiment does not compare the results to a control group of children who learns the same facts through these traditional means, is that the approach and quality of books, movies and lectures comes in many kinds and vary greatly within each category. E.g. if one particular book were to be used as a control condition, then the experiment would only tell us the difference between the VR application and *that* particular book. Other books might do much better or much worse. It is therefore unreasonable to generalize the particular methods against this VR application since such a single specimen would not be able to represent the entire host of books, movies or lectures.

4.2.2 Methodology

The target group to be tested consists of 12 middle school children at the age of 12 to 14. A test session will include one child and the facilitator will be present. The test will be recorded on video and the game sessions will be screen captured.
The test begins by evaluating the child's current knowledge of the solar system. The child is asked to draw the eight major planets on three separate pieces of A3 paper here from referred to as papers A (size) and B (distance). On paper A the child must draw the planets in correct *sizes* relative to each other. On paper A the child can also color the planets. On paper B the child must place the planet in the correct *order* and relative *distance* from the Sun. The Earth will be placed on both paper A and B for use as reference. This will allow for easier data comparison and will also give the child a point of reference.
After the VR experience the child will be asked to repeat the process so that the two samples can be compared. The average circumference of the planets will be measured on Paper A and the distance on Paper B likewise. The *number* of planets the child draws before and after will tell if the children learned new planets.

Before the experience, part 1 and 2 of the Engagement Sampling Questionnaire (ESQ) (Schnoenau-Fog, 2011) was presented to the child asking demographic questions, how much they play videogames and their favorite genre or game. They will also be asked how interesting they find astronomy on a scale from 1 to 7. The last questions will also be asked after the VR experience.

When the VR experience begins, the child will be briefly instructed by the facilitator on how to interact with the holographic interface of the virtual spaceship. During the VR experience, part 3 of the Engagement Sampling Questionnaire will be used in order to determine the level of continuation desire of the child. Part 3 is designed to be asked repeatedly in order to measure continuation desire at different points of the experience. In this experiment the child will be interrupted every three minutes and asked part 3 of the ESQ. The child will be interrupted a maximum of five times during the experiment, resulting in a maximum session length of 18 minutes. However, some sessions were longer due to the interruptions.

After the VR experience, the child will be presented with part 4 of the ESQ. When this is done the child is asked to draw paper A and B again like they did before the VR experience, but with their new knowledge of the solar system. The child is asked again about their interest in astronomy.

The VR experience and the interview both before and after will be recorded on video. The VR experience will also be screen captured. The user will be asked place his hands in front of them in the beginning of the VR experience so that the video recording and the screen capture can be synchronized later on.

Children at the age of 12 should be comfortable enough to be interviewed and evaluated one-on-one with the facilitator. The social dynamic of having more than one test person in the room, could influence the behavior of the person being evaluated. Furthermore, it is important to be able to isolate each child's knowledge of the Solar System both before and after the experiment.

4.2.3 Results

This section will deal with the results of the experiment based on the drawings the children made, the video and screen capture, the interviews and the Engagement Sampling Questionnaire. The t-tests and binomial test are one-tailed since we would like to know whether the after-condition is *greater* than the before-condition and not just different. All tests use a significance level of $\alpha = 0.05$.

When testing hypothesis B.1 it is important to notice that the meaning of *order* also includes the *knowledge* of which planets exists within the Solar System. The correct order of the planets is measured by counting how many planets are placed on the correct side for each planet plus the planets itself. A correct order will result in a maximum score of 8*8 = 64 points. The next highest score is 62 points, since incorrectly swapping two neighboring planets will results in each planet counting an error. the minimum score is 1, since Earth is placed as reference. This points system is referred to as the Planet Order Score (POS) from now on.

In summary, for planets included in the drawing, the following formula applies:

$$POS = \sum_{i=1}^{n} (P_{i,left} + P_{i,right} + 1) \tag{1}$$

Using POS yields a before mean of 20.17 and standard error of the mean of 3.49 and an after mean of 41.33 and a standard error of the mean of 5.72. A paired t-test yields a p-value of 0.000405. The null hypothesis of hypothesis B.1 can therefore be rejected. A graph of the results is found below in Figure 7.

