Sitting outside the Milky Way:

Communicating Science with Adults in a 3D Planetarium

Andrew Glester

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Abstract

Planetariums are evolving. In July 2015, the @Bristol Planetarium became the first 3D planetarium in the UK. Audiences are taken on a multimedia, 3D journey through the Cosmos to supplement the more traditional 2D representation of the night sky. This research sought to explore the role of the new 3D Planetarium in communicating science with adults. Three uses of the Planetarium were considered with self-completion questionnaires. Content analyses of the presenter's narration and interaction were also conducted. The audiences were a combination of people looking for a night out with friends and family with little or no previous interest in science and those coming specifically to further their interest in astronomy. The results suggest that adult audiences are strongly favourable to the 3D Planetarium experience, wishing to come back again to learn more about science and stargazing. It is also suggested that the 3D Planetarium provides an inspirational experience which leaves adult audiences planning to change their behaviour to reflect what they have learned. Further areas of study have emerged from the research, and more, long term studies into the efficacy of 3D Planetariums will further inform the topic as the technology matures.

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1. Introduction

This research considered the role of the newly installed 3D Planetarium at the @Bristol in science communication with adults. 3 adult only events were selected where audiences experienced the planetarium for different shows or uses. A specific requirement of @Bristol was to explore the impact for the audience of the new 3D capabilities of the planetarium.

The planetarium experience is not a new phenomenon. The Zeiss model 1 projector has its first public audience at the Deutches Museum in Munich in 1923 (Gustsch and Manning, 1996) and with it, began the era of the planetarium (Griffiths, 2008). The New York Times, in 1928, reported,

"A miracle happens. A switch has been thrown, and that ceruclean vault suddenly becomes a firmament of twinkling stars. Even trained astronomers who knew exactly what to expect cannot suppress a long drawn "Ah-h-h-h-" of astonishment and pleasure when they behold this dramatically presented counterfeit of the heavens for the first time". (Kaempffert, 1928)

During the Apollo era, the number of planetariums doubled in the space of six years to an estimated 700 to 800 worldwide (Gustsch and Manning, 1996). Today, there are approximately 4000 permanent planetariums known to the International Planetarium Society (IPS directories, 2015) with audiences of over 100,000,000 (Petersen, 2015). The overarching goals of planetarium operators are to **inspire**, **engage**, **educate** and **entertain** audiences with shows that predominately feature projections of the night skies. This is particularly important in towns and cities with the real skies so often obscured by clouds and light pollution (Gustsch and Manning, 1996).

Studies show that teachers, pupils and the public have misconceptions about astronomy (Bailey, Prather, and Slater, 2004; Bhathal, 2009; Preece & Clish 1985; Mant & Summers, 1993; Meadows, 2000; Baxter, 1995; Trumper, 2001; Turk & Kalkan, 2014). The misconceptions include incorrectly attributing seasons to the proximity of the Sun to Earth. Astronomy does not lend itself to practical experimentation in the way of many other sciences (Preece & Clish, 1985; Baxter, 1991), which may contribute to these misconceptions. Demonstrations and practical

experiments are less prevalent in astronomy education. The planetarium offers an opportunity to address these misconceptions, engaging large numbers in a science which interests audiences (Meadows, 2000) and facilitating an increase in their conceptual and spatial cognition of our universe. Astronomy is also often seen as a gateway to further interest in science and technology (Crabtree, 2012).

The literature review explored informal learning and existing efficacy research. Early planetarium research lacked significant sample sizes (Reed & Campbell, 1972) and research into the efficacy of planetariums with adult audiences is relatively scarce. As planetariums have developed, research has emerged into specific tools used in the shows such as humour and narrative. Before that, the literature review tracked the evolution of planetarium research as the planetariums were developed from 2D to full dome, 3D presentations.

1. i. Informal Learning

People spend under 10% of their life in formal education, meaning that informal education can have a significant role to play in an adult's learning. Informal learning forms close to half of the average American adult's understanding of science (Falk, Storksdieck, & Dierking, 2007). A planetarium is an informal learning environment, distinct from the formal learning of the classroom (Krishnamurthi, 2011; Lomb, 2009), which provides an opportunity to inform and excite audiences. Planetariums are part of an informal astronomy education which can be gained from books, radio, magazines, television, astronomy clubs, the internet, podcasts, science centres, teen groups and camps as well as planetariums (Fraknoi, 1996).

Bailey, Prather and Slater (2004) argue that planetariums operate in three "realms of learning"; the cognitive, affective and psychomotor. The cognitive concerns thought processing (Petty, Ostrom, and Brock, 1982). The psychomotor encompasses learning through doing (Noble, Baker, and Jones, 1964) which enters the planetarium experience with the more interactive or participatory shows of recent years (Bailey, Prather and Slater 2004). The affective realm concerns feelings which can be engaged by planetarium shows that encourage the audience to a deeper

appreciation and wonder of the universe we inhabit (Bailey, Prather and Slater 2004).

If this informal learning can address the common misconceptions about astronomy then it needs to cover the appropriate topics and Planetarium content is aligned with the astronomy content of the national curriculum in the UK (Tidey, 1998) so if Planetariums are effective then they can be a useful part of the science communication landscape.

1. ii. Efficacy research

Historic research into the efficacy of planetariums as compared to the classroom have garnered mixed results. In their 1972 study, Reed and Campbell found that college students were more able to correctly place the planets in order if they had classroom rather than planetarium instruction. However, some other tests of that period suggested that planetariums are more effective than the classroom (Dean and Lauck 1972; Wright 1968, Tuttle 1966) while others suggest that classroom based lessons are more effective than the Planetarium (Pitluga 1971; Reed 1970a; Smith 1966). Rosemergy (1986) found that classroom and planetarium instruction were equally effective at communicating concepts and Fletcher (1980) compared a traditional demonstration with a more participatory lesson approach for teaching the movement of the Sun and found no significant difference between the two methods in conceptual understanding.

Mallon and Bruce (1982) evaluated another participatory planetarium experience in comparison to a more traditional star mapping show. They found that the participatory show was superior in both the cognitive and affective realms but as Bailey and Slater conclude, these studies are "more indicative of the degree of students' intellectual engagement than anything else." (Bailey and Slater, 2003).

Planetarium software on home computers has also improved, giving another tool to astronomy education. Baxter and Preece (2000) found that there was no significant learning difference between planetarium software on a computer and a visit to a full dome planetarium for pupils but planetarium software for the home and planetariums has developed significantly since 2000. A study in 2009 used the newly

updated computer planetarium software Starry Night in a classroom environment and found that it appeared to enable young children to understand complex scientific principles more than they could on their own (Hobson et al, 2009).

A study by the American Museum of Natural History (quoted in Wyatt, 2002) found that the Hayden Planetarium show, which covered our "cosmic address", relative size and distance of stars, structure of the milky way and the formation of heavy elements, was well received by audiences from 8 to adult and that the audiences showed significant gains in their understanding of the key concepts. Plummer (2008) found that early elementary school children are capable of learning about celestial motion with a mix of kinesthetic teaching techniques and the "rich visual environment" of the Planetarium.

Planetariums have changed as technology has advanced so historical studies into efficacy must also be considered in that light. Direct comparisons are not possible between the planetariums of today and those of decades ago, and even since 2000 and 2009, as the audience experience has changed considerably. A 2014 study showed that students who visited a planetarium did show a statistically significant improvement in scientific understanding of astronomy concepts compared to those whose instruction was based in the classroom alone (Turk & Kalkan, 2014). A 2015 study showed that 5 out of 6 children aged 12-14 had a better understanding of the phases of the moon after instruction in a digital full dome planetarium (Chastenay, 2015) but the new 3D Planetarium is different again. Technology has changed the mechanisms of the planetarium but not the goals of the operators (Gustsch and Manning, 1996; Petersen, 1989; Sweitzer, 2012). The more static, star mapping shows pioneered in the 1970s and 1980s are making way for the full dome video in the planetariums of today.

1. iii. Full dome video

Spatial cognition is understood to be a key part of students' comprehension of astronomy (Eriksson et al., 2014; Plummer, 2014). Full dome planetariums are comparatively new to the research field considering Immersive Virtual Environments (Lantz, 2004, 2006; Wyatt 2007) and few empirical studies exist (Schnall at al., 2012).

Immersive Virtual Environments, however, have been shown to be effective for learning some of the complex spatial concepts of physical sciences (Emmart, 2005; Dede et al, 1996; Salzman et al 1998; Dede et al. 1999). As projectors and computers have advanced, planetarium operators have been able to give the audience visual demonstrations of the universe, enabling greater spatial cognition. The new technology has also given them the ability to use planetariums and immersive digital domes for a variety of experiences and purposes (Lantz, 2006; Bailensen et al., 2008; Wyatt, 2005).

A 2004 study comparing the full dome show with a traditional lecture and a standard video found that the least significant gains in understanding were for those with the traditional lecture (11.5%), followed by those who saw the standard video (18%). The greatest gain of percentage of questions right was 24% for those who saw the immersive full dome show (Sumners and Reiff, 2004).

Without reaching any efficacy conclusions, a 2008 study found that immersive Virtual Reality was a welcome resource for learning about chemical engineering to both students and professionals working in the field. The participants were able to experience an immersive experience of environments not usually accessible to them in their studies and work (Norton, et al., 2008), in a similar way to planetarium visitors who are able to visualise the Earth and Milky Way Galaxy from deep space. Sumners's 2008 study found that all participants showed statistically significant short-term increase in knowledge of basic Earth science concepts after a single 22-min show in an immersive digital planetarium. The improvements were more pronounced where a mix of teaching/learning styles were combined (two or more of "hearing, seeing, discussion, and immersion") and the topics covered were intrinsically three-dimensional (Sumners et al., 2008).

Some full dome video planetariums have been upgraded to 3D in recent years and, in the case of @Bristol's planetarium, can fly the audience through a 3D realisation of Saturn's rings. The question emerges of whether the 3D gives a greater sense of the scale and distances involved in astronomy?

1.iv. 3D or not 3D?

"Astronomy and astrophysics are inherently 3D Subjects – We don't live in Edwin Abbott's, Flatland." (Sweitzer, 2012)

Previous research into the use of 3D in a planetarium is scarce due to the novelty of the technology in operation (Schnall, Hedge and Weaver, 2012). For example, the 3D planetarium in Bristol is the first in the UK.

Stereoscopy (3D), the technique used to provide a sense of depth in an image or film, has been used in museums since the 1970s (Parker, 1983) and its popularity has risen and fallen over time (Gurevitch, 2013). With the advent of active 3D technology, 3D films have seen a return to the cinema recently (Taylor, 2011) with some commentators suggesting their popularity has waned again (Agnew, 2015). The question emerges of whether the 3D Planetarium, with its novelty, can be effective at gathering, entertaining, educating and inspiring audiences.

The first 3D planetarium in France saw an increase of 44% of paying public visits to the planetarium, after it was upgraded to 3D, compared to the previous three years (Frappa, 2012), suggesting that the technology can attract new visitors. In terms of education, a study of 498 adults visiting another 3D planetarium in 2014 found that there was no difference in short term learning between 2D and 3D versions of the same film. 123 of the participants were also interviewed 6 months later and only those who had seen the 3D version of the film showed long term learning gains (Price, Lee, and Malatesta, 2014).

In 2010, Price and Lee found that, in a sample of 19 middle school students, there was no increase or decrease in accuracy for either 2D or 3D but that those who had experienced the 3D aspects took significantly longer to complete the same tasks (Price, 2010). Price's research into 3D continued in 2014, away from the planetarium. 261 children were shown photographs of spatial scientific objects, randomly shown in either 2D or 3D. Again, there was no statistical difference in responses to the questions between those who saw the 2D or 3D but where the children were ask to draw the image they had seen, they drew a more complex version if they had seen the 3D (Price, 2014). This may go some way to explaining

the extra time taken in Price's 2010 study as perhaps the students were considering the questions with more complexity. This may result in more time taken but not necessarily more correct answers.

Wyatt argued that the switch from 2D star mapping to full dome video demanded a new approach to the production of planetarium shows with a greater focus on the audience experience (Wyatt, 2005). The planetariums of today enhance the customer experience even before they step inside the dome. Hayden Planetarium in New York is positioned in an enormous glass box "as an object of beauty and wonder" which "performs much of the show's discursive work even before the visitors reach the 'departure lounge'" (Griffiths, 2008). Given the importance of the audience experience in the new 3D planetarium, the question of whether they audience feel that the 3D enhanced their experience comes into focus. Research into this is usually carried out in house and is not published so, along with research into the efficacy of planetariums for adult audiences, is scarce in the literature.

1. v. Narrative

Research by Gandolfi and collaborators suggested that the planetarium is an ideal place to blend scientific learning with enchantment and the mystic. In exploring different narrative techniques, they found that "usually, the best solution is a voyage in space and time, with a point of view oscillating between the earth's surface and the depths of space." (Gandolfi et al. 2005). Indeed, a study published in 2013 supported the hypothesis that planetarium shows were more effective when they mixed earth-based observation with space perspectives (Plummer et al., 2013). The study consisted of interviews with children aged 8-9, rather than the adult audiences.

Wyatt argues that "narrative", in the sense of more traditional storytelling, is too often talked about with regard to Planetariums "because the medium shifts emphasis from story to environment, a full dome planetarium show is more about taking a journey than watching a story. " (Wyatt, 2005) This led the research question away from narrative, looking more broadly at the customer experience and

the content analysis considered narrative in the senses suggested by Wyatt, Plummer, Gandolfi and associates.

1. vi. The use of Humour

Entertainment has always been part of the planetarium show and is, arguably, even more so with the full dome and 3D technologies. Humour is a part of entertainment and there are notes of caution in the literature as Fisher (1996) found that humour led to less retention of information from a planetarium show and Riesch (2015) suggested that humour is not always helpful for science communication with stereotyping and insider jokes alienating some audiences. Clearly, the use of humour should be considered carefully in the light of this research.

Objectives

The objectives for this study which emerged from this literature review are:

1. Discover whether the 3D Planetarium events inspire
2. Discover whether the 3D Planetarium events engage
3. Discover whether the 3D Planetarium events educate
4. Assess the content of 3 of the events to discover different communication techniques used and any results they might have

As the literature review suggested, the operators of new 3D Planetariums need to focus on the customer experience so the audience were surveyed with a self-completed questionnaire to gage the audience's experience. In order to assess the content of the shows, a content analysis was conducted.

In addition, @Bristol suggested a research question, also emergent from the literature review, which was explored through a number of questions in the questionnaire;

5. "What difference does the 3D aspect make for the audience?"

3. Methodology

The study was conducted at the Planetarium at @Bristol Science Centre between June and October 2015. Three events were selected for the study; Planetarium Nights, Aliens and Blue Marvel. All events were sold out and the Planetarium has a capacity of 95.

