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Examination of using monoscopic three-dimensional (M3D) and stereoscopic three-dimensional (S3D) animation on students

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Abstract
This study examined the effect of using Monoscopic Three-Dimensional (M3D) and Stereoscopic Three-Dimensional (S3D) animation on students' achievement and perceptions. A total of 66 ninth-grade students participated in this Explanatory Sequential Mixed Design study. At the beginning of the study, an academic achievement test was applied, and then at the end of the study the same academic achievement test, plus an animation opinion scale, an animation rubric, and a structured interview form were applied to both groups. T-test, descriptive statistics, and content analysis were used for the data analysis. The results showed a significant difference in the post-test scores in favour of the students using the S3D animation. Both groups of students provided positive feedback concerning the use of animations in their course; however, they highlighted that S3D animations were more effective and enjoyable. Conclusively, this study is expected to contribute to the limited literature and open a new window for future studies. Additionally, this study may guide instructors towards increasing the effectiveness and efficiency of their instruction within courses that require visual input and scaffolding.

Keywords Monoscopic three-dimensional animation · Stereoscopic three-dimensional animation · Visualisation · Education

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1 Introduction

Technology is still rapidly advancing and making its presence felt in all areas of human life, especially in the field of education. Changes in modern societies have driven educational institutions to review the influence of their teaching strategies. In this respect, today's rapidly developing technology has taken its place within educational processes. Computer-Aided Teaching (CAT), meaning computer technologies utilised as an assist in education, has become an expansive as well as more diverse method. The development of multimedia applications such as graphics, animations, videos, texts and sound has contributed to ensuring a more effective, permanent and interactive learning experience for students through the diversification of learning environments. It has been previously stated that interactions made possible through multimedia tools have generated positive effects in the field of education in terms of the academic achievement and motivation of students (Akkoyunlu and Yılmaz 2005), in increasing the effectiveness of permanent learning and teaching (Dale 1969), making the teaching and perception of complex and difficult subjects much easier (Koşar et al. 2005), transforming abstract concepts into concrete concepts (Roblyer and Edwards 2000), and creating a positive effect on students' active participation in the learning process (Alessi and Trollip 2001). Along with this, multimedia applications may vary according to the content, cognitive features of students, and the objectives intended (Yünkül 2014).

The scholarly literature includes numerous studies on CAT applications. These studies have revealed that CAT applications not only positively affect students' academic achievement, motivation and attitude towards their courses in comparison to traditional teaching methods, but that they have also helped to ensure students' active participation in the learning process and demonstrated higher levels of comprehension of the knowledge acquired (Çelik 2007; Clarke 2001; Curtain-Phillips 1999; Fennema and Sherman 1976; Goodchild et al. 2007; Handal and Herrington 2003; Krendl and Clark 1994; Kulik 2002; Proctor and Richardson 1997; Tankut 2008; Vlachos and Kehagias 2000). In addition, it has been determined that CAT applications composed of visual presentations are more useful in teaching subjects based on complex and abstract concepts such as geography, biology and science, which involve learning facts that students do not have the chance to directly observe or experience (Buckley 2000; Hegarty et al. 1991). Learning by means of visual input means interacting with various types of depictive and descriptive representations (Schnotz and Bannert 2003), ensuring a deeper form of learning and understanding (Ainsworth 2006). There have been numerous research studies which have emphasised the importance of using visuals in teaching difficult and complex subjects such as geography, biology, and the sciences in general (Hubber et al. 2010; Prain and Waldrip 2006; Tytler et al. 2006). However, the problem faced at this juncture is teachers' use of two-dimensional (2D) figures in conveying concepts that are inherently difficult to visualise, leaving it to the respective capacities of students to interpret such visuals (Pillay 1998).

Unlike 2D visuals, it has been stated that various effects of 3D visuals develop the visualisation skills of students, deepening their discernment of structures, features, and functions of objects (Unver 2006). It is claimed that 3D visualisations contribute to the development of students' three-dimensional problem-solving skills, thereby facilitating their learning (Simoneau et al. 1987). Along with this, it has been explained that 3D visualisation of contents can increase the interest, participation, and motivation of students (Alam et al. 2010; Korakakis et al. 2009). Due to the lack of depth in perception as a result of being reflected onto a single plane, 2D visuals are also called Monoscopic 3D (M3D) visuals. As Stereoscopic 3D (S3D) images present more lifelike images thanks to their real depth perception, contrary to M3D images, it has replaced M3D images with the rapid development of technology. However, there is very little evidence available concerning the positive or negative aspects of S3D technology in education (McIntire et al. 2014).

Introducing a more effective learning environment by making use of rapidly developing visual technology falls within the objectives of educators. However, studies conducted to date offer limited information regarding which imaging technologies, M3D or S3D, should be preferred in relevant contexts. The current study is important in terms of its aims to present an opinion regarding the utilisation of 3D learning environments in teaching subjects which involve complex or difficult to observe phenomena and abstract concepts. The study intends to examine students' achievements based on M3D and S3D imaging technologies, as well as their opinions regarding 3D imaging technologies in this study. In this context, this study is deemed to be important not only in terms of its contribution to the integration of 3D imaging technologies in the literature, but also in terms of its attempt to open a new window in this field by examining the role of these technologies within education.

2 Related literature

2.1 3D virtual environments and methods of imaging 3D virtual environments

Virtual environments designed via computers may be developed either as 2D (two-dimensional) or 3D (three-dimensional). In comparison to 2D, environments that are 3D allow objects to interact with their surroundings within a more realistic and complex environment. It is possible to display 3D virtual environments by means of two different methods:

- Monoscopic 3D (M3D) imaging
- Stereoscopic 3D (S3D) imaging

2.1.1 M3D imaging methods

M3D images, or 2D (two-dimensional) images, have a limited capacity for providing clues about depth. In virtual environments, standard (monocular) cameras display 2D images on the X-Y plane.