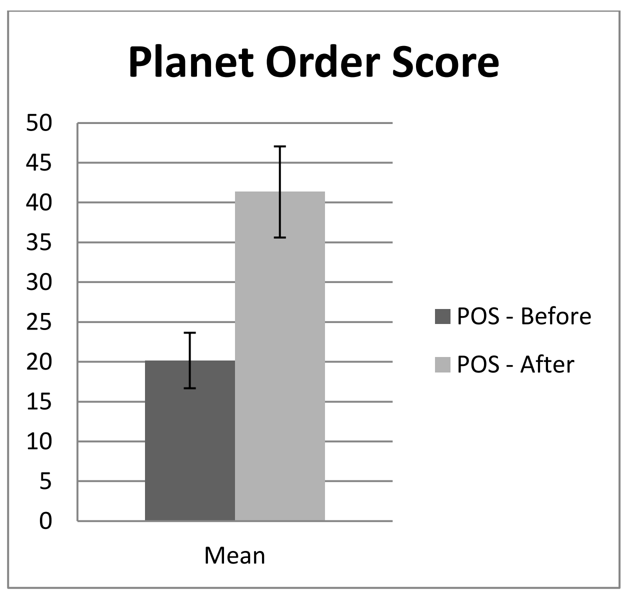

Figure 7. *Planet Order Score - Mean and standard error of the mean*

In order to further establish the rejection of the null hypothesis of hypothesis B.1, a binomial test is conducted. By conducting a binomial test it is possible see of the number of completely correct answers are significantly higher than what would be expected of the children had not learned about the order of the planets from the application. On the before-condition none of the children could give a correct answer about the order of the planets, but on the after-condition three of the children could. The probability of a child guessing the right answer by chance is 1 in 8! = 1/40320. The binomial test yielded a p-value of 3.36E-9 which strongly rejects the null hypothesis of hypothesis B.1. Two ways of measuring the same data have therefore come to the same conclusion, that children have, with significant confidence, improved their knowledge of the order of the eight major planets of the Solar System.

Hypothesis B.1 presents a sub-hypothesis, namely whether the children have come to know more planets by using the VR application. In this case we have two datasets for the same hypothesis - namely how many planets are drawn on the distance papers and the size papers. The results for each planet is shown in

Figure **8** and Figure 9. The p-value for the size paper dataset yields a p-value of 0,0266 and the distance paper yield a p-value of 0.0070. Both tests therefore rejects the null hypothesis of hypothesis B.1.

Figure 8 and Figure 9 below shows that Mercury, Uranus and Neptune have benefited most with Neptune in the lead.