The Planetarium Nights show took place in the Planetarium at @Bristol over two nights (June 27 and September 16). The show covered stargazing, navigating the night sky, Greek myths of constellation and the science of astronomy. It was created by the team at @Bristol. It combined a live narrator with a mix of full dome 3D and 2D films and demonstrations of the night sky. There were two shows per night, leading to a total of 380 attendees.

The Blue Marvel events took place on October 8 2015. The Blue Marvel show was created by the Cabot Institute and the @Bristol team. Blue Marvel is a show about how space exploration has led to a deeper understanding of Earth ecology and the importance of looking after our planet. There were 4 showings, leading to a total of 380 attendees.

The Aliens showings took place on August 29 and 30. The show was a screening of the James Cameron 1986 film Aliens. The “Aliens” sample is the control group. They were a group of adults, using the Planetarium without any science communication taking place within the Planetarium. There was no narrator but a presenter did welcome them and ask them to complete the questionnaire at the end. There were two showings, leading to a total of 190 attendees.

For all three events, the audience were invited to explore the Space Gallery before and after their show. The Space Gallery was newly launched in June 2015, alongside the 3D Planetarium upgrade and is made up of a combination of static and interactive exhibits which explore different aspects of space science. For the Blue Marvel event, the audience had access to the whole of the @Bristol Science Centre for an evening event exploring the theme “Earth”.

For each event, the questionnaires were positioned on high tables opposite the Planetarium exit, inside the space gallery. Pens were provided and the presenter or narrator invited the audience to complete the questionnaire at the end of each show. The questionnaire was titled "Planetarium Questionnaire" and had signage with that wording to guide participants to answer the question about their planetarium experience, as opposed to the rest of their visit to @Bristol.

3. i. The Questionnaire

The questionnaires (Appendix 2,3,4) were designed in collaboration with @Bristol, to explore the objectives which emerged from the literature review and the research question stipulated by @Bristol.

Questions were designed to address the objectives and, due to the different topics covered, were partly altered for the Blue Marvel show (Appendix 3). Six questions were omitted from the questionnaire for the control (Aliens) group as they were not relevant to that event. (Appendix 2). This ensured that the questions were relevant to the show seen by the respondents.

3. ii. Segmentation

The audience was entirely composed of adults. Sixteen was the minimum recommended age for each event. No further age or gender segmentation was designed into the study. This was, in part, due to the small sample numbers but mainly because the study was designed to see how the shows worked for adults as a whole, rather than for different segments. Previous studies had shown no statistically significant difference between age groups but Baxter and Preece (2000) did find significant gender differences in their study. Female pupils scored worse than their male counterparts before the planetarium visit and better than them after it. More research would be needed to draw conclusions from this and the sample sizes for this 3D Planetarium study would not have been able to significantly contribute to gender studies.

Segmentation was carried out using the question; "Why did you come to see the show in the @Bristol Planetarium?" The respondents were given the following

options; night out with friends, night out with family, night out on my own, an interest in astronomy, an interest in science and other.

3. iii. Objective 1: Discover whether the events Inspire

To gage inspiration, questions were designed to test whether the shows had inspired the audience to change their behaviours. If, when leaving the auditorium, the audience felt like they wanted to change their behaviour as a result of what they had experienced, then the shows had inspired them in some way.

For the control (Aliens) and Planetarium Nights questionnaire, the question was; "How often do you look up at the stars/go stargazing?" and "Do you think that will increase as a result of seeing this show?"

For Blue Marvel, the question needed to be a bit more involved; "How important is 'potential environmental impact' to you when you do the following: Shopping, Traveling to work, Going on Holiday, Home Improvements, Selecting Energy Supplier?" The follow up question was. "Do you think that will be less, the same or more as a result of seeing this Planetarium show (for each)?".

3. iv. Objective 2: Discover whether the events Engage

A mix of qualitative and quantitative questions were used to test for the how engaged with the show the audience felt. Questions were designed to bring out responses demonstrating aspects of the show that the audience were keen to record their delight/interest/memory of. Open-ended questions were posed to give participants freedom to express themselves, rather than leading their answers. If they were engaged by something, they would remember it and might voluntarily include it in their answer.

"What was the best / most memorable part of the show?"

The wording of this question was intended to draw out which elements had engaged the audience the most. By asking for the "best / most memorable" part of the show, the question was designed to encourage the audience to record the aspects which had most thrilled/excited or engaged them. It was considered that simply asking for

the best part of the show might lead to too much deliberation and, as participants were leaving the show and likely to be more likely to answer a shorter questionnaire. Equally, just asking for the most memorable might lead to memorable but negative aspects being recorded and this question was specifically designed to test for positive engagement. Negative aspects could be recorded elsewhere in the questionnaire.

Responses were coded for:

Saturn: Anything which referenced the 3D Saturn section

Galaxy: Anything which referenced the 3D view of the Milky Way from the outside.

Stargazing: Anything which referenced the 2D stargazing/navigating the night sky sections

Pluto: Anything which referenced the information provided about Pluto. This was in 3D but responses were about the immediacy and interest of the information, rather than the 3D element.

Black Hole: Anything which referenced the 3D view of a black hole

Commentary: Anything which referenced the narration provided by the presenter.

Traveling (to planets): Anything which referenced the 3D visualizations of flight through space to and from planets and stars. This includes references to the Pluto section where the emphasis was on the visualization, as opposed to the information.

Close ups: Anything which references the 3D close ups of planets, galaxies and stars

3D: Anything which specifically referenced the 3D.

Myths: Anything which referenced the greek myths (2D).

3. v. Objective 5: Did you think the 3D enhanced your experience?

The Planetarium Nights and Blue Marvel show both included 3D elements and this question was designed to provide part of the answer to @Bristol's desire to evaluate the 3D element.

Responses coded as Saturn, Galaxy, Black Hole, Travelling, Close ups and 3D in the replies to the "What was the best/most memorable part of the show?" question were also considered in the evaluation of the 3D elements of the shows. If the 3D

sections engaged them then they would be likely to record them as the most memorable/best part of the show.

3. vi. Discover whether the events Educate

The questionnaire, by default, could not test for long-term retention of information but could test whether the shows introduced new information to the audience and if they felt they had learned anything. Two questions were posed to test for this objective “Did you feel you learned anything?” In effect, this question asked, “Was there anything new to you in the show?” The second question was “What did you learn?” This question was designed to ascertain which aspects of the show had been new to the audience. This open-ended question could also suggest engagement as the audience were answering the questions quickly and they might be more inclined to record the aspects which came to mind quickest, implying they were most engaged by those aspects.

The answers were coded for Stargazing, Saturn, Stars, Universe, Myths and Pluto. Stargazing encompassed responses which stated that they had learned something about navigating the night sky. The Saturn code was every answer citing something to do with Saturn. The Stars code was all responses regarding the composition or colours of Stars, as opposed to the Universe code which includes all those which referred to the number of stars in the universe or facts about the universe as a whole.

For example, “I learned that there are more stars in the universe than there are grains of sand on all the beaches of earth” would be coded as Universe. “I learned that stars have different colours” and ‘I learned that brighter stars aren’t necessarily closer” would both be coded as Stars.

Two further questions were posed to inform @Bristol’s operation and marketing of the Planetarium. They were:

Would you be interested in seeing any of the following in the Planetarium? Music Concerts, Art Shows, Films, The same show again, Another astronomy related show and Other.

The responses to this question were also considered in the analysis of the Engagement.

Did you see any of the following about the show tonight? (tick all that apply) Poster, Flyer, Bus Advert, Facebook, Twitter, Newspaper article, @Bristol website, Word of Mouth.

This question was designed to discover which aspects of the marketing mix were being noticed. By suggesting the options and requesting that they tick all that apply, the respondent is given the opportunity to record everything they remember seeing.

3. vii. Objective 4 – Content Analysis.

The narrator's speech was recorded on September 16th for the Planetarium Nights. (Appendix 5) and on October 8th for the Blue Marvel shows. (Appendix 6). There was no narrator for the Aliens screening.

The total words were counted and the recordings were coded and the number of words in each code recorded and expressed as a percentage of the total show.

The recordings were coded for:

Instructions: Words intended to direct the audience. For example, "Put on your 3D glasses now" and "follow my laser pointer round to the front of the dome".

Myths: Spoken sentences intended to inform the audience about myths and legends of the constellations. For example, "Lyra was the source of all the music on Earth."

Stargazing: Words intended to inform the audience about night sky navigation. For example, "if you follow the line of these two stars, you will reach Polaris, the North Star."

Science: Words intended to inform the audience about science. For example, "Saturn's rings are made of trillions of pieces of rock, ice and dust."

Technology: Words intended to inform the audience about the technology of the Planetarium. For example, "They have a resolution of 4K, a contrast ratio of 2,000 to 1 and they each put out 30,000 lumens".

Light pollution: Words intended to inform the audience about light pollution. For example, “This is light pollution caused by car lights, street lights and house lights.”

Emotional response: Words expressing the narrator‘s response to something. For example, “That is the reaction I was hoping for” and “Good reaction.”

Outside of the word count percentages, the recordings were also coded for interactivity and humour as follows:

Interactivity: Number of direct questions and invited responses from the narrator to the audience. For example, “Have you heard that that the North Star is the brightest star in the night sky? [Audience replies; Yes] “Well, you’ve been lied to.”

Humour: Number of times the audience laughter is audible on the recording.

Results - The questionnaire

29 people responded to the questionnaire from the Planetarium Nights shows, 21 from the Aliens screenings and 10 from the Blue Marvel shows. The results of those questionnaire responses are as follows:

Why did you come to see the show in the @Bristol Planetarium?

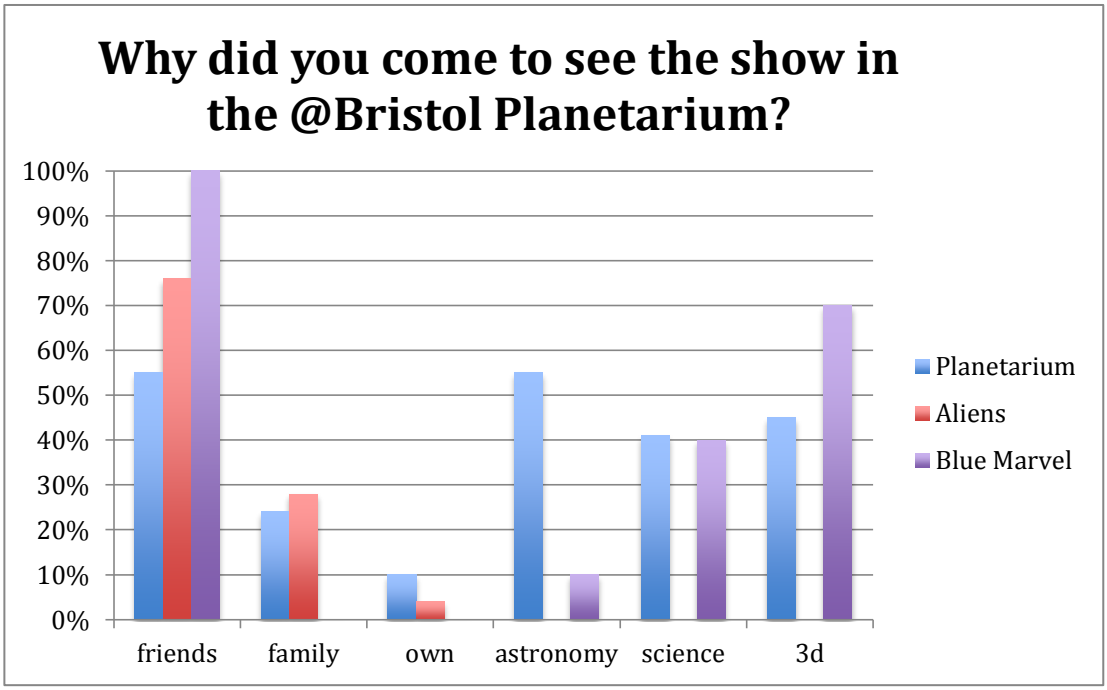

Figure 1. Why did you come to see the show in the @Bristol Planetarium?

100% of the Blue Marvel audience, 55% of those who came to the Planetarium Nights and 76% of the Aliens audience came with friends. 28% of the Aliens audience came with family and 4% on their own, compared to 24% and 10% of the Planetarium Nights audience.

10% of the Blue Marvel audience declared an interest in Astronomy as part of their reason for coming to see the show and 40% declared an interest in Science. For the Planetarium Nights shows, 55% declared an interest in Astronomy and 41% in science.

70% of the Blue Marvel audience said they had come to see the show to experience the new 3D Planetarium, compared with 45% of the Planetarium Nights audience. None of the audience for the Aliens declared an interest in science or astronomy for their reason for coming to see the show in the

Planetarium. Similarly none declared that they had come to experience the new 3D Planetarium.

How would you rate the show?

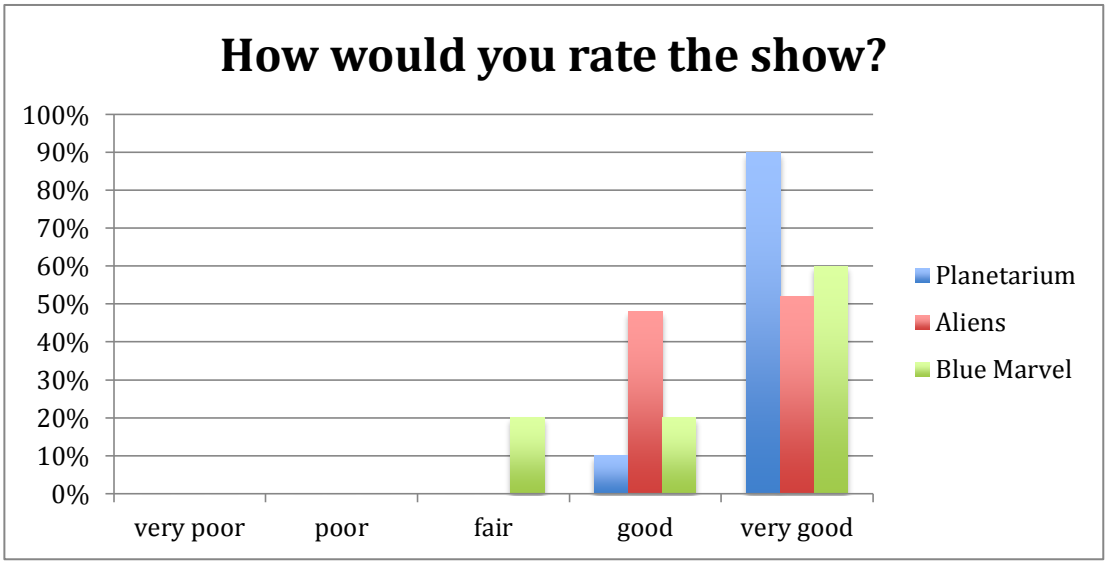

Figure. 2. How would you rate the show?