Thanks to today's advanced technologies, the desire to move towards having all images displayed in 3D, as they are in real life, has become inevitable. In life, people naturally see and perceive all objects in 3D. With the help of layers in the eyes, people are able to perceive the shapes, colours and depths of objects around them by means of perceiving the light reflected on these objects and transmitting this information to the brain. The addition of the depths of objects to their colours and shapes brings about what is termed the third dimension. While the act of seeing in real life is based on this process, when people attempt to perform the act of seeing and perceiving via a computer display screen, they encounter sensory problems in assessing and sensing the dimension of depth. Despite the fact that the object to be displayed is three-dimensional, computer screens are of course two-dimensional devices, and that is the root cause of the problem (Erdun 1993).

2.1.2 S3D imaging methods

Stereoscopic imaging technologies operate as an imitation of stereoscopic imaging in daily life. In the course of stereoscopic imaging in daily life, each eye sees a single image (of the same object), and the image of this object differs according to the visual angle (Howard and Rogers 1995). This difference between the eyes brings about the sense of depth for the displayed objects. Objects displayed within digital environments with a sense of depth offer a more realistic image that is closer to that of how the object is seen in real life.

Today, stereoscopic imaging techniques are also being utilised in the field of education. Considering just the educational content, low-cost techniques which cause the least eye fatigue are preferred. In view of these requirements, active S3D imaging and passive S3D techniques are the most commonly used stereoscopic imaging techniques.

Active stereoscopic imaging: This is performed by synchronising a 60 fps image in both the left and right eyes with the use of active glasses (Seel 2010). When the projector displays a right-eye image, the synchronised glasses allow this image to be displayed only by the right lens; the same process is then repeated for the left lens with the left-eye image.

Passive stereoscopic imaging: This technique is divided into Anaglyphic and Polarised 3D imaging technologies, with each technology having its own advantages and disadvantages.

- Anaglyphic: Known as the first 3D image acquisition technique. A 3D image is acquired from the image being reflected in different colours by two different projections onto a two-dimensional screen upon being separated by means of compatible glasses.
- Polarised: All passive stereo systems generally make use of a pair of projectors (for instance, circular or diagonal) that are equipped with polarised filters. The filters are needed for a passive system in order to maintain the overlapping of the stereo images acquired by each eye.

Active S3D imaging technology was used as the S3D imaging technology in the current study. It was preferred by the researchers due to the possibility of acquiring more realistic, higher resolution imaging with these glasses. Additionally, its easier setup and advanced imaging technology have led to this active S3D imaging technique to be the most preferred tool in an education context.

In the current study, 3D educational content developed for the course was applied to the control group in the M3D environment and to the experimental group in the S3D environment.

2.2 Research conducted on M3D and S3D imaging methods

An experimental study conducted by Barbalios et al. (Barbalios et al. 2013) revealed that students who received 3D-sourced education within the scope of environmental education demonstrated a higher level of cognitive development in acquiring knowledge of complex concepts. In a study conducted in another field, Wu and Chiang (Wu and Chiang 2013) made use of two different types of visualisation methods which consisted of 2D static and 3D animations in the teaching of orthographic landscapes (2D image landscapes) within a graphic context to 120 (72 male, 48 female) students in Taiwan. In conclusion, it was stated that 3D animations demonstrated better performance in perceiving the appearances of the objects.

In a study conducted with undergraduate students, Hirmas et al. (Hirmas et al. 2014) taught physical geography concepts by means of static (2D) images to one group of students, and by means of a GeoWall (a passive 3D projection system) screen via Google Earth within a large classroom. The study's findings revealed that the students achieved much better results by means of S3D imaging technology, without the requirement of arranging seating at a certain angle. On another note, seating angles can create significant differences in students' learning. In light of these results, a significant differentiation between the S3D and M3D imaging technologies is only possible by closely adhering to the instructions of use. In another study conducted with imaging technologies which have an extensive range of use (McIntire et al. 2014), 184 experimental studies were examined. The study concluded that S3D imaging technology displayed an advanced level of performance in comparison to M3D imaging technology in 60% of cases. On the other hand, 15% of the remaining 40% were found to have ambiguous and complex results, and the remaining 25% were found to have ineffective results.

There have been numerous studies conducted in the field of biology. In a study conducted among 144 eighth-grade students, Remmele et al. (Remmele et al. 2015) compared the effectiveness of S3D and M3D technologies in the educational process. Their findings pointed to the conclusion that S3D visualisations are more effective in teaching complex and abstract knowledge about the internal structure of the human nose. Similarly, in a study conducted among high-school students within the scope of biology courses, the subjects of brain function and human anatomy were taught by means of S3D materials (Ferdig et al. 2015). Data obtained from both studies point to a significantly large difference between the achievement test means gained by the students from the group in which S3D materials were used, and those from the control group. Research conducted by Mississippi Medical Centre University focussed on whether or not S3D models constituted an effective educational material in teaching the vascular anatomy of the head and neck (Cui et al. 2016). In another study, Jang et al. (Jang et al. 2017) taught one group of students in a 3D virtual reality environment, and another group by means of 2D passive images. At the end of the study, when comparing the academic achievements of both groups, the researchers clearly indicated that based on analysis of the participants' comments on the 3D virtual reality environment, those students in the 3D group were more capable of interpreting complex anatomic structures than participants from the 2D group.

However, there are also studies which assert the opposite of these findings. For instance, in Liu and Chai's (Liu and Chai 2012) study conducted within the scope of children's safety education, the researchers utilised both 3D and 2D animations, and then interpreted the results comparatively. Having taken the cognitive levels of young children into consideration, the authors concluded that 2D animations composed of 2D cartoons were more suited to children's safety education compared to the 3D animations. In view of these conclusions, it may be inferred that the subject of experimental studies and the cognitive features of the target populations can affect the studies' conclusions. In another exemplary experimental study conducted among 129 biology students over a 2-year period, researchers examined the effectiveness of both M3D and S3D learning environments in view of students' learning outputs (Richards and Taylor 2015). In their study, 2D models were developed using the NetLogo program, while the 3D models were developed using the Unity3D program. Data obtained from the study demonstrated that the 2D virtual environments proved to be more successful than the 3D models since they were less complex and less distracting.