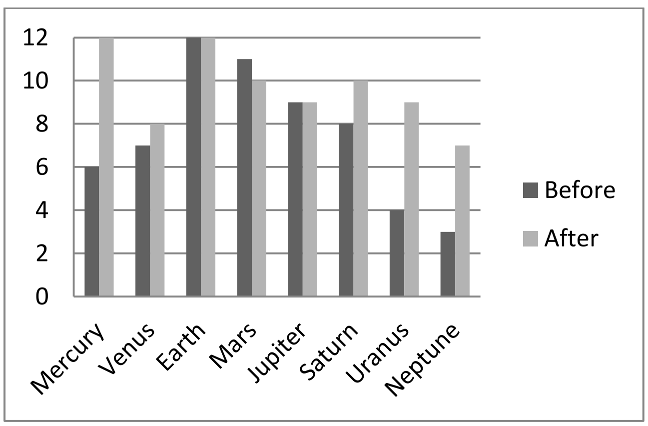

Figure 8: *Number of planets drawn on Paper A (Size)*

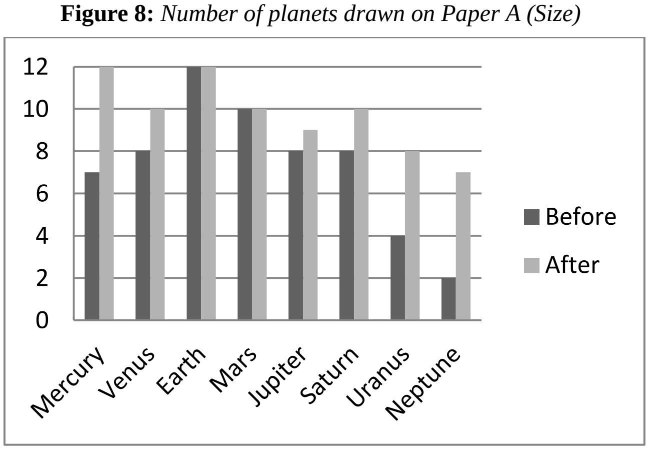

Figure 9: *Number of planets drawn on Paper B (distance)*

To compare size and distance the drawn planets are measured, but this cannot be done using a paired t-test since most children have not drawn the same number of planets before and after the session, and a pair wise comparison is therefore not always possible. In order to use all the samples the samples will be treated independently. The unequal samples sizes of the before and after condition thus requires the use of a two-sample t-test for testing hypothesis B.2 and B.3. This means that the test does not compare the improvement of each child, but compares the overall improvement instead. The improvement will be measured as the difference between the circumference/distance of the drawn planet from what the correct circumference/distance should be in relation to the Earth. Homogeneity of variance will be tested for each planet on both size and distance to determine whether to use an equal or unequal variance two-sample t-test (Welsh's t-test) for that planet. Each planet will be tested independently and this will show how each planets has benefited from the application. The p-values for all the planets are listed in Table 1 and

Table **2** below.

Table 1: *p-values for planets on Paper A (Size)*

Planet	p-value (F-test)	df	p-value (t-test)	H0 rejection (α = 0.05)
Mercury	**0,0089**	16	0.2450	No
Venus	**0,0002**	13	0.0732	No
Earth	-	-	-	-
Mars	0,1568	19	0.2878	No
Jupiter	0,3366	16	0.1018	No
Saturn	0,1679	16	0.4087	No
Uranus	0,7837	11	0.4923	No
Neptune	0,1605	8	**0.0348**	**Yes**

Table 2: *p-values for planets on Paper B (distance)*

Planet	p-value (F-test)	df	p-value (t-test)	H0 rejection (α = 0.05)
Mercury	**0,0000**	17	0.1375	No
Venus	**0,0000**	16	0.0865	No
Earth	-	-	-	-
Mars	0,7151	18	0.2599	No
Jupiter	0,2849	15	0.4778	No
Saturn	0,8386	16	0.1727	No
Uranus	0,5079	10	0.1581	No
Neptune	0,4112	7	**0.0356**	**Yes**

The results for understanding of both size and distance show that only Neptune has been significantly better understood on both parameters. The null hypothesis of hypothesis B.2 and B.3 can therefore not be rejected with the exception of Neptune. The possible reasons for this will be discussed in the Discussion section. The differences between the correct answers and the stated answers are listed below in Figure 10Figure 11.