90% of the Planetarium Nights audience rated it as very good with 10% rating it as good. 60% of the Blue Marvel audience rated it as very good, 20% as good and 20% as fair. 52% of the Aliens audience rated is as very good with 48% as good.

Would you like more or less Myths, Stargazing and Science?

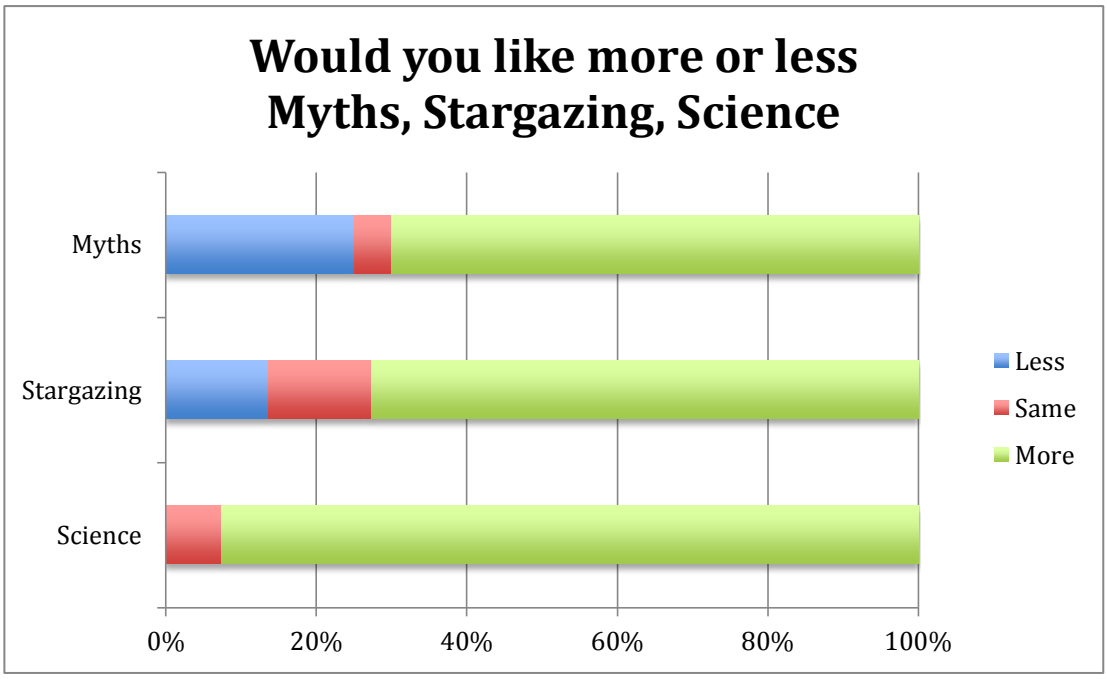

Figure 3. Would you like more or less Myths, Stargazing and Science?

This question was only relevant to the Planetarium Nights audience. Nobody wanted less science. 93% wanted more science and 7% wanted the same amount. 73% wanted more stargazing or night sky navigation information. 13% wanted the same amount and 13% less. 70% wanted more myths about the constellations 5% the same amount and 25% less.

"What was the best / most memorable part of the show?"

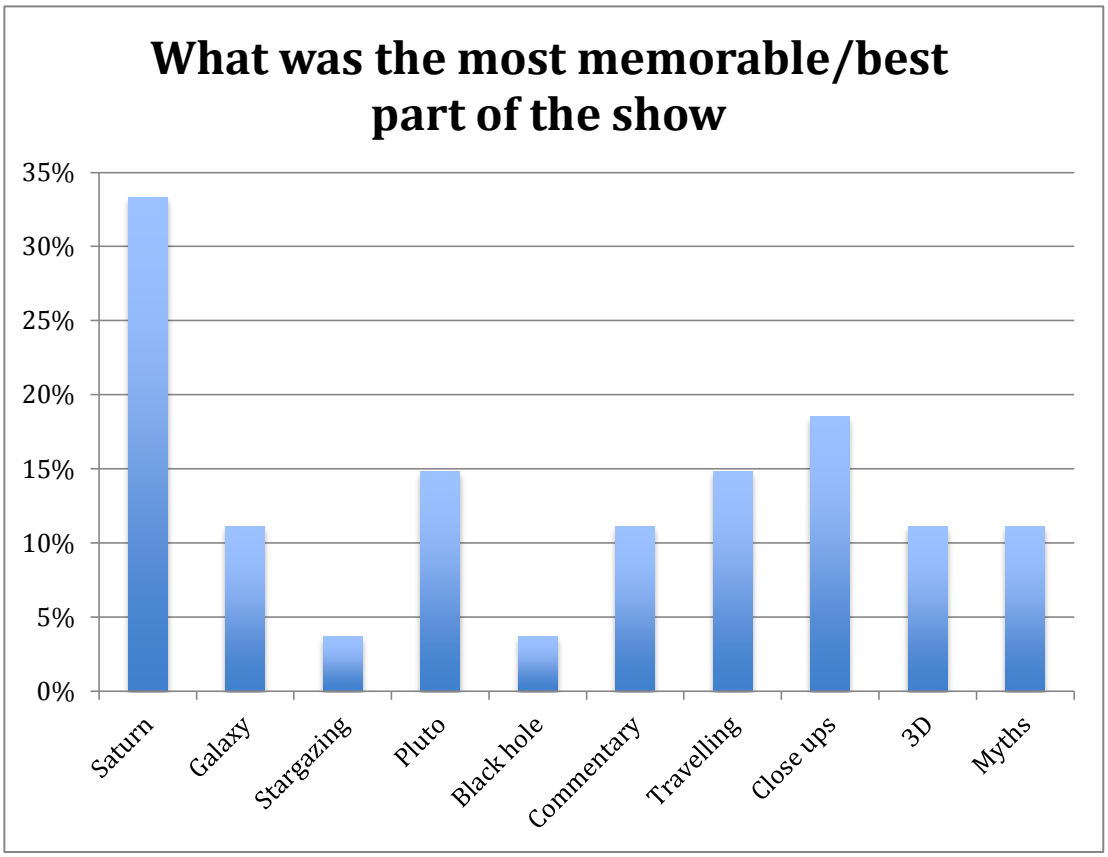

Figure. 4. What was the most memorable part of the show?

11% of the audience explicitly stated that the 3D aspects were the best/most memorable part of the show and 70% chose something which was in 3D, rather than the 2D aspects of the show. 11% said that the myths were the most/memorable part of the show with 26% citing an aspect of the scientific information they received.

20% of the Blue Marvel audience said that the sense of perspective of our planet that they got from the 3D visualisations was the best or most memorable part of the show. 20% said it was the global warming information and message. 20% said that experiencing the 3D visualisations was the best/most memorable part and 40% said it was seeing the planets.

Did you feel you learned anything?

100% of the Planetarium Nights said that they learned something from the show. 14% of the audience for the Aliens screening said that they learned something. 90% of the Blue Marvel audience said that they learned something.

What did you learn?

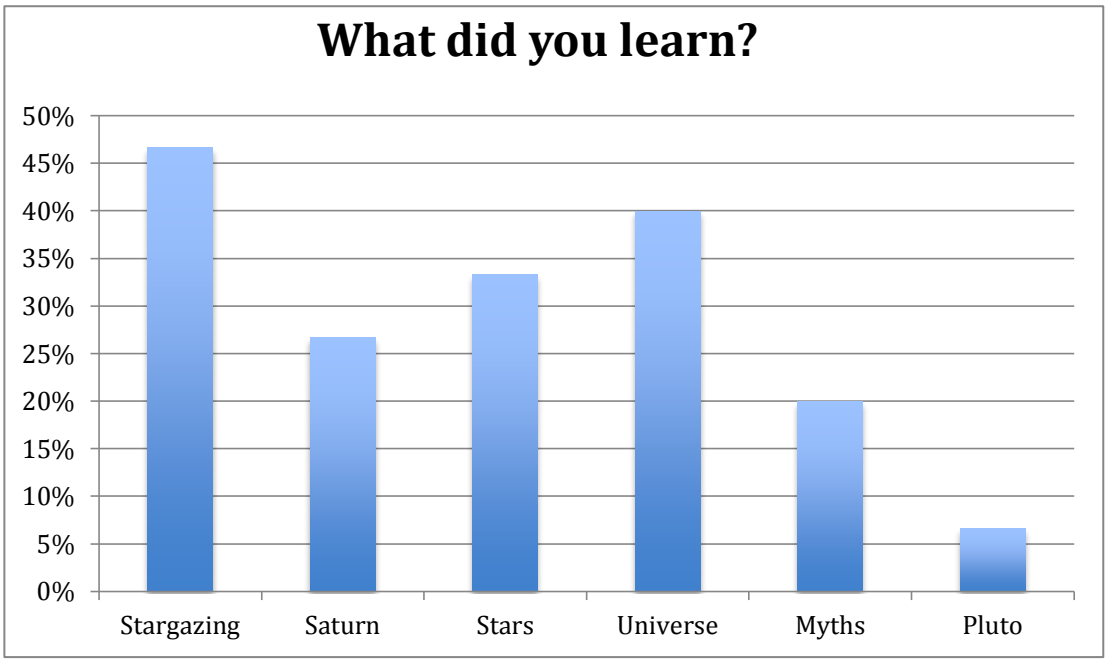

Figure. 5 What did you learn?

15 people from Planetarium Nights responded to this question, recording 26 responses. 47% of the respondents stated that they learned about navigating the night sky (Stargazing), 40% something about the Universe and 33% about stars. 27% mentioned something they had learned about Saturn and 7% about Pluto. 20% mentioned that they had learned something about the myths about the constellations.

Two people from the Aliens screening responded to this question. One stated "it's cool to watch films lying back. Curved screens are OK" and the other said, "Looked at the cold chamber afterwards". The cold chamber is part of the space gallery. This was the only reference to the space gallery in all responses across all three events.

Six people from the Blue Marvel show's audience responded to this question. 3 of them recorded more general responses, "Our planet is really the only choice",

"To be more open minded and to cherish what we have" and "Figures and more info about Earth". The other three recorded specific points, "How much the sea level is meant to rise in the next 100 years", "Saturn's Moon's geyser" and "about the lack of renewable energy in the UK".

Did you think that the 3D effect enhanced your experience?

25 members of the Planetarium audience answered this question and ten of the Blue Marvel audience. Unanimously, they replied "Yes".

Four people from the Planetarium Nights audience added comments to their response; "DEFINITELY!", "makes you feel like you are in space", "would like more!" and "breathtaking travelling into the planets and galaxies".

Would you be interested in seeing any of the following in the Planetarium?

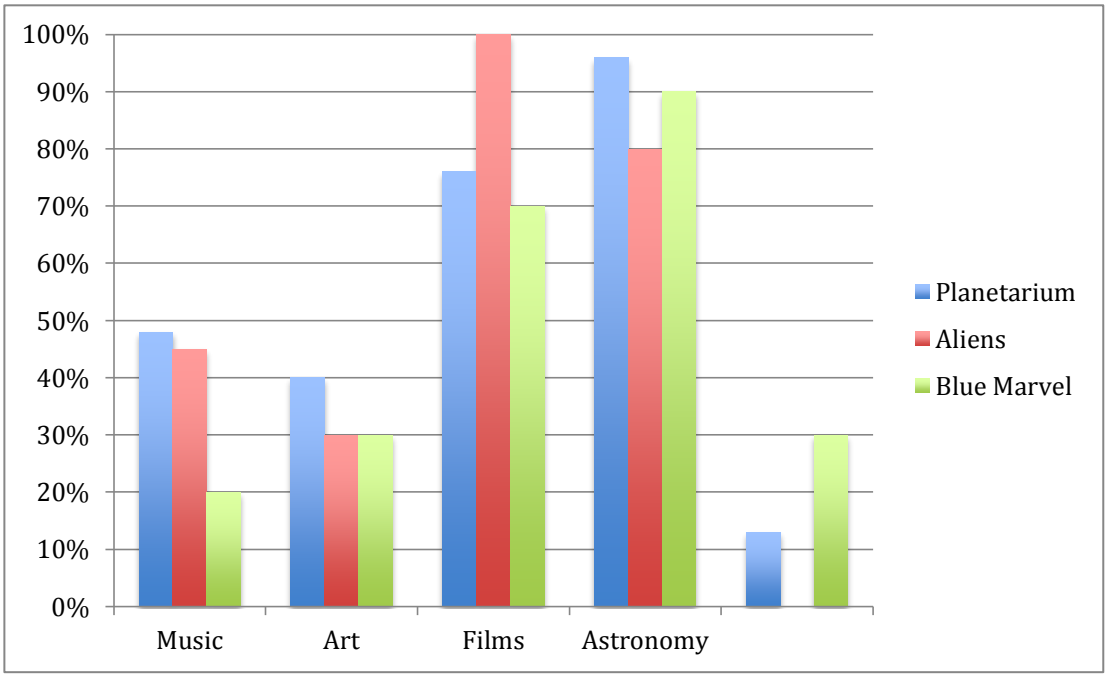

Figure. 6 Would you be interested in seeing any of the following in the Planetarium

25 people from the Planetarium nights audiences answered this question, 20 from the Aliens screening and ten from Blue Marvel. Astronomy was the most popular choice with 96% of Planetarium Nights, 90% of Blue Marvel and 80% of the Aliens audience saying that they would like to see (another) astronomy related show. Films were also selected often with 76% of Planetarium Nights, 70% of Blue Marvel and 100% of the Aliens screening audiences saying they would like to watch (more) films in the Planetarium.

48% of Planetarium Nights, 45% of the Aliens screening and 20% of the Blue Marvel audiences would like to see music concerts in the planetarium. 40%, 30% and 30%, respectively would be interested in seeing art shows in there.

30% of the Blue Marvel audience, 13% of the Planetarium Nights audience and none of the people who saw the Aliens screening would like to see the same show again.

Which topics would you like to be included in future shows?

7 people responded to this question from the Planetarium Nights showings. Nobody responded to it from the Blue Marvel audiences.

Their responses were:

"The moon. Individual planets' details and facts"
"Black holes"
"More about other planets in our galaxy and other galaxies in the universe"
"Planets, Galaxies"
"Effect of stars on surrounding planets"
"Biology and History"
"More of the same but new stories and constellations. Maybe something about work and life on the space station."

How often do you look up at the stars/go stargazing?