Considering the studies conducted in Turkey, it is observed that 2D animations have been used more within the educational context. It is therefore clear that there is a need for studies to be carried out regarding the use of S3D applications. In view of the previous research conducted in the field of education regarding the use of M3D and S3D imaging methods, it is observed that the studies were designed based on the experimental design method, and also that they were conducted mostly in areas which require the use of visuals such as biology, geography, and in medicine. It is also observed that studies have been conducted with S3D visualisation technologies either for subjects in which learning difficulties have been encountered, or for those involving complex abstract concepts. The findings from these studies are therefore seen as a guiding tool for educators and for experts whose aim is to develop the learning process so that it is easier and more comprehensible. It is emphasised that, in comparison to the M3D visualisation technique, the S3D visualisation technique has been proven to be the more effective. However, it is also stated that these findings vary according to the cognitive features of the target population and also based on the subject of the studies being conducted.

2.3 Research problems

The objective of this research is to examine the utilisation of M3D and S3D animations in teaching 'The Shape and Movements of the Earth' unit of ninth-grade Geography in Turkey from the aspect of the students' academic achievements and their opinions. The primary research problem that guided the current study, and its associated sub-problems, are detailed as follows.

Research Problem: Were there any significant differences between the academic achievements and opinions of students having received education by means of M3D (2D) animations and those who experienced the same teaching process by means of S3D animations?

Research Sub-problems:

(1) Were there any significant differences between the academic achievement of the control group's students taught using M3D animation, and those of the experimental group taught using S3D animation for 'The Shape and Movements of the Earth' unit in the Turkish ninth-grade Geography course, prior to the application of the procedure?

(2) Were there any significant differences between the academic achievement of the control group's students taught using M3D animation, and those of the experimental group taught using S3D animation for 'The Shape and Movements of the Earth' unit in the Turkish ninth-grade Geography course, after the application of the procedure?
(3) Were there any significant differences between the students' pre-test and post-test scores with regard to levels of academic achievement of the control group who were taught using M3D animation for 'The Shape and Movements of the Earth' unit in the Turkish ninth-grade Geography course?
(4) Were there any significant differences between the students' pre-test and post-test scores with regard to levels of academic achievement of the experimental group who were taught using S3D animation for 'The Shape and Movements of the Earth' unit in the Turkish ninth-grade Geography course?
(5) What are the opinions of the control group's students who were taught using M3D animation in terms of animation utilised as a teaching method?
(6) What are the opinions of the experimental group's students who were taught using S3D animation in terms of animation utilised as a teaching method?
(7) What are the opinions of the M3D group's students with regard to the M3D animation utilised in the study?
(8) What are the opinions of the S3D group's students with regard to the S3D animation utilised in the study?

3 Methodology

3.1 Research design

The Explanatory Sequential Mixed Design, which is one of the mixed research methods involving both quantitative and qualitative methods, was utilised in the current study. Creswell (Creswell 2013) reported that the intent of this method was to generate more detailed explanation or exemplification of quantitative data by supporting it with qualitative data. The quantitative part of this research was designed based on the pre-test–post-test control group semi-experimental design (Fraenkel et al. 2012) (see Table 1). The qualitative part of the study is comprised of the qualitative data obtained from the Structured Interview Form, including open-ended questions applied to the students at the end of the procedure. In addition, data obtained from the M3D and S3D Animation Rubric and Animation Opinion Scale was collected at the end of the procedure in order to support the experimental design.

3.2 Participants

The study's participants were students studying at four randomly chosen classes from the ninth grade of a foundation school in Turkey. Out of these four classes, two were randomly selected as the control group, while the other two were assigned as the experimental group. However, the selection of students within these groups was not random. Both groups consisted of 33 students.

Table 1 Pre-test–post-test control groups design

Group	Pre-test	Procedure	Post-test
E (Experimental)	O_1	X	O_3
C (Control)	O_2	Y	O_4

E Experimental group (group taught with S3D animation), C Control group (group taught with M3D animation), X S3D animation (independent variable), Y M3D animation (independent variable), O_1 and O_3: Pre-test and post-test measurements of the experimental group, O_2 and O_4: Pre-test and post-test measurements of the control group

There were 14 female and 19 male students in the control group. Of these students, more than half ($n = 19$) stated that they used computers for an average of 1–3 h per day, while 11 stated that they used computers for an average of 3–5 h per day. A much smaller number of students ($n = 3$) stated that they used computers for an average of 5–7 h per day. In terms of their computer skills, nearly all of the students in the control group ($n = 31$) stated that they had advanced computer skills.

In view of the demographic data obtained from the experimental group, 13 of the students were female and 20 were male. While nearly half of these students ($n = 16$) stated that they used a computer for an average of 1–3 h per day, 13 stated an average of 3–5 h per day; and the remaining four were recorded as having used a computer for an average of 5–7 h per day. Similar to the control group, nearly all of the students ($n = 32$) within the experimental group stated that they had advanced computer skills.

All of the students within both groups had previously had the opportunity of viewing M3D and S3D animations. Equally, all had also previously watched 3D movies at the cinema prior to the commencement of the study.

3.3 Designing of the learning environment

The foundation of the current study was having witnessed the difficulties encountered by some students in learning concepts which required them to form mental images in 'The Shape and the Movements of the Earth' unit, which forms part of the ninth-grade Geography course in Turkey. A literature review was then conducted, and the requirements of the study subsequently identified with experts from the subject field. It was decided that 3D animations, which were perceived as being of help to the students for comprehending the movements of the world in 3D, would be developed for the study.

First of all, the content of the 3D animation to be developed was determined. A scenario was then created by two subject matter experts, one education technologist and one design expert, along with a hardware technician for the unit to be taught to ninth-grade students by taking into account the learning outcomes of the unit, the students' levels of attendance, and the features of the 3D programs to be used. The learning outcomes of the 'Natural Systems' learning environment forms part of the Turkish Ministry of National Education's ninth-grade curriculum (Ministry of National Education 2018).

Programs that can be used for the development of 3D animations were then examined, and the Autodesk 3DS Max[1] and Maya[2] programs were found to be fit for the intended purpose. The latest free-for-student versions of the programs were utilised. The user-friendly interfaces and the amount of available resources (e.g., videos, books) were primary reasons behind the selection of these programs. Furthermore, the multiple plug-ins of these programs allowed them to serve a wider range of fields. While the drawing of the 3D models was performed using the Autodesk 3DS Max program, the Autodesk Maya program was preferred for bringing the 3D models into motion, and then for converting them into animations.