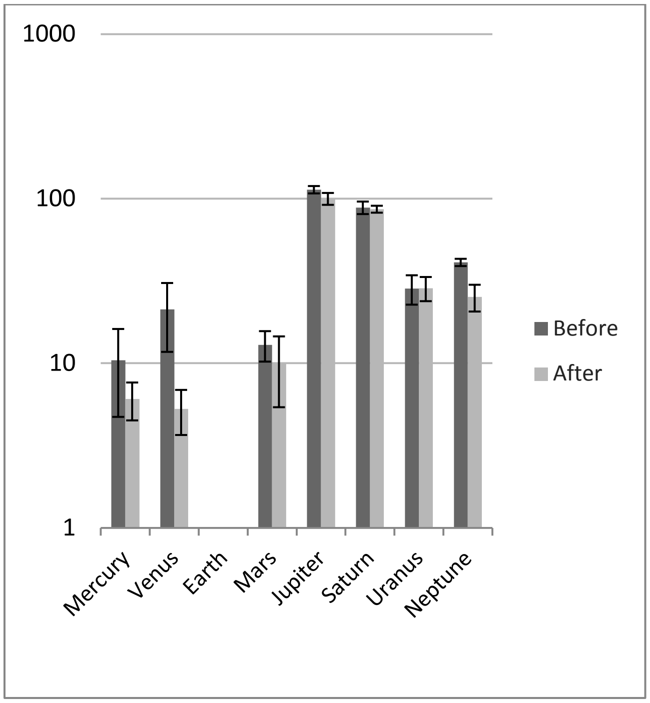

Figure 10: *Mean difference in mm between correct answer and given answers for Paper A (size). Earth is depicted beforehand and used as reference for the other planets. Thus it has no data.*

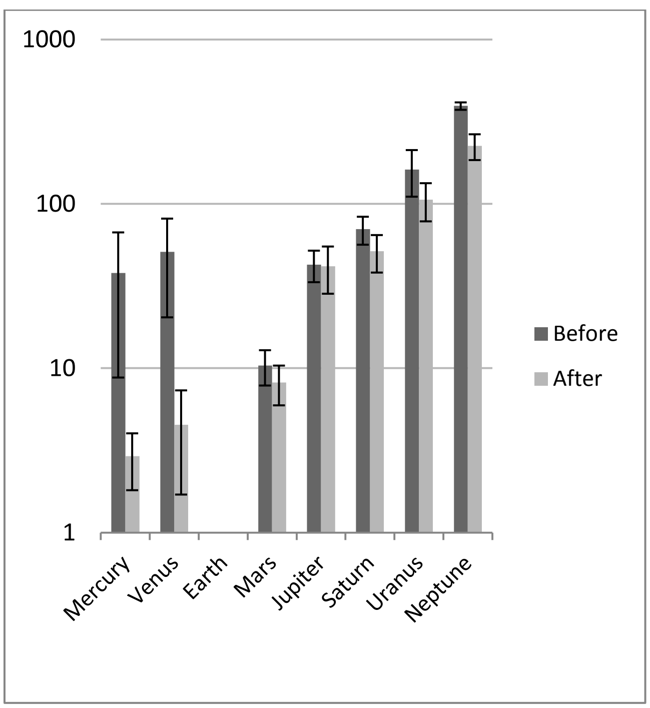

Figure 11: *Mean difference in mm between correct answer and given answers for Paper B (distance)*

4.2.3.1 Results from the Questionnaire and Interviews

This subsection will evaluate the results from the Engagement Sampling Questionnaire (ESQ) along with the interviews, logs and observations during the game session captured by screen capture and camera. These will be used to provide measurements on which to make conclusion of hypothesis A.1 and A.2.

The main purpose of the ESQ was to evaluate the Continuation Desire (CD) throughout the game session in hence provide measurement for hypothesis A.2. Figure 12 shows that CD drops quickly after about 6 minutes of gameplay. Almost none of the children played the game for all 15 minutes. However, the desire to try the application again was relatively high, but still lower than the desire to try the application before the game session.

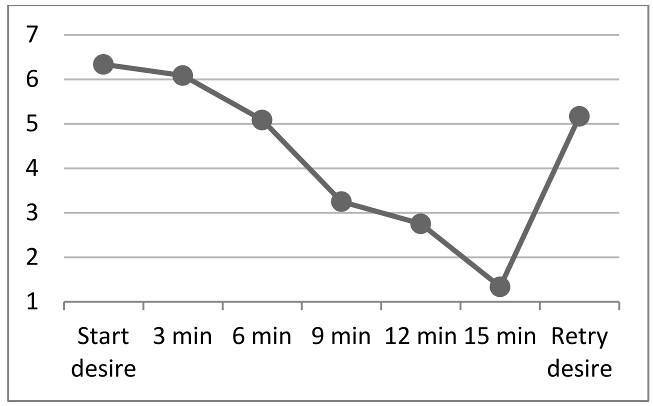

Figure 12: *Mean Continuation Desire throughout the game session. Horizontal axis approximate game time*

The reasons stated for the drop in CD were mainly the lack of clear purpose within the game. Some children were more specific and stated the desire for gamification elements within the VR application. Most children also stated that they felt that they had "seen it all" around 9 minutes of game play. Some also stated the lack of free flight around the planets as a reason for lowered CD. These statements will be followed up on in the Future Work section.