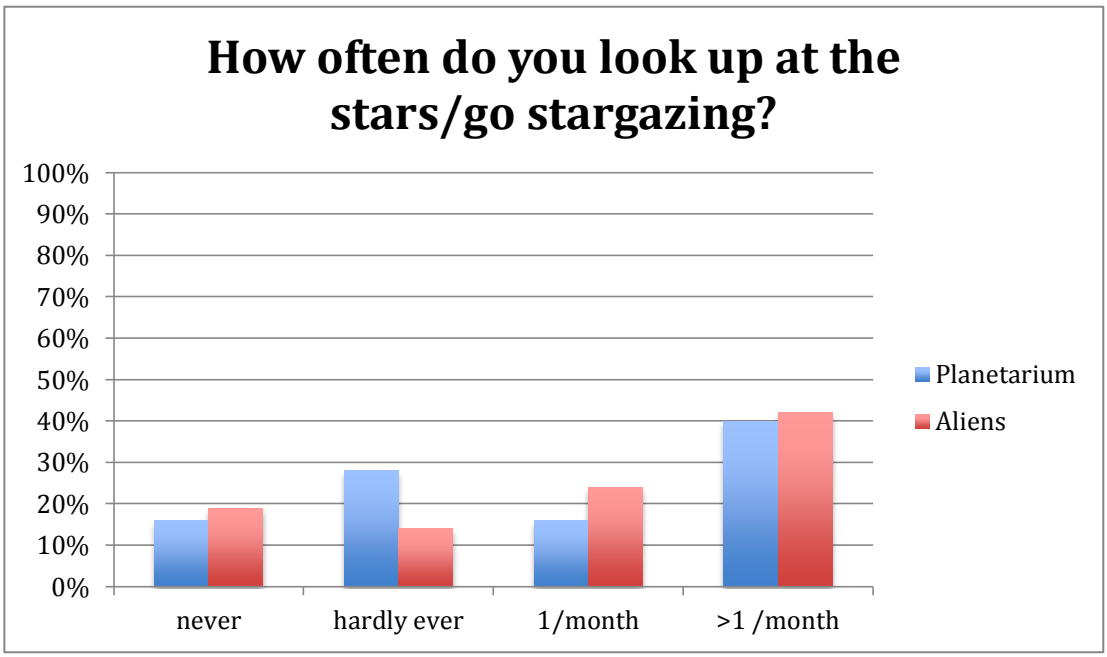

Figure 7. How often do you look up at the stars/go stargazing?

25 people in the Planetarium Nights audience responded to this question and 21 in the Aliens screenings. 40% of the Planetarium Nights and 42% of the Aliens audiences said look up at the stars or went stargazing more than one a month. 16% of the Planetarium Nights audiences and 24% of the Aliens audiences said they do it once a month. 28% and 14% respectively said they hardly ever did and 16% and 19% said they never did.

Do you think that will be increase as a result of seeing this show?

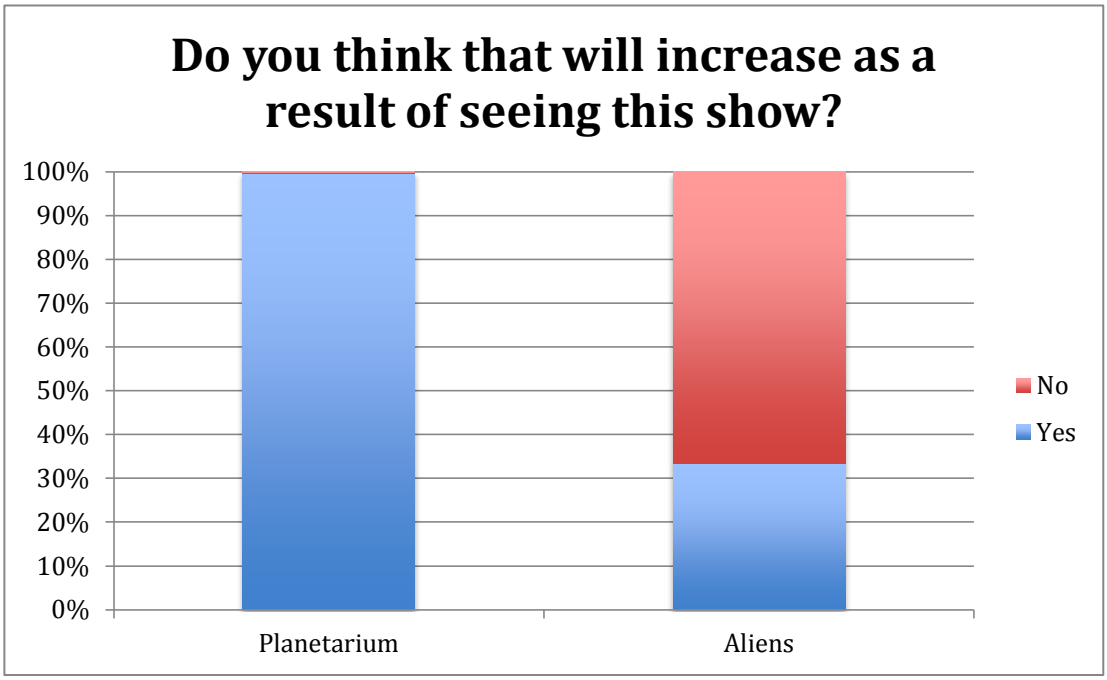

Figure 8. Do you think that will increase as a result of seeing this show?

25 people in the Planetarium Nights audience responded to this question and 21 in the Aliens screenings. 96% of the respondents from the Planetarium Nights audience said that it would increase. The 4% (one person) who did not think it would increase already went stargazing more than once a month.

33% of the people who responded after watching Aliens in the Planetarium said that they would look up at the stars/go stargazing more often as a result.

How important is "potential environmental impact" to you?

More people (40%) said that the potential environmental impact of the energy supplier was "very important" than any other category. The only category which had anybody rating it as "not at all important" was going on holiday (30%). A further 30% said it was not very important. Figure.8 shows the distribution of results.

	Not at all	Slightly	Moderately	Important	Very
Shopping	0%	20%	30%	40%	10%
Travelling to work	0%	10%	20%	50%	20%
Going on Holiday	30%	30%	0%	30%	10%
Home Improvements	0%	20%	30%	30%	20%
Selecting Energy Supplier	0%	20%	10%	30%	40%

Table 1. How important is potential environmental impact to you when doing…

Figure 9 How important is potential environmental impact to you when you do your shopping?

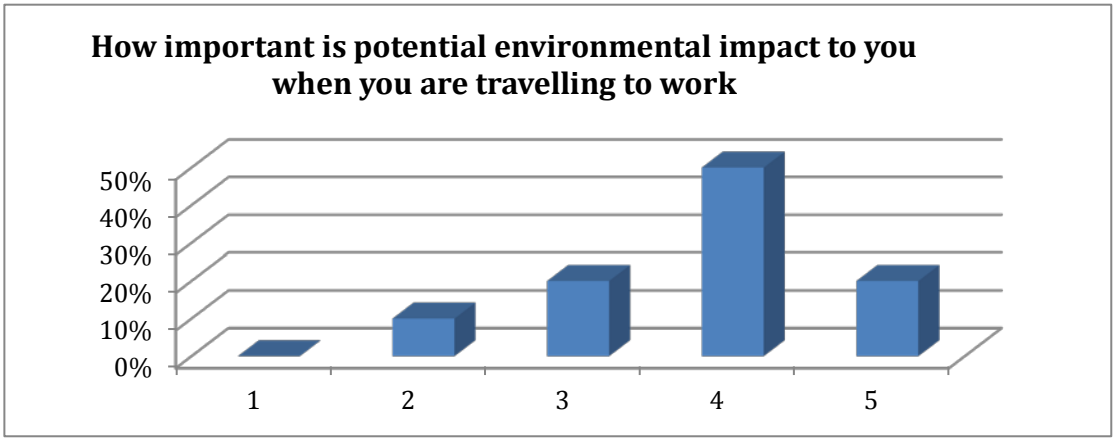

Figure 10. How important is potential environmental impact to you when you are travelling to work

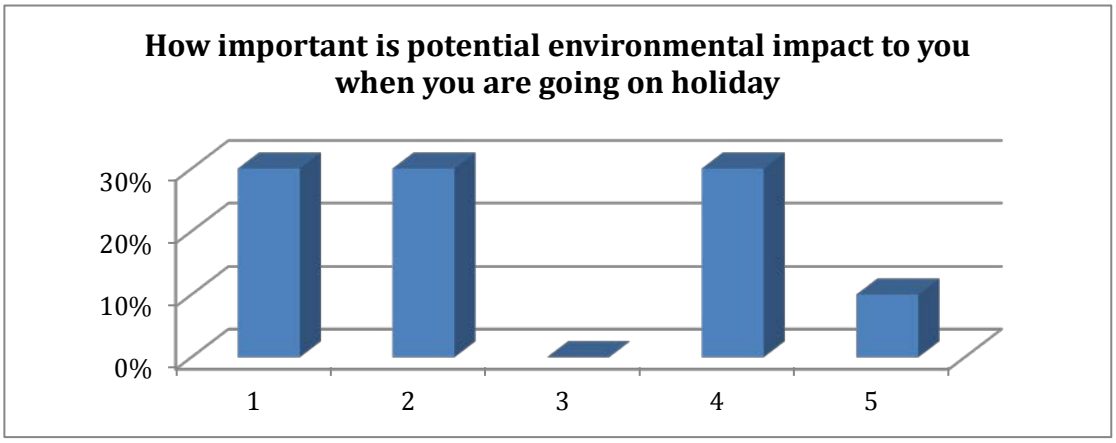

Figure 11. How important is potential environmental impact to you when you are going on holiday?

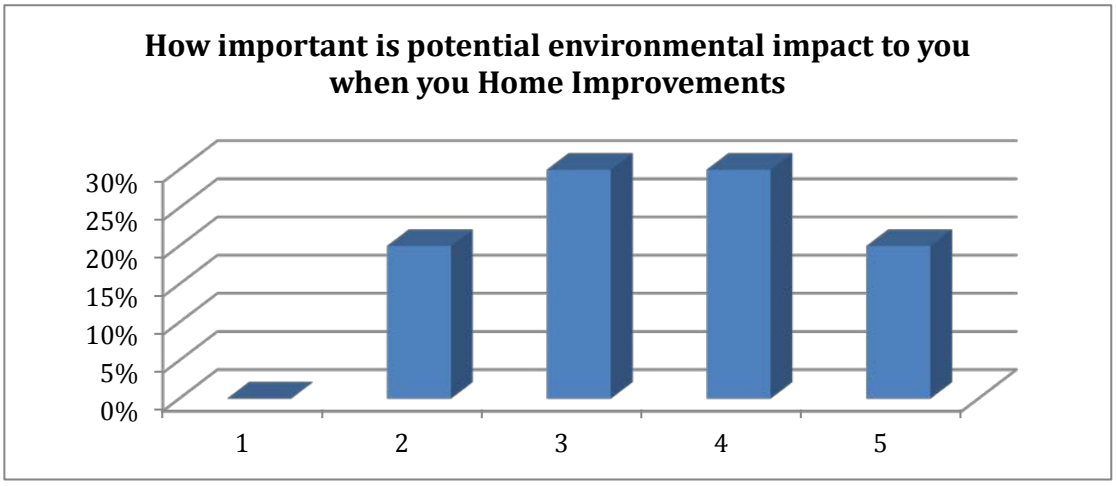

Figure. 12. How important is potential environmental impact to you when you make Home Improvements?

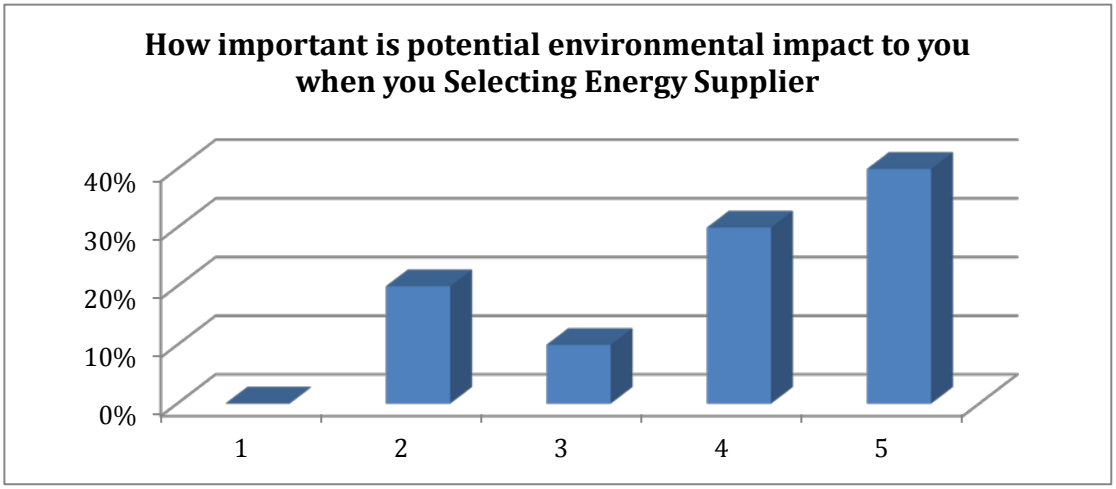

Figure 13. How important is potential environmental impact to you when you are selecting Energy Suppliers?

Do you think that will be less, the same or more as a result of seeing this Planetarium show?

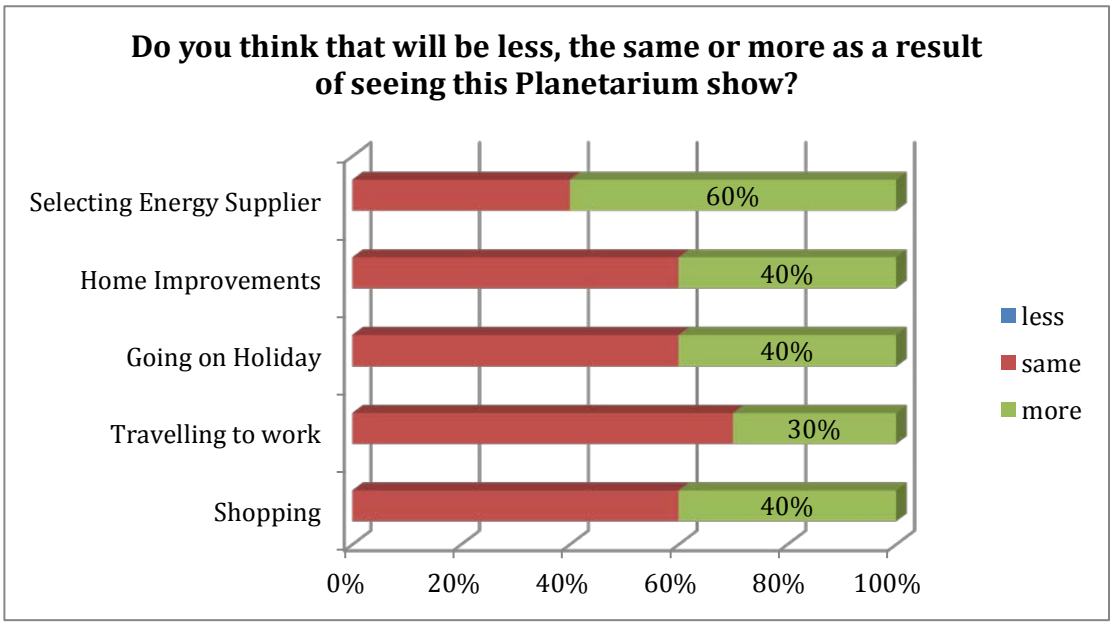

Figure 14. Do you think that will be less, the same or more as a result of seeing this Planetarium show?