First saved in .jpg format, the 3D models and moving animations created in these programs were then converted to video format using the Adobe After Effects program. Sound and subtitle effects were then added to the animation in video format. Development of the material took a total of 12 weeks (see Fig. 1). The animation was then tested in its finalised form by a group of Geography teachers in M3D and S3D environments; and the developed 3D content was then revised in consideration of the feedback received. The duration of the animation was 12 min.

3.4 Data collection tools

The academic achievement test consisted of 10 questions based on the learning outcomes of the selected unit. The test was prepared by a group of Geography teachers as well as evaluation and assessment experts on the basis of the subject field, the unit's learning outcomes and assessment principles, and was then applied to both groups as a pre-test at the beginning of the study. A total of 502 students took the pre-test procedure for the validity and reliability testing of the achievement test, and the confidence coefficient of the scale was calculated as being $\alpha = .78$. Item analysis was then carried out in order to ensure the validity of the achievement test (see Appendix A). According to the results of the analysis, the distinction coefficient of the 10 problems in the test ranged from .54 to .80. The distinction coefficient is expected to be.30 or greater than .30 (Büyüköztürk 2007). In the current study, the reliability coefficient of the scale applied to the 66 students from both groups was calculated as being $\alpha = .68$. Furthermore, the opinions of four experts (two content experts, plus two evaluation and assessment experts) were sought in order to ensure the content and appearance validity of the test. Based on the feedback received, no further changes were applied to the test.

The Animation Opinion Scale (AOS) was developed by Daşdemir (Daşdemir 2006). Consisting of 18 Likert-type rated scale items (1 = I definitely do not agree, 2 = I do not agree, 3 = I partially agree, 4 = I agree, 5 = I definitely agree). The scale was used by Daşdemir (Daşdemir 2006) in order to determine the opinions of primary school students regarding the teaching of science courses with animation. The reliability coefficient of the scale was calculated as being $\alpha = .82$. Permission was obtained from the scale's developer for it to be used within the current study. Prior to applying the scale, a pre-procedure was conducted with 120 students studying in the ninth grade, and the reliability coefficient of the scale was calculated as being $\alpha = .83$. The scale was then applied to the 66 students from both study groups (experimental and control), and

[1] https://www.autodesk.com/products/maya/overview
[2] https://www.autodesk.com/products/3ds-max/overview

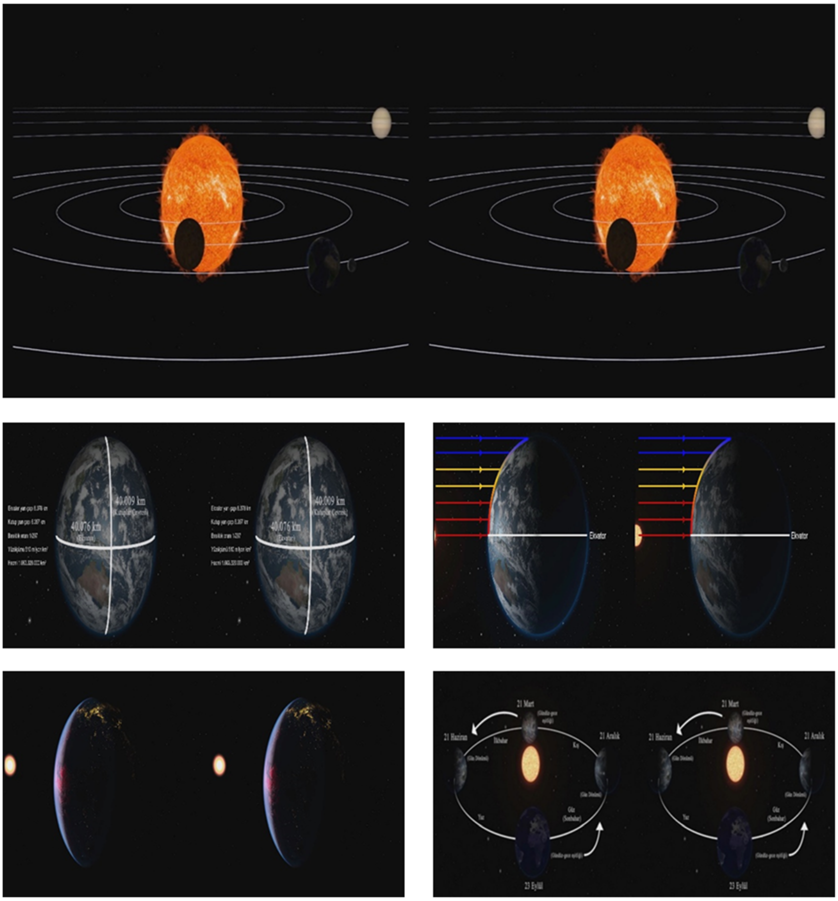

Fig. 1 Animation screenshots

the reliability coefficient of the scale was calculated as being $\alpha = .82$. Scoring was made in the form of 1 = 'I definitely do not agree' and 5 = 'I definitely agree' for the items consisting of positive statements, and reversely for negative items.

The rubric was developed in consideration of both expert opinion and the related literature (see Appendix B). The rubric was designed to evaluate the learning environment and the process that constructed the M3D animation for the control group, and the S3D animation for the experimental group. In the rubric, which consisted of 14 statements, participants' opinions were sought with regard to the statements as 'High Quality', 'Medium Quality', or 'Low Quality'. The M3D and S3D animation rubrics were applied to each respective group after being taught with animation (M3D for the control group; S3D for the experimental group).

Finally, in order to obtain in-depth data, a Student Interview Form was developed by the researcher that included open-ended questions based on the objective of the research and the related literature (see Appendix C). This form consisted of questions intended to reveal the participant students' opinions with regard to teaching geography with M3D and S3D animations, whether or not these animations increased their motivation, and their opinions about the developed materials. The aim of the interview form was to support the quantitative data with qualitative data, and thereby to facilitate a more in-depth analysis. Following the development of the form, experts from the Computer Instruction and Educational Technologies department, Evaluation and Assessment, and Educational Programmes and Teaching were consulted and the form finalised in accordance with their expert feedback. The form contained a total of nine open-ended questions in its finalised form, and was applied to the both study groups at the end of the study.