Another purpose of the ESQ was to evaluate whether the application has increased the children's interest in astronomy. Before and after the game session the children were asked to rank their interest for astronomy on a 7-point scale. A Wilcoxon Signed Rank test was used to test if a significant increase in astronomy interest had occurred. The test yielded a p-value of 0.03906 which is enough to reject the null hypothesis of hypothesis A.1. However, the strength of this evidence will be discussed in the Discussion section.

5 Discussion

The Planet Room in the preliminary study indicated that visualizing the planets in relatively correct sizes was effective in teaching the users the true size differences between the planets. The outcome of the final evaluation showed that the children had significantly improved their knowledge of what planets exist and their order. However, the evaluation also showed that knowledge about the relative size and distance between the planets had not been significantly improved except for Neptune. This result was not expected due to the indication of the preliminary test which indicated more positive results. The most obvious reason was that in the Planet Room all the planets were placed permanently together in full-color graphics, while the final application only offered this comparison with blue, smaller and semi-transparent planets in the spaceship. The "true" planets could only be visited one by one in the final application. The Planet Room also utilized more space for the planets allowing for larger scales and thereby more visible differences in size. It could very well be this more dedicated visualization in the Planet Room that made the difference. The fact that children were tested in pairs in the preliminary study could also provide a bias towards a better understanding of the size differences since they were able to help each other in drawing the planets.

Regarding the lacking understanding of the distances, some children didn't notice the distance visualization while traveling between planets. The distance visualization should be made much easier to notice. The relatively small sample size was a problem in achieving statistical significance. Most of the children did not draw all the planets on neither drawings before or after which was a significant factor in decreasing sample sizes.

Only a few of the children remained interested in the application after more than 10 minutes. An often stated reason for this was the lack of purpose or objectives within the application. This relatively brief session time could also be a limiting factor when learning inside a VR application since previous research suggest that the right kind of effort has a positive effect on retention. In the present application, the user is an interactive *spectator*. If the user was able to interact with the virtual world in more challenging ways, better learning outcome might be achieved.

6 Conclusion

This paper investigated whether a VR application can be an effective tool towards teaching astronomy to middle school children. The inherent 3D nature of astronomy combined with the pioneering aspects of space travel and beauty of astronomy makes it an apparent ideal match for learning experiences inside a virtual world. A preliminary study showed promising results for teaching middle school children the relative sizes between the eight major planets and the Sun. Most of the children seemed amazed by the VR application and some showed a great deal of investigative behavior. The results from the preliminary study encouraged the development of a more complex VR application with more learning objectives. The new application allowed the users to visit the different planets and their moons in spaceship. The spaceship features an interactive holographic display to show the relative sizes of the celestial bodies, their order and the distance between them. The applications implemented travel time proportional to the distance between the planets in order to give the experience of traveling different distances. A study was conducted using 12 middle school children to determine the learning outcome of *size*, *distance* and *order* among the planets. The children's interest in the application was measured by Continuation Desire using the Engagement Sampling Questionnaire. The children did not significantly improve their knowledge of the relative size and distance among the planets, but they significantly improved their knowledge of the order and existence of the planets within the Solar System. The children were allowed to play for around 18 minutes, but most did not play for this long. The children's desire to try the application was very high, but their desire to continue playing began to drop already after six minutes of play. Thus the application was not very successful in retaining the engagement of most of the children for very long.