10 people answered this question. None of them thought that the show would lessen the importance of "potential environmental impact" in any category. 60% thought it would increase the importance with regard to selecting energy supplier. 40% thought it would increase the importance with regard to Home Improvements, Going on Holiday and shopping, respectively. 30% thought it would become more important when they think about travelling to work.

Did you see any of the following about the show tonight?

The @Bristol website (10) and Facebook (9) were the most ticked with Word of Mouth (5) and Poster (4) also being recalled. Twitter was remembered twice and one person saw a flyer and one saw an item on Made in Bristol TV.

Results – Content Analysis

54% of the Planetarium Nights show's narration was about science, 14% about Stargazing, 12% about Myths, 3% light pollution, 3% technology and 2% an emotional response from the narrator. The remaining 12% was taken up with instructions.

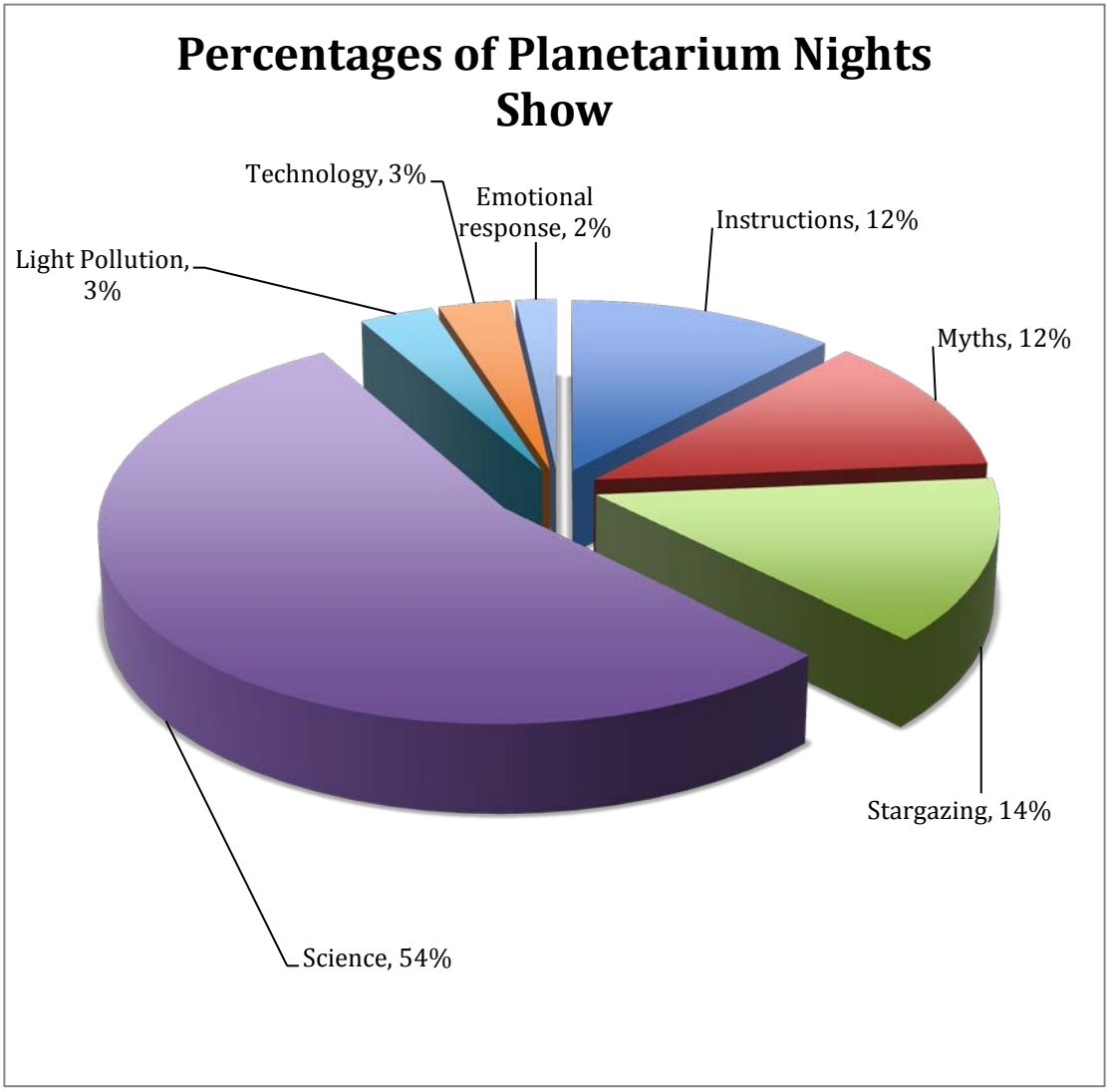

Figure. 15. Content Analysis: Percentage of Planetarium Nights Show

74% of the Blue Marvel show's narration was about Science and 8% about providing a perspective of Earth from space, giving a sense of the planet's place in the universe. 17% was made up of instructions.

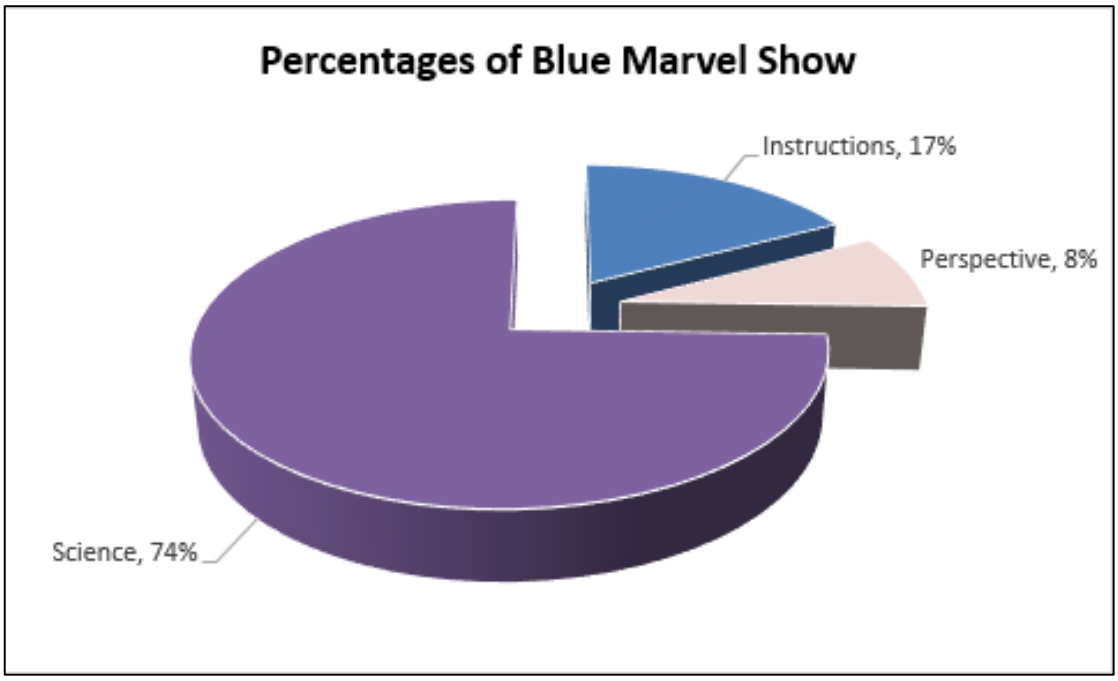

Figure. 16. Content Analysis: Percentage of Blue Marvel Show

Content analysis – Interactivity and Humour.

In the Planetarium Nights show the narrator asked 18 direct questions and invited 8 further responses and consistently used "we" when referring to the audience. Laughter from the audience was audible six times and the audience made the "a-h-h-h-h" sound of "astonishment and pleasure", as described by the New York times in 1928, four times

The Blue Marvel show narrator asked 2 questions, both in the show's pre-amble. There were no invited responses and no audible laughter from the audience.

Content analysis – Narrative

There was an overarching narrative in the Blue Marvel show with the theme of our understanding of Planet Earth that has come from space exploration. There were also shorter narratives within the show about specific space missions, for example Apollo and New Horizons.

The narrative of the Planetarium Nights show is much more along the lines of taking the audience on a journey. It is not a linear journey but finds the audience starting on earth and seeing their destination (e.g. Saturn) as they would in the night sky before putting on their 3D glasses together and “blasting off into space”. They then return to Earth to find their next destination and repeat the process. There are also short narratives such as explaining the New Horizon’s space mission to Pluto while showing a 3D realisation of the probe arriving at the planet.

5. Discussion

5. i. New and Established Audiences

Every show was completely sold out ahead of the night, suggesting a healthy adult audience for planetariums shows. Only 55% (Figure.1) of the Planetarium Nights audience and 10% of the Blue Marvel audience declared an interest in Astronomy as a reason for them coming to see the show. With only 41% and 40%, respectively, citing an interest in Science as a motivating factor, it seems that the 3D Planetarium is an opportunity to reach adult audiences with varying degrees of interest in science and astronomy.

The audience for the Blue Marvel were at @Bristol for a special late night event, where the whole science centre was open exclusively to adults. The theme of the evening was Earth, meaning that the audience were there for a night dedicated to the topic of Planet Earth. This is in contrast to those who had come specifically to see the Planetarium Nights show and could partly explain why only 10% of the audience said they were interested in astronomy. That said, the small sample numbers make it difficult to draw firm conclusions and, at best, the Blue Marvel data can provide only suggestions.

The Planetarium Nights audience were there specifically to see the Planetarium show and the Space Gallery. 45% of those who came to see the Planetarium Nights show did not come because they were interested in astronomy and 60% did not declare an interest in Science, particularly when considering their positive responses to the science (Figures. 3, 4).

The new 3D upgrade of the Planetarium was a motivating factor for 45% of the Planetarium Nights audience and 70% of the Blue Marvel audience. Combining the audiences of Planetarium Nights and Blue Marvel, 19% came to experience the new 3D Planetarium without declaring an interest in science or astronomy. A further 24% came to experience the new 3D planetarium with an interest in Science but not astronomy. 10% came to experience the planetarium and were already interested in astronomy but not science. 38% came because they were interested in astronomy but were not motivated by the new 3D Planetarium or an interest in science.

More, larger samples are needed but there seems to be a strong suggestion that the new 3D Planetarium is a good opportunity to attract adult audiences who are not already interested in science and astronomy.

5. ii. Objective 1: Inspiration

96% of the Planetarium audience thought that they would go stargazing/look up at the stars more often as a result of seeing the show (Figure. 8). The 4% who did not think it would increase said they were already doing it more than once a month, (Figure.7) suggesting that they were already at saturation point. That is compared to 33% of the Aliens screening. There is a strong suggestion that 3D Planetarium shows do inspire audiences to engage in more stargazing. More follow up studies could be done to test whether they followed up on that inspiration with action, and if not, what stopped them from doing so.

The test of inspiration for the Blue Marvel audience was more complicated. The audience were asked whether they thought the show would elevate the importance of "potential environmental impact" in their minds when considering a range of activities. Again, it is difficult to draw too many conclusions from the small sample size but going on holiday (Figure. 9) appears to be an outlier in terms of how important potential environmental impact is in making decisions. 60% of the audience said that "potential environmental impact" was not at all or slightly important. By comparison shopping, selecting energy supplier, and home improvements were each rated as "slightly important" by 20% and by 10% for travelling to work.

The show featured 3D visualisations of the energy consumption of the UK in terms of renewable energies and the carbon and money saved by @Bristol by using renewable energies. This seems to have inspired the audience to act. 60% said they thought that potential environmental impact would be more important when they selected energy suppliers after the show. 70% said it was already important to them. 40% said it would be elevated in importance for each of home improvements, going on holiday and shopping.

5. iii. Objective 2: Engagement

Participants used the comment spaces on the questionnaire to express their delight with comments like, “The WOW factor”, “Great. Keep it up.”, “Breathtaking” and “Great show- will come again” for the Planetarium Nights. With 100% of the Planetarium Nights and 80% of the Blue Marvel audiences rating the shows as good or very good (Figure.2), it appears that they were engaged by the shows. It is interesting to note, by contrast, that 60% the audience for Aliens, seeing a film they presumably love to see again rated is as very good, compared to 90% for Planetarium Nights.

One less encouraging note is that 20% of the Blue Marvel audience rated the show as 3/5 (fair). This suggests a lower level of engagement for some in this audience as, although the Blue Marvel sample is small, none of the Planetarium Nights or Aliens audience rated their shows less than 4/5. Based on the literature review, there are some suggestions that shows which combine 2D and 3D do engage audiences more effectively than those which are entirely in 3D (Gandolfi et al. 2005; Plummer et al., 2013). It is possible that this could be a contributing factor to explain why the Planetarium Nights show was rated higher than the Blue Marvel show.

What are they engaged with?

93% of the Planetarium Nights audience, who saw a show which was 54% science, wanted more science. None of them wanted less science but 24% wanted less about myths and 14% wanted less stargazing. 14% of the show was stargazing and 12% was about myths. The audience were getting a lot of science and wanted more. The suggestion is that the science in the show as engaging them most of all. It is worth remembering again that 59% of this audience did not declare an interest in science as a reason for coming to see the show.

The responses to the question, “What was the most memorable/best part of the show?” also provide insight into what engaged the audience most. With 33% of the Planetarium Nights audience referencing Saturn, 11% the Milky Way Galaxy, 15% Pluto, 4% Black Holes and 11% the commentary, the science content was the most frequently recalled. The 3D aspects (11%), travelling through the universe (15%) and

close ups (19%), combined with Saturn, Milky Way, Pluto and Black Holes all suggest that the audience were engaged by the 3D nature of the show and 100% of the audience said that the 3D enhanced their experience. Respondents answered the questions quite quickly and the low percentages here must be considered in that light. The fact that people spent time writing a response suggests a level of engagement.

The Blue Marvel show was 74% science, encompassing climate change and astronomy. The entire show was in 3D. 60% did not reference science and 90% did not reference astronomy as a reason for coming to see the show. Again, the sample size was too small to draw any firm conclusions but the 20% recorded climate change, 40% planets, 20% the perspective provided of our life on this planet and 20% the 3D effects as the most memorable/best part of the show. More studies are needed but there is further suggestion that audiences not already interested in science can be engaged by science in a planetarium show.