3.5 Data collection and procedure process

The experimental and control groups were determined during the pre-study phase. Both groups were then applied the achievement test as a pre-test with the classroom environment where the researcher was present. As the procedure phase, which followed the pre-test, the subject titled 'The Shape and Movements of the Earth' was presented to both groups by the same teacher within the classroom environment. This was followed by the presentation of the 3D educational content developed within the scope of the current study. The control group were shown animations developed in the M3D environment, and the experimental group were shown S3D-developed animations. For the control group, the M3D media content was displayed using a projector in the classroom, while the S3D media was presented using 3D active shutter glasses together with 3D projection.

In the subsequent post-study phase, the achievement-test was reapplied as a post-test to both study groups in the classroom environment, again with the researcher present. In addition to the achievement test, the Animation Opinion Scale (AOS) was applied to both study groups in order to garner student opinion with regard to the teaching they had received utilising the developed animation. In addition, the M3D and S3D animation rubrics were applied to the respective study groups in order that the students could evaluate the 3D educational content. Finally, the Structured Interview Form was applied in order to attain in-depth opinions from the students concerning the learning process. The procedure and data collection process lasted a total of 4 weeks.

3.6 Data analysis

An independent sample *t*-test was implemented in order to determine whether or not the two study groups differed in their respective pre-tests and post-tests (Büyüköztürk et al. 2017; Field 2009; Gravetter and Wallnau 2016). Subsequently, both groups were examined by means of a dependent sample *t*-test on whether or not they showed any significant difference in their pre-test and post-test mean scores. The IBM SPSS (version 13.0) statistics program was used for the analysis of the data. The significance level was set as .05 for the analysis. When taking into account the Skewness and Kurtosis values of the data before proceeding with the statistical analysis, the data were found to be distributed normally (Skewness: −.07; Kurtosis: −.70). While the values for the pre-test and post-test were identified as Skewness = −.08 and Kurtosis = −1.00 for the control group, the values for the experimental group were identified as Skewness = −.01 and Kurtosis = −.80. Furthermore, according to the Kolmogorov-Smirnov test results, all data were identified as showing normal distribution ($p > .05$) for both the pre-test and post-test.

Findings with regard to the AOS, as well as the M3D and S3D Animation Rubrics were interpreted descriptively with their mean, percentage, and frequency values. Data collected through the Structured Interview Form's application were analysed using the content analysis method. When analysing the content of the study, codes were determined based on the literature related to the research problem, and themes deemed to be suitable for these codes were established (Miles and Huberman 1994; Yıldırım and Şimşek 2008). The data was then examined in terms of these themes. In order to ensure the reliability of the data, the researcher twice coded the data obtained from the interview form with a 1-week interval, and then calculated the 'time-reliability' of the coding. The coding reliability was thereby calculated as being .75. Interrater reliability using the Cohen's Kappa value was calculated as being .85 in the study. With this method, another researcher with expertise in qualitative research coded the data, and then the relation between the two coders was examined.

4 Findings

4.1 Findings related to academic achievement

Dependent and independent sample *t*-test results for academic achievement are shown in Table 2.

As a result of the independent sample *t*-test for pre-test, although the pre-test academic achievement test mean scores of the students in the experimental group were higher ($\overline{X}_2 = 5.42$, $SD_2 = 2.26$) than those of the control group ($\overline{X}_1 = 4.42$, $SD_1 = 2.66$), the difference between the achievement test mean scores of both groups in the pre-test was not found to be significant, $t(64) = -1.64$, $p = .10$. For the independent sample *t*-test for post-test, the difference between the achievement test mean scores of the groups in the post-test was significant, $t(64) = -2.56$, $p = .01$. In terms of the achievement test mean scores, the students in the experimental group ($\overline{X}_2 = 6.94$, $SD_2 = 2.60$) were more successful than those in the control group ($\overline{X}_1 = 5.45$, $SD_1 = 2.09$). The standard effect

Table 2 Independent sample t-test findings for The Shape and Movements of the Earth Unit Academic Achievement Test

Groups	*N*	$\overline{X}$	*SD*	*t*-test		*d*
				t	*p*	
M3D (Pre-test)	33	4.42	2.66	−1.64	.10	
S3D (Pre-test)	33	5.42	2.26			
M3D (Post-test)	33	5.45	2.09	−2.56	.01	.63
S3D (Post-test)	33	6.94	2.60			
M3D (Pre-test)	33	4.42	2.66	−2.09	.04	.43
M3D (Post-test)	33	5.45	2.09			
S3D (Pre-test)	33	5.42	2.26	−2.76	.01	.62
S3D (Post-test)	33	6.94	2.60			

size value was calculated as $d = .63$ using Cohen's 'd' formula. This value indicates that the impact value was at the medium level (Green and Salkind 2013).

As seen from the results of dependent sample *t*-test in Table 2, there was a statistically significant difference found between the control group students' pre-test and post-test means in the achievement test of the unit, $t(32) = -2.09$, $p = .04$. The post-test mean scores ($\overline{X}_{post} = 5.45$, $SD_{post} = 2.09$) of the students which were taught the unit in Geography course with M3D animation were higher than their pre-test mean scores ($\overline{X}_{pre} = 4.42$, $SD_{pre} = 2.66$). The standard effect size value was calculated as Cohen's $d = .43$ being closer to a medium level. Also there was a statistically significant difference found between the experimental group students' pre-test and post-test mean scores in the achievement test of the unit, $t(32) = -2.76$, $p = .01$. The post-test mean scores ($\overline{X}_{post} = 6.94$, $SD_{post} = 2.60$) of the students which were taught the unit in Geography course with S3D animation were higher than their pre-test mean scores ($\overline{X}_{pre} = 5.42$, $SD_{pre} = 2.26$). The standard effect size value was calculated as Cohen's $d = .62$ at a medium level.

4.2 Students' post-procedure opinions with regard to teaching with M3D and S3D animations

The Structured Interview Form consisted of open-ended questions, and was applied separately to both study groups. While the control group students were asked their opinions about the M3D animations, the experimental group students were asked for their opinions regarding the S3D animations. As a result of the content analysis, the opinions of both groups were collated under three themes.

- Learning with M3D and S3D animations.
- Strengths and weaknesses of the M3D and S3D animations.
- Utilisation of M3D and S3D animations in other disciplines.