7 Future Work

The application faced two problems. First of all, some learning parameters need to improve. Secondly, the application must be able to engage the user for longer periods of time. A solution that would keep users engaged for longer periods of time could also help people learn more, as exposure to the content will increase. Many of the children expressed the lack of purpose within the virtual world and one directly suggested the introduction of gamification elements. Furthermore, the ability to view a planet or moon from more angles and distances could also be a source of greater explorative engagement as well as aesthetic experience. Visiting the surface or atmosphere of planets and moons could introduce greater variety of learning experiences and let the user experience trademark phenomena of planets and moons which could make individual planets and moons more memorable. E.g., the ice geysers of Europa or the turbulent Red Eye of Jupiter could serve as memorable locations which both show the strangeness and wonder of the Solar System, but also help distinguish different planets and moons.

Implementing gamification elements into the VR application could increase user engagement and thereby prolong game sessions leading to increased exposure of the content and thereby increased learning outcome. Gamification elements could also help in establishing cognitive to different parts of the learning material. E.g. the different phenomena found on the different worlds in the Solar System could serve as important game elements or be the centre of game plots thereby forcing the user to engage in meaningful cognitive effort which is suggested to improve retention. Hence, the gamification elements should always exist to serve the educational purpose of the game. Looking at Bartle's four player types (Bartle, 1996), the current state of the game appeals solely to Explorers and even this appeal is not very deep. Gamification elements make it possible to appeal to Achievers as well as Explorers. Since the game needs more content to explore, gamification could direct users to interesting experiences and location within the game.

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References

Abrash, M. (2014). What VR could, should, and almost certainly will be within two years. Steam Dev Days.

Barab, S. A., Hay, K. E., Barnett, M., & Keating, T. (2000). Virtual Solar System Project: Building Understanding through Model Building. *Journal of Reseach in Science Teaching*, 719-756.

Barnett, M., Yamagata-Lynch, L., Keating, T., Barab, S. A., & Hay, K. E. (2005). Using Virtual Reality Computer Models to Support Students Understanding of Astronomical Concepts. *Journal of Computers in Mathematics and Science Teaching*, 333-356.

Bartle, R. A. (1996). Hearts, Clubs, Diamonds and Spades: Players Who Suit Muds.

Blown, E. J., & Bryce, T. G. (2007). Knowledge Restructuring in the Development of Children's Cosmologies. *International Journey of Science Education*, 1411-1462.

Bryce, T. G., & Blown, E. J. (2012). Children's Concept of the Shape and Size of the Earth, Sun and Moon. *International Journal of Science Education*, 388-446.

Laha, B., Sensharma, K., Schiffbauer, J. D., & Bowman, D. A. (2012). Effects of Immersion on Visual Analysis of Volume Data. *IEEE Transactions on Visualization and Computer Graphics*, 597-606.

Lombard, M., & Ditton, T. (1997). At the Heart of It All: The Concept of Presence. *Journal of Computer-Mediated Communication*, 1-29.

Nicholson, D. T., Chalk, C., Funnel, R., & Daniel, S. J. (2006). Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. *Medical Education*, 1081-1087.

Psotka, J. (1995). Immersive training systems: Virtual reality and education and training. *Instructional Science*, 405-431.

Ragan, E. D., Huber, K. J., Laha, B., & Bowman, D. A. (2012). The Effects of Navigational Control and Environment Detail on Learning in 3D Environments. *IEEE Virtual Reality*, 11-14.

Schneider, C. I., & Ohadi, M. M. (1997). Unraveling Students' Misconceptions about the Earth Shape and Gravity. *Science Education*, 265-284.

Schnoenau-Fog, H. (2011). Hooked! - Evaluating Engagement as Continuation Desire in Interactive Narratives. *ICIDS*, 219-230.

Sweller, J., Chandler, P., Tierney, P., & Cooper, M. (1990). Cognitive Load as a Factor in Structuring of Technical Material. *Journal of Experimental Psycology*, 176-192.

Trumper, R. (2003). The need for change in elemtary school teachers training - a cross-collage age study of future teachers' conceptions of basic astronomy concepts. *Teaching and Teacher Education*, 309-323.

Wickens, C. D. (1992). Virtual Reality and Education. *IEEE*.

Yair, Y., Schur, Y., & Mintz, R. (2003). A "Thinking Journey" to the Planets Using Scientific Visualization Technologies: Implications to Astronomy Education. *Journal of Science Education and Technology*, 43-49.