Along with mixing 3D and 2D, the Planetarium Nights show mixed content with myths, technology and light pollution joining science and stargazing. The Planetarium Nights show also had considerably more interaction and humour than the Blue Marvel show but managed to avoid the stereotyping and insider jokes which have previously been found to be off-putting for audiences who are not already interested in science Riesch (2015). The humour does not appear to have lessened the engagement but it is not possible from this study to tell whether it did affect the retention of information.

5. iv. Objective 3: Did they learn anything?

Further studies are needed to evaluate how much information is retained long term from a 3D Planetarium show and this study can only consider whether the audience felt they had learned something and what aspects of that they were prepared to divulge. As an anonymous questionnaire, there was no sense that people would be embarrassed to admit that they did not already know something.

100% of the Planetarium Nights show said they learned something. 100% is often a concerning statistic but the show covers a wide range of topics from classical myths

to the latest science from the New Horizons mission. As such, it is likely that few people would already know everything they heard in the show. 90% of the Blue Marvel audience said they learned something new. There is a strong sense that the audience felt they did learn something from the 3D Planetarium shows and the study then looked at what they learned.

15 people from the Planetarium Nights audience gave 26 responses to the question "What did you learn?" 62% of the responses referenced an aspect of the science in the show, 27% said they learned something about stargazing and 11% about myths. Again, this suggests that the audience were most engaged by the Science as it seems unlikely that 89% of the audience would know that in Greek mythology Lyra was the source of all music on Earth, for example. It seems more likely that they simply did not recall the things they had learned from the greek myths sections or did not mention it as they were more engaged by the science aspects of the show.

5. v. The impact of the use of 3D

The audience were unanimous across the Planetarium Nights shows and the Blue Marvel shows. They all said that the 3D enhanced their experience and often cited a 3D aspect of the show as their most memorable/best part of the Planetarium Nights show. After the Planetarium Nights show, 70% of the people who answered the question chose something which was shown in 3D as the most memorable/best part of the show with 11% specifically stating that the fact that it was in 3D was the most memorable/best part. For Blue Marvel, which was entirely in 3D, 20% said that the fact that it was in 3D was the most memorable/best part, 20% said it was the perspective afforded to them by the stereoscopy and 40% said it was seeing the planets, which were in 3D, like the rest of the show. The remaining 20% said that it was the information in the show which was the best/most memorably thing about it.

One observation is that the Planetarium Nights show, which mixed 2D and 3D was rated more highly than the Blue Marvel show which was entirely in 3D. That said, that could be a result of any number of other factors and the sample sizes are small. It is recommended that further studies be carried out to discover whether mixing 2D and 3D enhances the impact and increases the enjoyment of the show.

The impact of the 3D on learning and retention of information remains an intriguing area for further study. If audiences are more entertained, are they less (or indeed, more) educated, inspired or engaged by the science if the show is in 3D? Does seeing the show in 3D increase the retention of learned information as has been previously suggested (Price, Lee and Malatesta, 2014)?

5. vi. The use of narrative

Narrative, in the sense of storytelling, was not prevalent in either the Blue Marvel or Planetarium Nights show and both were more along the lines of Wyatt's (2005) observation that the immersive digital environment is more akin to taking the audience on a journey than telling them a story. The narrative of Blue Marvel is the journey humanity has taken to learn about our planet by studying the universe around us. The Planetarium Nights show had less of an overarching narrative, confined more to the storytelling of the ancient myths about constellations and taking the audience, for example, through the New Horizons mission with a 3D realization of the spacecraft orbiting the planet combined with the latest 2D imagery from NASA. There was nothing in the data to lead to any conclusions on the efficacy or otherwise on the various forms of narrative used across the shows. A larger study may be able to ascertain some information on this area.

6. Limitations

Small response rates are relatively common with self-completion questionnaires as there is no real pressure to complete them. This method of research was chosen, despite this, to reduce risk of interviewer bias and to allow participants to be more open and honest about their thoughts and feelings. The narrator on each night (and presenter at the Aliens screening) asked the audience to complete the questionnaire just before they left the auditorium.

The small sample sizes make strong conclusions difficult to form. At the Blue Marvel event, there were a few people who had been drinking quite a lot of alcohol. They spent a good period of time tampering with the questionnaires, making it not possible for others to complete them. It is largely for this reason that only 10 completed questionnaires were available for the Blue Marvel events.

Another consideration is that the narrators are able to deviate from the script. Not everybody who responded heard exactly the same narration. This may slightly skew the percentages in the content analysis but it is not significant. The author was in the planetarium for each of the shows and any deviations were the odd word changed or a slightly different way of phrasing the same concept or instruction. Recordings were made of the other nights and shows but all but one for each was lost due to a theft. That said, this limitation is very slight and should not bring the results too much into question.

This research was primarily set up to gage audience reaction to the show. As such, it was designed to be answered immediately after the show. This means that there was no pre-test of knowledge or motivations. This limitation was addressed in the design of the questionnaire by asking double questions. For example, the question "How often do you go stargazing?" was immediately followed by "Do you think that will increase as a result of seeing this show?" By pairing the questions together in this way, the respondent is guided to respond to the opening question in terms of how they felt/what they did before seeing the show.

Due to time constraints, it was not possible to return to the participants and test for long term retention. It would be welcome for future research to consider this, particularly after the interesting result seen elsewhere that 3D leads to better retention (Price, Lee, and Malatesta 2014).

7. Conclusions

3D Planetariums are new and there is a suggestion from the literature that a mix 3D and 2D within a show leads to a more engaging and enjoyable experience for the audience (Gandolfi et al. 2005; Plummer et al., 2013). There seems to be some support for this suggested within the results of this research. It will be interesting to see how audience reactions change as audiences get used to experiencing what the new 3D technology can offer in a planetarium setting. There is a strong suggestion from this and other research (Frappa, 2012) that audiences are increased in volume and enjoy the show more when 3D is used as part of the show in the early months of operation. The interest in 3D films appears to wax and wane and it will also be

interesting for further research to see if this is also true of the use of 3D within Planetariums.

The audiences, under 50% of whom declared a pre-existing interest in science, were most engaged by the science in the shows. It would appear that the 3D planetarium of today remains a way to attract and engage new audiences with science. Astronomy and climate science were both well received by the audiences. In addition, the audiences were sufficiently inspired by the shows to wish to change their behaviours accordingly. It would be interesting for further research to design studies which follow up on this to see if those intentions are followed through.

Planetariums attract audiences around the world and the new 3D capabilities appear to be another opportunity to attract audiences who are not all already interested in science and astronomy as well as those seeking to indulge their interest in science and astronomy. Careful programming and the creation of engaging shows will be needed to maintain this high level of interest but the opportunities are there as adult planetarium audiences are entertained, **engaged**, **inspired** and feel as though they have **learned something**.

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Appendix 2: Planetarium Questionnaire for MSc at UWE (Planetarium Nights

Thank you for taking the time to complete this questionnaire. Your answers will help us to understand and improve the customer experience. It is also part of a research project at the University of the West of England. If you would like to know more about the research please write your email address or phone number here
……..

Why did you come to see the show in the @Bristol Planetarium? (tick all that apply)

Night out with friends ☐ Night out with family ☐ Night out on my own ☐

Interest in astronomy/stargazing ☐ Interest in science ☐

To experience the new 3D planetarium ☐

Other……..

How would you rate the show? Circle the relevant number

very poor	poor	fair	good	very good
1	**2**	**3**	**4**	**5**

Would you like the show to include: (circle more or less for each topic)

- more / same / less star spotting
- more / same / less myths and legends
- more / same / less science

What was the most memorable experience / best part of the show?

Did you feel you learned anything new?

Yes ☐ No ☐ **What did you learn?**

PTO

Did you feel that the show was good value for money?

Yes ☐ No ☐ Comment

Did you think the 3D effect enhanced your experience?

Yes ☐ No ☐ Comment

Would you be interested in seeing any of the following in the Planetarium?
(tick all that apply)

music concerts ☐ art shows ☐ films ☐ the same show again ☐

another astronomy related show ☐ Other ……..

Which topics would you like to be included in future shows?

How often do you look up at the stars/go stargazing?

More than once a month ☐ Once a month ☐ Hardly Ever ☐ Never ☐

Other……

Do you think that will increase as a result of seeing this show?

Yes ☐ No ☐

Did you see any of the following about the show tonight (tick all that apply)

Poster ☐ Flyer ☐ Bus advert ☐ Facebook ☐ Twitter ☐

Newspaper article ☐ @Bristol website ☐ Other website ☐ Word of Mouth ☐

Other……

Any further comments?

Appendix 3: Planetarium Questionnaire for MSc at UWE (Aliens)

Thank you for taking the time to complete this questionnaire. Your answers will help us to understand and improve the customer experience. It is also part of a research project at the University of the West of England. If you would like to know more about the research please write your email address or phone number here

……..

Why did you come to see the film in the @Bristol Planetarium? (tick all that apply)

Night out with friends ☐ Night out with family ☐ Night out on my own ☐

Interest in astronomy/stargazing ☐ Interest in science ☐

To experience the new 3D planetarium ☐

Other……..

How would you rate the experience of seeing a film in the planetarium?
(Circle the relevant number)

very poor	poor	fair	good	very good
1	**2**	**3**	**4**	**5**

Did you feel you learned anything new from the experience?

Yes ☐ No ☐ **What did you learn?**

Would you be interested in seeing any of the following in the Planetarium?
(tick all that apply)

astronomy show ☐ music concerts ☐ art shows ☐ films ☐

other science shows ☐

How often do you look up at the stars/go stargazing?

More than once a month ☐ Once a month ☐ Hardly Ever ☐ Never ☐

Other……

Do you think that will increase as a result of this experience?

Yes ☐ No ☐

Any comments?

Appendix 4: Planetarium Questionnaire for MSc at UWE (Blue Marvel)

Thank you for taking the time to complete this questionnaire about your experience in the Planetarium. Your answers will help us to improve the customer experience and is part of a research project at the University of the West of England. If you would like to know more about the research please write your email address or phone number here ……

Why did you come to see the show in the @Bristol Planetarium? (tick all that apply)

Night out with friends ☐ Night out with family ☐ Night out on my own ☐

Interest in astronomy/stargazing ☐ Interest in science ☐

To experience the new 3D planetarium ☐

Other……..

How would you rate the show? Circle the relevant number

very poor	poor	fair	good	very good
1	**2**	**3**	**4**	**5**

What was the most memorable experience / best part of the show?

Did you feel you learned anything new?

Yes ☐ No ☐ **What did you learn?**

……

Did you feel that the show was good value for money?

Yes ☐ No ☐ Comment

Did you think the 3D effect enhanced your experience?

Yes ☐ No ☐ Comment PTO

Would you be interested in seeing any of the following in the Planetarium?
(tick all that apply)

music concerts ☐ art shows ☐ films ☐ the same show again ☐

another astronomy related show ☐ Other ……..

How important is "potential environmental impact" to you when you do the following:
(circle the relevant number)

	Not at all	Slightly	Moderately	Important	Very
- Shopping	1	2	3	4	5
- Travelling to work	1	2	3	4	5
- Going on holiday	1	2	3	4	5
- Home Improvements	1	2	3	4	5
- Selecting energy supplier	1	2	3	4	5

Do you think that will be less, the same or more as a result of seeing this Planetarium show?

- Shopping	more / same / less
- Travelling to work	more / same / less
- Going on holiday	more / same / less
- Home Improvements	more / same / less
- Selecting Energy Supplier	more / same / less

Any further comments?

Appendix 5: Transcript of Planetarium Nights event

- Narrator in plain text. [Audience reaction in brackets]

Hello everybody. Welcome to the @Bristol Planetarium. My name is Lee. I'm the Planetarium Manager and for the next 45 minutes or so I'll be presenting a supercharged version of our Summer Stargazing Show.

Have you all seen the big silver ball outside? Yes, that is what we're sat in at the moment. A bit like the TARDIS, it seems bigger on the inside than it does on the outside.

For my own curiosity, could we have a quick show of hands. Who has never been to the @Bristol planetarium before? Lots of people! OK, welcome to all the new faces. Welcome back to those of you who have been here before.

I want to tell you a little bit about the technology we've got here because it's pretty impressive. We just had a major upgrade and we now have the latest in full dome digital technology.

[Woos from the audience]

Good reaction. Yeah. Great. That projector there in front is the first one of its type ever made in the world.

[woos from the audience]

and it has a twin at the back which is the second one of it's type ever made in the world.

[woos from the audience]

They have a resolution of 4K, a contrast ratio of 2,000 to 1 and they each put out 30,000 lumens. That's a lot of lumens.

And this means that, in conjunction, they put out 1.6 billion pixels every second onto the dome above us. Technically, that makes us the highest resolution cinema in the UK.

[woos from the audience]

but because our screen is a dome, it means we're the most advanced planetarium in the UK….and we use this amazing equipment to present our sky shows but before we blast off into space, I need to make sure we are firmly on the ground with the obligatory Health and Safety speech.

Have you all got some 3D glasses? You don't need to put those on, just yet. We're going to do a little bit of 2D stargazing first of all but I'll be sure to let you know when to put those glasses on. If, during any of the 3D sections, you feel like you are floating in space a little bit too much, just close your eyes and the feeling should pass, I hope.

For now sit back, relax as we begin the show by opening the dome around us.

[dome opens]

Be honest, were you hoping to see more stars? Yeah. I don't blame you but you can't see that many from the centre of a city like Bristol because of this orange glow all around the horizon. This is light pollution caused by car lights, street lights and house lights. It shines up into the sky and drowns out the fainter stars. Light pollution in Bristol is usually this orangey colour because our street lights tend to use sodium and our street lights glow orange.

We can use a powerful planetarium to get a much better view. So, we're going to turn off all this light pollution. For the most dramatic effect, I invite you all to close your eyes and I will count down from 3, 2, 1 and open your eyes,

[woos from the audience]

That is the reaction I was hoping for.

[laughter]

Save for actually going up on a mountain in the Brecon Beacons or somewhere like that, this is actually the best view of the night sky that you can get in the country and it's much warmer in here so it gets my vote.

Now, instead of seeing a few hundred stars, we can see a few thousand. SO many that it can be a little intimidating for beginner stargazers. You might not be sure where to start and how to navigate the sky. Well, I'm going to show you a really useful trick.

We're going to look fro a pattern made of 7 fairly bright stars. It goes by a few different names; The plough is the traditional name in this country. Our American friend like to call it the big dipper, in @Bristol, we like to call it the saucepan.