4.2.1 Learning with M3D and S3D animations

The majority of the control group students stated that the course was 'more enjoyable' (74%). However, there were also students who thought that the course was 'partly more enjoyable' (14%), or 'not enjoyable at all' (12%). On the other hand, nearly all of the experimental group students stated that the course was 'more enjoyable' (91%), whilst only a few (9%) found it 'partly enjoyable'. One student's opinion on this subject was as follows:

"I can say that the lesson we take with two-dimensional animation is fun. It also made it easier for me to learn the lesson. (S7)".

Another question was whether or not the M3D and S3D animations facilitated the students' learning, and thereby contributed to their learning process, and whether or not they had any impact on their motivation. While 83% of the control group students stated that these animations facilitated their learning, 73% stated that they contributed to their learning, and 65% stated that they increased their motivation. On the other hand, while almost all (91%) of the experimental group students stated the S3D animations facilitated and thereby contributed (97%) to their learning, 83% stated that they increased their motivation. One student's opinion on this subject was as follows:

"S3D animations really facilitated my learning, contributed to my learning and increased my motivation. I really enjoyed learning with S3D animation, because the subjects were very abstract and made me see them as if they were real life. (S12)".

4.2.2 Strengths and weaknesses of the M3D and S3D animations

The students in both study groups positively expressed certain common features of the animations, including the 'design of the content', the 'visuals', the 'flow', and the 'music' that was used. 'Enjoyable', 'facilitates and reinforces the learning experience', 'comprehensible', and 'appealing to various senses' were also defined as common positive qualities. The control group students mentioned the 'sound quality', the 'effects', and the 'voiceover' as features that could be improved upon. The experimental group students, on the other hand, mentioned the 'effects', and the 'duration' as features that could be improved. The students were then asked to score some of the animations' features by means of the M3D and S3D animation rubric. The findings are summarised in Table 3.

According to Table 3, in both groups, related to content, explanatory and colour coherence features of animations were expressed as high quality. Reinforces learning, facilitates learning, text quality/legibility, sound quality, sound matching, utilises graphics and image transitions features of animations were expressed as high or medium quality. Engages attention/arouses interest, relevant to daily life, close to reality were expressed as medium or low quality. "Duration" was specified as high quality for M3D animation, and medium or low quality for S3D animation. "Close to reality" was a low quality feature that needed to be developed for M3D animation,

Table 3 Scores of control and experimental group students for M3D and S3D animations' features

Group *Grading feature*	Control / Experimental *High quality*	Control / Experimental *Medium quality*	Control / Experimental *Low quality*
Related to content	30 / 30	2 / 3	1 / -
Reinforces learning	21 / 16	9 / 16	3 / 1
Facilitates learning	24 / 21	7 / 12	2 / -
Explanatory	27 / 24	5 / 8	1 / 1
Engages attention/arouses interest	10 / 13	15 / 13	8 / 7
Duration	28 / 10	4 / 17	1 / 6
Relevant to daily life	5 / 13	17 / 14	11 / 6
Close to reality	1 / 19	21 / 14	11 / -
Text quality/legibility	17 / 25	10 / 6	6 / 2
Colour coherence	27 / 24	4 / 7	2 / 2
Sound quality	21 / 19	8 / 13	4 / 1
Sound matching	21 / 19	7 / 11	5 / 3
Utilises graphics	23 / 26	9 / 6	1 / 1
Image transitions	25 / 24	7 / 8	1 / 1

while it was seen as a high quality feature for S3D animation. These results revealed the difference of the two animations.

4.2.3 Utilisation of M3D and S3D animations in other disciplines

Opinions varied with regard to the utilisation of the M3D and S3D animations in other disciplines. In view of the common answers given by students from both of the study groups, it was concluded that such animations should be used in biology and history courses, followed by physics, chemistry, and mathematics. A small number of students mentioned other social sciences subjects, along with foreign language courses. The utilisation of S3D animations in physical education, religious culture and literature were also suggested by a small number of students. Two students gave their opinions on this subject as follows:

"I think these animations can be used most in biology and history classes. Because there are difficult issues to envision. (S5)".

"It can be used in biology and history courses, as well as in hard-to-understand courses such as physics, chemistry and mathematics. (S17)".

4.3 Opinions of students on animations used in the procedure

Results of the descriptive analysis of the answers given by the 33 students in both groups (66 in total) to the AOS are presented in Table 4.

In Table 4, the mean value of the questions to which the students responded positively is above 3. This means that the majority of students in both groups had common positive opinions with regard to the animations used during the procedure. On the other hand, experimental group's students delivered more positive opinions than the control group's students in terms of their expressions on the subjects taught with animations. These course subjects engaged their interest more. The experimental group's students also had more positive opinions on animations that make them think in more detail and help them to think creatively. Additionally, the control group's students had more positive opinions than those from the experimental group in terms of their expressions that animations should always be used in geography courses. They also thought that learning with animations was not boring, animations did not cause disruption in the course and did not create learning difficulties.

In summary, the students had both common positive opinions as well as different opinions on learning with M3D and S3D animations, and about the animations themselves. This difference arose from the impact of the S3D animations on the students, thanks to the visualisation technology applied, and the realistic visual experience that presenting a 3D sense of depth, which is in line with the ever-increasing developments in technology. In view of the demographical characteristics of the students from both groups, there are significant similarities to be seen. It was determined that it was not the first time both groups had watched S3D animations, a new visualisation technology, and that they had prior experience with M3D and S3D visualisation technologies predating the procedure. It was also observed that the students described their computer skills as advanced. All of the students previously had the opportunity to watch 3D movies. Nevertheless, it appears that their opinions differed according to their current experiences.

Table 4 Opinions of control and experimental group students on animation

Group	Control/ Experimental	Control/ Experimental
Scale items	$\overline{X}$	*SD*
1. The subjects covered engaged my interest more.	3.73/4.45	1.33/.75
2. Animations helped me solve subject-related questions.	3.73/3.85	1.01/.97
3. Utilisation of animations made me think about the subject in more detail.	3.55/4.09	1.28/.76
4. Utilisation of animations encouraged me to investigate further.	3.03/3.12	1.36/1.16
5. The animations made me like the geography course.	3.27/3.63	1.40/1.29
6. Animations should be utilised in geography courses all the time.	4.42/4.24	.97/1.09
7. Animations should be utilised in other courses, too.	4.33/4.69	.92/.63
8. Utilisation of animations helped me focus on the subject.	3.70/3.97	1.21/.98
9. I enjoyed the subjects taught with animations very much.	3.58/4.18	1.20/.88
10. It is great to be taught the course using animations.	4.30/4.51	1.10/.75
11. Utilisation of animations helped me think creatively.	3.72/4.33	1.33/.82
12. I was unable to learn the subjects taught because the animations were very complicated.	.49/.67	.67/.69
13. Utilisation of animations in courses is very useful.	4.48/4.54	.87/.66
14. Animations helped me comprehend the course better.	3.88/4.00	1.27/1.03
15. Learning with animations is boring.	.24/.43	.56/.66
16. The utilisation of animations caused disruption in the course.	.10/.58	.29/.66
17. Utilisation of animations made it difficult to comprehend the subjects being taught.	.12/.37	.33/.55
18. Animations should not be utilised in geography courses.	.09/.21	.29/.48

5 Conclusions

5.1 Academic achievements of students taught with M3D and S3D animations

According to the result of the pre-test conducted prior to the application of the procedure, it was determined that the difference between the achievement test of the control and experimental groups was not found to be statistically significant. Accordingly, it may be concluded that the preliminary knowledge of both groups was equal.

In view of the findings attained from the independent sample *t*-test related to the post-test conducted after the application of the procedure, a significant difference in favour of the experimental group was found to exist between the achievement test of the control and experimental groups. Similar results can be seen in the relevant literature (Jang et al. 2017; Remmele et al. 2015; Wu and Chiang 2013). In a meta-analysis study conducted in this field (McIntire et al. 2014), the impact of S3D imaging technologies on academic performance was found to be greater than that of M3D in more than half the 160 publications reviewed. Based on these results, it may be concluded that S3D animations not only provide the opportunity for abstract concepts to be viewed in a concrete fashion, but also offer an effective learning environment that positively impacts on students' academic achievement in comparison to the use of M3D animations, as well as their opinions concerning teaching with animations.

However, there are also studies that present opposing findings. In the study conducted by Liu and Chai (Liu and Chai 2012), it was concluded that 2D animations were more appropriate than 3D animations for use in safety education for young children, and Richards and Taylor (Richards and Taylor 2015) concluded that 2D animations were more effective for students on a biology course. Based on these results, it may be concluded that S3D animations are complex and difficult for young children and also that it will not provide an effective learning environment for every subject. It may further be concluded, within the context of the current study, that its utilisation for students from older age groups may be effective in yielding positive findings with regard to M3D.

Dependent sample *t*-test was used to determine whether or not there was a significant difference in the academic achievements of students in the control group for the geography course unit in view of their pre-test and post-test scores. As a result of the analysis, it was determined that there was a statistically significant difference between the pre-test and post-test mean scores. Similarly, it was determined that there was a statistically significant difference between the pre-test and post-test mean scores of the experimental group's students.

Upon review of the relevant literature, it became apparent that similar studies have revealed positive effects of teaching with animation based on students' academic achievements. Çepni et al. (Çepni et al. 2006) stated that computer-assisted teaching materials applied to biology courses positively affected the academic achievements of primary school students. Daşdemir and Doymuş (Daşdemir and Doymuş 2012) revealed that animations prepared for teaching the movement and force unit in eighth-grade primary school classes had a positive effect on the students' academic achievement, the lasting quality of the knowledge they acquired, and on their scientific process skills. Based on these results, it may be concluded that M3D animations are helpful for students during the learning process.

5.2 Students' opinions concerning teaching with M3D and S3D animations, and animations utilised in the procedure

The significant difference between the achievement test mean scores of the two study groups was reinforced by their opinions gathered after the procedure's application with regard to the M3D and S3D animations. Although it was higher in the experimental group, AOS revealed that students from both groups have positive opinions about animation. The findings obtained from the AOS and those obtained from the Structured Interview Form and Animation Rubric appear supportive of each other. From a review of the opinions of the participant students with regard to having been taught using M3D or S3D animations, there were opinions supporting the significant differences seen between the achievement test mean scores of the two study groups in favour of those taught with S3D animation. As a result of the content analysis, the opinions of both groups were collected under three themes; namely, opinions about learning with M3D and S3D animations, the strengths and weaknesses of animations, and the utilisation of animations in other disciplines. Upon comparison of these opinions, while the opinions of experimental and the control group's students were similar, it was seen that opinions of experimental group's students using S3D animation were the more positive. In other words, while almost all of the experimental group's students stated that teaching with S3D animation made the course more enjoyable, a few of the control group's students stated that the course was 'partly more enjoyable' or 'not enjoyable at all'. Similar results were also found in the opinions delivered with regard to motivation towards the course. Almost all of the experimental group's students stated that S3D animations facilitated and contributed to their learning and increased their motivation.

Additionally, in order to support these views, the students were also asked to score some of the features of the animation utilised in the procedure by means of the M3D and S3D animation rubrics. Having compared the mean scores of the two study groups, the experimental group's students were found to have scored the items higher on mean than the control group's students especially with regard to the "close to reality". In reviewing the relevant literature, the published studies are noted to have been conducted over a long period, and concentrated mostly on fields where the feature of "close to reality" is important such as medicine, geography, and robotics. French (French 1974) stated that the use of monoscopic media in geographic models caused impairment in the structure of maps; therefore, stereoscopic media was preferable in order to overcome this deficiency. Similarly, studies conducted in the field of medicine point to S3D media environments causing an increase in participants' spatial visualisation skills (i.e., (Anastakis et al. 2000; Brandt and Davies 2006; Roche et al. 2012)).

Studies conducted at the K-12 level, on the other hand, seem to be limited mainly to the comparison of 2D and 3D media (i.e., (Akıllı and Seven 2014; Günter et al. 2011; Mayer and Gallini 1990)). For instance, in an experimental study conducted in the field of mathematics teaching, sixth-grade students were taught the subject of prisms in a mathematics course using 3D software (Şimşek and Yücekaya 2014). Although the results of their study showed no significant difference found between the groups in terms of their Spatial Skill Test scores, the experimental group's students reported that the 3D program made their learning not only easier, but also more enjoyable and interesting.