If you think you've found it, just point it out. We've got a few confident stargazers pointing in completely the wrong direction. [laughter] Oh yes, you guys on the left. Well done. Oh and at the back. Good job. OK. We've got a handful of competent astronomers. By the end, you will be definitely qualified. Alright, let me help you out.

If you look right to the front, we're going to use my laser pointer here. If we go over our right shoulder [laughter] yeah, now you can see how wrong you were [laughter] 1 2 3 4 5 6 7. That is our saucepan pattern or The Plough, or The Big Dipper or whatever you want to call it.

And it's a really useful pattern because these 2 end stars point close to, it's not exactly on, but close two that star there. Any idea which star that might be?

[North Star]

Yeah, the North Star. Have you heard that the North Star is the brightest star in the night sky?

[Yes]

Yes? You've been lied to. It's not true. The North Star is the 44th brightest star in the night sky. That's why you need to use the pointers from the plough to find it.

Once you've found the North Star, you'll know that the closest horizon gives you North. You can then use that trick to navigate.

It's a very useful trick. Before we had GPS satellites, explorers would use that trick to discover whole new countries and whole new continents

So, we've looked at some stars. Next we are going to look for a planet.

and it's a planet which is up in the sky this summer. It's been pretty high in the South but because we are reaching the end of summer, it's a bit lower in the sky now. Let me bring up my pointer and I'll just show you where it is.

Pretty low to the horizon, to the front and to the right. Has anyone here ever seen Saturn in the night sky with their own eyes?

Maybe a few amateur astronomers. I bet most of you have but haven't actually realised it because if you didn't know better you would think that Saturn was just a star. That's what it looks like in the night sky. But Saturn is much much closer to us because Saturn is within our own Solar System and we can use the planetarium to actually fly there.

This is a good moment to all out on your 3D glasses. Hold onto your seats and we blast off, up towards Saturn.

[laughter and woos and WOWs]

Saturn is called the jewel of the Solar System and it's easy to see why. Nobody has ever been this close to Saturn to see it quite like this. Saturn is a Gas Giant. It's mostly made of Hydrogen and Helium with a few other things thrown in for good measure and it really is a giant, you could fit planet earth inside this over 800 times.

Saturn was first observed through a telescope by the famous Italian astronomer called Galileo. He did this in late 1609. He was the first person to use a telescope to study the night sky. The telescope optics he was using weren't quite good enough to resolve the rings fully. He saw them as bulges either side of the planet.

In his notebook, he rather fancifully referred them as the ears of the planet although on more careful consideration he thought they were probably moons either side of Saturn. That was a pretty good prediction. Although, with our more modern technology we now know that they are ring system we even know what they are made of. To find this out, we can take a closer view.

[woops and cheers]

Saturn's rings are made of trillions of pieces of rock, ice and dust. Most are tiny but some are more like boulders. We think they were made a long time ago when a moon of Saturn's was fractured and destroyed, leaving all these pieces orbiting the planet.

The rings are so dense that we don't even dare send space probes into them but we do know that the rings contain a secret. Not many people know this. We're going to find out what it is by taking a slightly different view.

{gasps]

This is Pan. It is a moon within Saturn's rings. Pan is about 35km across. It's fairly small for a moon but has sufficient mass to have a decent amount of gravity and as it orbits the planet Saturn, it sweeps up material throughout the rings and that means that this moon actually creates a gap within Saturn's rings and we call that gap the Encke division after the scientist who first saw it.

We can see that Pan is a strange shape. It has these bulges at the top and the bottom. 19.18 We think that's where the material that is swept up gathers. It builds up and builds up and creates this strange shape. Perhaps some time in the future, we'll be able to send a robotic mission or even a manned mission to Pan but for now, this is the best view that anyone can have.

Let's had back to Earth as we are going to do a bit of stargazing. This section is in 2D so, if you like, you can take your 3D glasses off and give your eyes a bit of a rest

There's a pattern which his very well placed to see throughout the summer.

It's made of 3 bright stars so it is imaginatively called the Summer Triangle. I know what you're thinking, there are lots of triangles in the night sky. You're right but I am looking for one triangle in particular.

Have a look and see if you can point it out. If you were hopelessly wrong with the plough, this is your chance for redemption. Half of you have just squandered that chance. What a shame. You guys at the back? I expect more (laughs)

Ah, I think of you have got it. I'll give you a clue, it's right in front of us. The Summer triangle is made of 3 stars, Vega, Deneb and Altair. It's a lot easier with the markers.

The ancient Greeks didn't see this as a triangle but rather as 3 separate constellations. Because the Summer Triangle isn't actually a constellation. It's what we call an asterism. An asterism is like an unofficial constellation and the summer triangle was popularised by the late, great Sir Patrick Moore.

We're going to look at the ancient Greek constellations that make it up so let's clear our summer triangle away.

The first constellation is called Aquila the eagle. I'll point it out with my laser pointer. There's a star here called Altair and I see that as the eye. Of the Eagle and some head feathers here. I see a wing coming out here and another wing coming out here and he's got some fluffy tail feathers here. What's your imagination like can you see an eagle there?

Some of you can. We've got some doubters in the audience. Yes, I heard you but if you saw a different pattern, don't worry because there are actually lots of different interpretations of this constellation. Let me show you another one. This is what some people think the bird looks like. Now all of a sudden my one seems a lot better doesn't it?

This particular picture is showing one of the myths behind Aquila the eagle. According to the story, he was one of the eagles that belonged to the god Zeus, the king of the gods and Aquila ran errands for Zeus such as carrying sun clocks. One day Zeus was in his home on mount Olympus high in the clouds and he looked down on earth and saw a handsome shepherd boy who rather took his fancy.

SO Zeus sent Aquila down from the sky to pick this shepherd boy up and carry all the way back to mount Olympus to be Zeus's cup bearer, nudge nudge wink wink.

[Laughter]

The king of the gods certainly cast a wide net. This shepherd boy was granted eternal youth and immortality in return for his services to Zeus.

Let's go back to the next constellation. We're looking to the bright star at the top right of the triangle. That star is called Vega and it's the brightest star in the constellation of Lyra the Harp. It's a very small pattern this is the handle of the harp and these stars make the corners so the strings would go up and down like that. Pretty small but a good one for a beginner stargazer.

Let's take a look. That's their interpretation of it. According to the story, Lyra was a very special harp. It's the source of all the music on earth. One day it was dropped into a river. This was a disaster because without Lyra there could be no music on earth. Zeus saw this happen and he liked music so he sent Aquila the Eagle down from Mount Olympus and plunged into the river, picked up the harp and placed in the night sky for safe keeping. Thereby guaranteeing that there would always be music on earth.

I've saved what I think is the best constellation for last. If you look to the top left of our triangle, that star is called Deneb and that is the brightest star in Cygnus the Swan. Deneb is the tail of the swan. He has a wing that comes out here and a wing that comes out here and along neck with a little pointy head.

This is sometimes abbreviated to the Northern Cross as the brightest stars in the constellation make a cross shape.

According to the ancient Greeks, Zeus used to disguise himself as this swan when he wanted to come down to earth and well, let's say impress the mortal ladies.

Let's go back just to those three summer triangle stars. 24.57

When we look at the stars in the night sky, we tend to assume that the brighter stars must be close to us and the fainter stars must be further away but that isn't always the case

If we look at Vega, Deneb and Altair, they all look a similar brightness so we might assume that they are a similar distance to us. We can use the planetarium to test this.

We're going to fly to these stars. So if you'd to all put your 3D glasses back on and first of all we are going to fly towards Altair. Altair is 17 light years from

earth. What that means is if we were travelling there in a rocket ship, the journey would take us about 250,000 years but this is one of our celestial neighbours.

Let's head on towards Vega. Vega is 25 lights years away so our rocket ship journey would take about 375,000 years. Let's head on towards Deneb.

Deneb is a lot further away. 2600 light years away. In our rocket ship that journey would take 40 million years. It's over 150 times further away from earth than Altair is. But remember that all those stars in the summer triangle look a similar brightness from earth but they are very different distances. What we can't easily tell from earth is that this star is different from the other ones.

This is a Hyper Giant Star. It's much much larger and much much brighter so even though it's really far away, it still looks a similar brightness to Altair and Vega.

SO just because a star is really bright doesn't mean it is necessarily close to us. And just because a star is really far away doesn't necessarily mean that it is further away.

Let's head back to the surface of earth. There's a strange astronomical object in the constellation of Cygnus.

When we look in that direction, we are actually looking towards something called a black hole but we can never directly see the black hole. To explain why, I am going to show you a close up view of what we think they look like.

It's just coming in here from the left. Black holes are really big. They have such intense gravity that they pull in anything that gets too close, even light. That means we can never directly observe them but we can clues that they are around, like how the light around the outside is distorted and bent out of shape. We can see a disk of light around the outside as well. That's the event horizon. Technical name is the Schwartz child radius.

That's the point of no return. If you go past that, it doesn't matter how fast you are, even if you are light, you are getting pulled in.

If you were to get pulled in, you would be stretched from head to toe. The scientific term for that is spaghettification.

But luckily all black holes are a long, long way away so we don't have to worry about them.

We've seen that some stars are closer to us. Some stars are far away. But did you know that stars are also subtly different colours. That's quite difficult for us to see as our eyes aren't particularly good at seeing colours in low light conditions like in the night time but if anyone here has used a small telescope or a pair of binoculars to look at the night sky, you will definitely know what I am talking about.

The stars up there are distinctly different colours. I'm going to scale up a few of my favourite colour stars. I'm going to make them all the same size so we can fairly compare them.

These are all actual stars you can see in the summer night sky. We've got a good range of colours here. We've got some oranges, some blues, and there's a white star behind us, Polaris, the North star just above us there. I think we're missing a star. The star that's closest to us. Which star might that be? The Sun, well done.

The Sun is the closest star to Earth. A lot of people don't think it's a star because it looks so different but it only looks like that because it is so much closer to us.

I'm going to bring the sun up right in front of us. Just before I do, I would like you to predict what colour it will be.

[Green?]

No, there are no green stars. Ask me why after the show if you are interested. The Sun is actually a slightly off white colour. Most people assume that it is yellow. When we draw pictures of the sun, we draw it as yellow but actually it only looks yellow because the light from it is scattered by our atmosphere.

If you were to go up into space and look at the Sun? Well, you'd be blinded. It's a terrible idea. Never do that. But if you were to wear special filters, you will see that it is slightly off white.

The colours of the stars give us clues to the stars temperatures. On Earth we think of red things as being hot and blue things as being cold but with stars, it's actually the other way around. The hottest stars are actually the blue and white stars. They can be up to 40 thousands of degrees C on the surface. The orangey red stars are the coolest around 3 or 4 thousand degrees C. For reference, our own Sun is middlish, just shy of 6000 degrees C.

Let's take all those stars away.

If you do go out stargazing in the summer and go to a night dark site, you might be able to see the Milky Way. This is a band of stars which spans from horizon to horizon. I bet you can see it right now. From the front and to the left, let me make it a bit brighter.

The milky way is the name of the galaxy in which we live so we're inside the galaxy, we can also see it in the sky. That's quite a tricky thing to explain but what we could do is use the planetarium to fly all the way out of our galaxy to see it from the outside. Hold onto your seats because this is going to be the furthest we have ever gone.

We've now travelled so far that we can truly see what the milky way is. A star city. There are around 400 billion stars in the milky way galaxy. Our star is just one of those.

We occupy a tiny region of this galaxy. The Sun and pretty much every star that we can see in the night sky all fit within this circle. To see further afield we need to use binoculars, we need to use telescopes.

But the milky way is just one galaxy. A big question for modern astronomers has been how many galaxies are there in the universe?

To find the answer, a very clever experiment was devised using a clever telescope.

To see this we are going to travel back to earth but we are not going to land on earth this time. We are just going to go back to low earth orbit. Any idea what the name of this satellite is?

[Hubble]

Hubble Space Telescope. One of the greatest inventions ever, in my opinion. It's fair to say that Hubble has revolutionised the way that we view the universe. Largely because of it's fantastic location above the Earth's atmosphere and also because of its work in the experiment to devise the answer to how many galaxies there are in the universe. Firstly, a patch of sky was found which looked completely empty. It's near that star Plough pattern that we looked at in the beginning. See if you can find it this time.

I'll give you a clue, it's moved from where it was. Oh this is clear evidence of progression. You're all pointing in the right location. Good job. Let me add some lines for you. It's at the front and to the left.

Near that pattern is a patch of sky that looks completely empty. It's actually a lot smaller than this maker. It's so small that it would actually be about the same size as a tennis ball held out at 100 metres distance. That patch of sky looks completely empty. There's nothing there. And a group of astronomers wanted to use the Hubble telescope to stare at that patch of sky for ten days to build up a picture. To gather the precious photons to see what was there.

A lot of people thought this was a waste of time. "We can see there's nothing in that patch of sky". But others thought we should give it ago. Let me show you the actual photo that was made.

[Wow]

This is the Hubble Deep Field. It's a real photograph. Almost every blob and dot we can see there is a galaxy, containing hundreds of billions of stars. All those from that tiny patch of sky. If we multiply that over the entire sky, we get an estimate of how many galaxies there are in the universe. More than 100 billion. Imagine we could fly through this picture. WE think it would look a little bit like this.

There are more stars in the universe than there are grains of sand on every beach on earth. It makes you wonder how many planets are out there. Are there any home to life? This is something we'll look at more in our Autumn Stargazing show.

Next I want to show you a little bonus section we have put together based on a space mission which was in the news recently. This is the new horizons probe. That flew by Pluto in the middle of July.

This was a culmination of 9 year journey. 4.5 billion kilometres it flew. In the middle of July, it took close up pictures of the surface of Pluto. And actually the texture you can see on Pluto there in background are based on the information

that this probe sent back. That means we are some of the first people in the world to EVER see the surface of Pluto in 3D.

NASA has been releasing the pictures that the probe has sent back and what I'm going to do next is go off piste a little bit and I've actually been on the NSAA website just before the start of the show and what I am going to do is bring up onto the dome some of the latest pictures and I'm doing all of this in real time so let me bring up this picture first.

Fade up in 3, 2, 1, There we go, that's pretty good. This was the first high resolution picture of Pluto that anyone has ever seen. This was taken as this probe as it flew past. And this picture completely astounded us. Everyone thought that Pluto would be a completely dead rock on the outskirts of our solar system but this picture shows that that's not quite the case. We can see Mountain ranges, we can see valleys. We can see what could be volcanoes and all that shows us that Pluto is a geologically active world. Where the energy for all this dynamism is coming from, noone is quite sure. It could be a radioactive core, it could be something else. At the moment, nobody really knows.

We can see that big plain, at the bottom. It's been nicknamed, the heart of Pluto and new horizons took some close up pictures and one of those was released just 2 days ago. This is the very latest to be sent back and I've got it just here. I'm going to bring it up on the right and it should come up in 3, 2, 1. There we go.

That's a close up that showing that heart of Pluto. We can see some craters at the bottom and some valleys on the left but actually the most amazing thing about this picture isn't what it is showing but rather what it isn't showing and that is an absence of craters at the top and the right. Whenever we see an absence of craters, that tells us that there must be some sort of renewal mechanism going on going on on this world. Because wherever the craters were that were there a long time ago, something has happened to cover them or to erode them away. We're not too sure what could be going on .

We think that plain is a vast glacier made of nitrogen and that is somehow being replenished. Perhaps through those volcanoes. It could be there or perhaps through some gaps in the ground. It could be nitrogen swelling up from beneath the planet At the moment, it's another mystery.

Let me show you another picture. This one needs the most explanation but I kind of think it's the most impressive in a way. I'm going to bring it up right over us in 3, 2, 1 there we go. That is a photo the new horizons probe took as it past by Pluto and the sun was on the opposite side. So this is an eclipse of the sun by the planet Pluto. Pluto is the big black disk we can see and we can see the haze around it and that is completely astounding because that haze shows that Pluto has an atmosphere. I mean WHAT?! An atmosphere on Pluto. Nobody predicted this. Nobody at all. This was just out a few weeks ago really. Before that point, everyone would have said there was an atmosphere on Pluto but now we now it has an atmosphere. A very thin one. Very tenuous. Made of Nitrogen, we think. We think the material from those nitrogen glaciers is sublimating. That's when it turns from a solid straight into a gas. It skips the liquid phase. And is enveloping

the planet. Very thin. But it is still an atmosphere and nobody expected this. Pluto is clearly a very exciting world.

Now this probe is going to continue to send back information over the next 15 months. So I hope there will be many more discoveries to be made. I really do think that we live in a very exciting time.

When we can see pictures like this and this up to date information. TO think it was not too long ago that we didn't think that Pluto was anything like this. There was a quote released from one of the scientists just yesterday. He said looking at these pictures now, if, before the mission, an artist has drawn these, all the scientists would have said, No way, it's nothing like that you have exaggerated it. But actually we find it is has exceeded our wildest expectations.

Let's head back to earth and let's take a final look at the summer stars.

We've seen a lot of amazing things in the show so far. For your own star gazing adventures, in your back yard, using all the things we've found out form this show, the more you look, the more you see. You'll be surprised at how much you can see.

Let me fill the sky.

I've taken the 3d effect off and I promised you a photo opportunity. So if you like, you can take off your glasses and you're welcome to take some pictures. The stars are so bright that if you use your camera phone it will turn out pretty well but here's a pro tip. Turn the flash on your cameras off, you'll get a much better result that way.

I've had a lot of good wows in this show so you deserve a treat. I'm going to throw up some extra constellations for you

[wow]

There are 88 constellations in the night show. We pick different ones in each seasonal show. In our upcoming autumn show we look at Perseus and Cassiopeia and Pegasus and Cetus. We also look at eclipsing binary stars, exoplanets and colliding galaxies.

OK just another moment to take some final pictures. You can see we've put up there @Bristol's twitter account and Facebook group. If you liked the show we'd love to see your pictures and your comments. If you haven't loved the show, then please keep those comments to yourself

[laughter]

45.6 and stop taking pictures in 3, 2, 1.

We're almost at the end of the show and I'm going to give you a special treat ext. These planetarium nights have been so popular that we are looking at running more of them in the future and we are looking at different kinds of shows that we can put on so I'm going to show you a trailer of one of the shows we are considering putting on. It's called We are Aliens and it's in 3D so if you would like

to put your 3D glasses on and as you leaver at the end put your thumbs up if thi sis the kind of show you'd like to see.

It looks pretty good doesn't it?

[Yes}

Laughs. Right, we are going to take one final look at the stars, Because we started the by opening the dome around us so it's entirely fitting that wend the show by closing the dome.

Once I've blocked out the stars I'll pop on some extra lights and you can leave through the doors at the back. Please deposit your 3d glasses as you go. There are some night sky guides on the walls. please feel free to take them.

I'll be around to answer any questions you might have. There are some questionnaires and it would be great to know what you feel about the show.

Thank you very much. Please enjoy the rest of your evening.

Please enjoy the rest of your evening.

ENDS

Appendix 6: Transcript of Blue Marvel event

Narrator in plain text. [Audience reaction in brackets]

Hello everyone. Nice to see you. Welcome to the Planetarium! My name is Sarah. I'm in 3D so you don't need your goggles on just yet

I'm going to tell you a couple of things about the show just before we begin. If we hear the fire alarm, it's very loud. Please stay in your seats while I put some lights on and then I'll lead us down these stairs at the front where we will pop out in Millennium square by the really big silver ball.

Have you seen the really big silver ball outside? DO you know where we are now? Well done you. We are inside the big silver ball which explains the dome ceiling. We are not expecting a fire alarm so fingers crossed we will exit using the doors you came in through at the back.

If you need to leave before the end of the show, that's totally fine. Leave through those doors at the back. Bear in mind that they will lock behind you and you will not be able to come back in again. Please just bear that in mind.

Please don't use phones and cameras during the show. It gets quite dark and flashes going off and even small screens lighting up is a big distraction for the rest of the audience so please keep those things away. I think that's it.

We're very proud of our 3D active Planetarium system. Really hope you enjoy the visuals.

If you feel like you're floating in space a little too much then just close your eyes for a bit and the feeling should pass.

This show is going to use our cool digital system to explore the way that space exploration has helped us learn about our planet and more about the challenges we have facing us in the coming years of looking after it. So pop your goggles on now.

We're going to start with an important moment in our history.

So In 1969 the Apollo 11 mission landed man on the Moon, kick-starting a golden age of space exploration. It was the first time humans had set foot on another world, but the sight that struck many astronauts was their view of the Earth. Those first explorers could hold up one thumb in front of them and blot out the Earth – an entire planet billions humans on a beautiful, distant pale blue globe in the vastness of space.

This photograph of planet Earth taken by the Apollo astronauts could be the most influential environmental picture ever taken, you could say it provides a powerful new perspective on our home planet.

Since the Apollo era we've expanded our exploration of space. Planet Earth is clearly special, but it's taken exploration of other worlds in the Solar System to fully

appreciate why. So we're going to take a look at three worlds in our Solar System to see just how they compare with our planet; Earth.

We're going to head first to our neighbouring planet, Mars.

More than 40 robotic probes have been sent to Mars. It's a really dangerous journey and loads didn't survive, but those that did have gathered some really fascinating data. Mars once had a thick carbon dioxide atmosphere that kept the temperatures warm enough for liquid water to exist. We think that Mars used to look something like this.

With flowing water on its surface, Mars was almost Earth-like. But this wasn't to last. Mars is lacking a strong magnetic field to protect its atmosphere from the stream of charged particles known as solar wind. They stripped away Mars' atmosphere, causing temperatures to drop, and the ocean to disappear.

And if you've been watching the news recently, you'll know that last week we discovered liquid water flowing on the surface of Mars which very very exciting because it massively increases the chances of finding life on this planet.

But we do know that it no longer has oceans likes this because of its lack of atmosphere.

There is a planet in our Solar System that does have a thick atmosphere though. We're going to go there next. We're heading to Venus.

Venus is made of rocky planet just like Earth, and is of a very similar size, but conditions are a lot more extreme. On Earth we have the right mix of atmospheric gases that allow us to breathe, but don't heat up our planet too much, or let us get too cold. Venus has an incredibly thick carbon dioxide atmosphere that traps heat and has raised the surface temperature to 500°C That is enough to melt metal

Radar imaging allows us to peer through the clouds to reveal a surface shaped by volcanic activity, but lacking any of the liquid water necessary for life as we know it.

We going to head somewhere in the solar system to find us some liquid water our Solar System journey to find liquid water. We're travelling toward the planet Saturn, but we're going to bypass this planet because we're most interested in its icy moon Enceladus.

In 2005 the space probe Cassini discovered a water-ice geyser erupting from icy Enceladus' south pole, really similar to those found on Earth. So Enceladus may have a liquid water ocean hidden beneath its icy surface, making it one of the most likely places in the Solar System to be host microbial alien life.

But there is one place that we know of in our Solar System that we know is filled with water… and life.

The more we use our space technology to learn about the Solar System, the more we realise that it is a truly exceptional world to live on.

Earth is situated within the Sun's Goldilocks Zone – so it's not too hot and not too cold, but just right temperature for liquid water – and life – to exist. But it isn't just our distance from the Sun that makes life on Earth possible. We were talking earlier about Mars's lack of magnetic field. The magnetic field around Earth protects us from all that harmful radiation, and prevents our atmosphere being stripped away.

We can see how far the influence of Earth's magnetic field extends out into space.

This field is caused by the motion of liquid iron in the core of our planet. Planets with a solid core can't create a strong magnetic field. We think this is why Mars lost its atmosphere.

The interaction of our magnetic field with charged particles from the Sun causes some really gorgeous effects. If anyone has been lucky enough In the Northern hemisphere to see the Aurora Borealis, or the Northern Lights.

Because of these factors, Earth is the most diverse world in the Solar System. The landscape on Mars, Venus or Enceladus doesn't vary very much, but on Earth we have a really wide range of different environments. All of these environments have different plants and animals. We call this variety of life biodiversity.

Of the huge variety of life that Earth hosts, one creature emerged with, arguably, intelligence beyond any of the others: humans. Over time we spread across the globe. We formed large communities and our habits changed. We began building. We created culture. We began farming. We've started to change our environment.

As our species became more advanced, our impact on Earth accelerated. By using Earth's resources, the Industrial Revolution sparked technological advances which have contributed to the longer and more comfortable lives that we enjoy in this country today.

Since the Industrial Revolution the human population has grown at an extraordinary rate. This is in part because of improvements in industry and technology. You can see the growing populations lit up on this earth.

15.18

The driver behind the Industrial Revolution, and population growth, has been the energy that we find in oil. Here we're comparing average oil consumption per person in different countries. Today we still consume a huge amount of oil in the developed world. Globally, we've consumed over 170 billion barrels of oil since the mid-19th Century.

In Britain we demand 2 trillion Mega Watt hours of energy every year from our power stations – equivalent to the energy stored in 180 million tonnes of oil. The vast majority of this energy comes from coal, gas and nuclear – these are all non-renewable sources – and you can see in this visualisation of the top 50 power stations in the National Grid. As global population grows globally, so does our thirst for energy, which is beginning to take a toll.

This challenge is being revealed by satellite observations we're making of our planet. I think this graphic is really cool it's showing you over 1000 active satellites in orbit around the Earth, assisting with communications, sharing data and a lot of them are observing our changing world. We are now in a golden age of Earth exploration.

And with that comes some difficult truths.

We're going to use some satellite data to create a model of what may happen to Earth in the future. The fossil fuels we're using produce carbon dioxide. This is a greenhouse gas and it contributes to global warming that we are experiencing. Over 30 billion tonnes were released into our atmosphere last year alone. This model of Earth has greatly exaggerated heights, with mountains 3000 times taller than they would normally seem. It will help us visualise the effect of global warming on our average global sea level.

As our planet gets hotter the ice is melting, and the volume of our oceans is expanding, causing the sea levels to rise. Our current best models suggest that the water will rise by up to 1 metre over the next 100 years That's going to be enough to flood Bangladesh and that will be enough to displace more than 15 million people. But Are we likely to see sea levels rising any higher than this?

Well, the last time the Earth had the same levels of carbon dioxide as today was 3.5 million years ago. Back then the sea level was 20 metres higher. We haven't seen this level of flooding yet because ice takes thousands of years to melt and it hasn't quite caught up but if the amount of carbon dioxide we're releasing today continues to rise then Earth's history tells us that when it reaches twice current levels, over millennia, all the planet's ice would melt resulting in a sea level almost 70 metres higher than today.

Another impact we're having on the Earth is the loss of forests. Here in green you can see the global forest cover in the year 2000. The rising human population has led to large areas of forest being cleared. The purple bits shows forest lost between the years 2000 and 2013, the yellow shows forest gained. 70% of Earth's animal and plant species live in forests, and many can't survive the deforestation that destroys their homes. Reduced biodiversity impacts people. Food supplies will be more vulnerable to pests and disease, and fresh water could be in short supply as well.

A major reason for deforestation, particularly in South America, is to make room for farms and settlements and place for people to live. The loss of forests also has an impact on carbon dioxide levels, making it all the more important that we reduce our carbon emissions.

To do that we could harness the renewable sources of energy that are all around us. So we're going to take a look at some of those. We're going to start with wind power. There are immense amounts of energy in the wind This is a snapshot of global wind flow patterns generated from satellite data and projected above the planet Earth. It allows us to see the strength and direction of winds as they flow around Earth. So the longer the lines, the stronger the winds. Let's fade away Earth so we can better see these patterns. We can still make out the shape of the continents by the winds that flow around them.

It's easy to see how powerful the wind can be when we look at amazing storms we get here. This is a model of hurricane Julio, captured by satellite again in 2014. Hurricanes like this Julio contain more energy than an atomic bomb in their surface winds alone.

Another unexploited source of renewable energy is really close to home. The Severn Estuary has the second highest tidal range in the world – about 15 metres. So the flowing tides in the Severn Estuary have the potential to generate more electricity than any current power station in the country, although not without harming the local ecosystem

And the third source of renewable energy we're going to talk about is solar, by far the largest energy resource on Earth. Here we see the energy output of At-Bristol's solar panels throughout the day. The solar energy that hits the Earth every second is equivalent to 4 trillion 100-watt light bulbs, The Sun is an excellent source of renewable energy. We've got a really big array up here on the roof at At-Bristol and it saves 27 tonnes of carbon dioxide every year; 27 tonnes of carbon dioxide is enough to fill this Planetarium 16 times.

Even better than that is how much we've managed to save by cutting down our energy usage – we've managed 359 tonnes of carbon dioxide That's enough to fill this Planetarium 226 times which just goes to show that while there are benefits to green energy, reducing use and increasing efficiency can have the greatest impact.

There are huge difficulties to overcome in making use of renewable energy and also decreasing our energy demands.

The challenge of the '60s was to reach the Moon. The challenge today is to preserve the Earth. The legacy of the Moon landings has led to our understanding of Earth as one tiny dot in a vast Universe. There could be billions of other planets out there. Chances are, some of may even be home to life. But for now, we only have one Blue Marvel. Preserving it won't be easy, but we haven't shied away from challenges before.

Folks, we really hope that this show will spark some discussion and some interesting thoughts. I'm going to be stood at the so if you have any questions or comments about the show, come and see me just outside. We also have some people here from the university of west England so if you have any thoughts, do please fill in a survey on your way out. That would be marvellous. Thank you so much for your attention. Don't forget to deposit your goggles.

I hope you enjoy the rest of your evening in At-Bristol! Thank you

ENDS