Finally, opinions of the current study's students regarding the utilisation of 3D animations in other disciplines were also obtained. Both of the groups indicated that the animations could also be used for biology and history courses. In addition, the students supported the use of animations in physics, chemistry, and also in mathematics. Subsequent studies may therefore focus on the impact of S3D technologies across different academic subjects with certain variables such as academic achievement, motivation, spatial visualisation skills, and mental rotation skills.

6 Suggestions

6.1 Suggestions for researchers

Content is an important issue that has to be taken into consideration when deciding on whether or not to use S3D or M3D animations in teaching. Of course, it may not be possible to teach all content by means of animation. The use of S3D visualisation technologies may also lead to confusion and learning difficulties if applied to younger or less experienced students. At the decision stage, the aim should be to create an effective learning process that utilises the available imaging technologies. Another suggestion is to use S3D technologies in other disciplines within the field of education. Educators and experts from different disciplines should be encouraged to conduct studies regarding the utilisation and effects of the technology in question. To date there has been limited research published with regard to S3D visualisation technologies, and future research in this area should therefore be supported and accelerated.

6.2 Suggestions for developers of S3D visualisation technology

In terms of computer-aided teaching materials, the needs, challenges, and particularly the available physical resources must be taken into consideration in the utilisation of M3D and S3D animations. These indicated points should form the focus of future studies conducted in this field.

It can be observed that studies conducted on technology utilisation in education have focused more on M3D visualisation technologies than S3D. However, S3D visualisation technologies, which are capable of delivering high resolution images, are now able to present images very close to real-life, thanks to the sense of depth made possible by today's advanced technologies. It is also possible to convert M3D animations to S3D, and vice versa, with the aid of conversion software. However, this process may result in certain losses, especially in the sense of depth. It would therefore be inappropriate to consider the S3D and M3D visualisation technologies as being alternatives to each other. Instead, material should only be developed using the design capabilities of suitable programs.

As a relatively new visualisation technology, information available in the literature regarding S3D visualisation technology is currently inadequate. Studies regarding its utilisation in the field of education are almost non-existent, with the related high costs a possible cause in addition to the technology's newness. However, having been introduced into our homes, and thereby becoming more widely utilised, this has resulted in S3D visualisation technology becoming cheaper. In this regard, studies on the utilisation of S3D imaging technologies in the field of education should now also become more commonplace.

The physical space in which S3D animations are to be utilised should be appropriately designed. That is, the distance between the viewers and the image, as well as the arrangement of seating are important factors. Failure to observe such physical requirements may lead to S3D visualisation technology not being able to fully convey the intended sense of depth to its viewers. In this respect, the relevant literature should be judiciously examined and this process meticulously planned.

Educational institutions could organise in-service training programmes for the development of S3D animations, so that this visualisation technology can be integrated more quickly into the respective fields of education.

7 Limitations

The research was limited to a sample group of 66 students, 10 multiple-choice test questions, the selected measurement tools applied, the procedure and data collection process lasting for 4 weeks, and 'The Shape and Movements of the Earth' unit of the Turkish curriculum's ninth-grade Geography course.

Appendix A. (Item analysis of the achievement test)

2015–2016 Academic Year Ninth Grade Geography Course 1. Semester 2. Written Exam - 16/12/2015

Question	Being Answered	Distinctiveness	Option	Being Answered	Double Point Double	
–	–	–	A	0.039	−0.289	−0.126
–	0.768	0.654	* B	0.768	0.654	0.472
1	–	–	C	0.084	−0.433	−0.241
–	–	–	D	0.081	−0.464	−0.255
–	–	–	E	0.026	−0.589	−0.224
–	–	–	A	0.285	−0.548	−0.412
–	–	–	B	0.029	−0.604	−0.238
2	–	–	C	0.014	−0.416	−0.126
–	–	–	D	0.041	−0.444	−0.197
–	0.629	0.736	* E	0.629	0.736	0.576
–	–	–	A	0.012	−0.412	−0.118
–	–	–	B	0.041	−0.513	−0.227
3	–	–	C	0.130	−0.615	−0.387
–	0.790	0.702	* D	0.790	0.702	0.497
–	–	–	E	0.026	−0.229	−0.087
–	–	–	A	0.220	−0.374	−0.267
–	–	–	B	0.130	−0.380	−0.239
4	0.495	0.630	* C	0.495	0.630	0.503
–	–	–	D	0.061	−0.450	−0.227
–	–	–	E	0.086	−0.042	−0.023
–	–	–	A	0.010	−0.390	−0.104
–	–	–	B	0.077	−0.368	−0.199
5	–	–	C	0.016	−0.395	−0.126
–	0.695	0.568	* D	0.695	0.568	0.432
–	–	–	E	0.198	−0.426	−0.298
–	0.458	0.543	* A	0.458	0.543	0.432
–	–	–	B	0.291	−0.478	−0.361
6	–	–	C	0.026	−0.180	−0.068
–	–	–	D	0.063	−0.313	−0.159
–	–	–	E	0.159	−0.002	−0.001
–	–	–	A	0.057	−0.457	−0.226
–	–	–	B	0.016	−0.235	−0.075
7	0.764	0.590	* C	0.764	0.590	0.428

Question	Being Answered	Distinctiveness	Option	Being Answered	Double Point Double	
–	–	–	A	0.039	−0.289	−0.126
–	–	–	D	0.094	−0.262	−0.151
–	–	–	E	0.065	−0.594	−0.306
–	–	–	A	0.071	−0.477	−0.252
–	0.635	0.636	* B	0.635	0.636	0.496
8	–	–	C	0.061	−0.325	−0.164
–	–	–	D	0.191	−0.430	−0.298
–	–	–	E	0.039	−0.186	−0.081
–	–	–	A	0.006	−0.349	−0.077
–	–	–	B	0.041	−0.357	−0.158
9	0.778	0.557	* C	0.778	0.557	0.399
–	–	–	D	0.136	−0.483	−0.307
–	–	–	E	0.037	−0.276	−0.118
–	0.585	0.799	* A	0.585	0.799	0.632
–	–	–	B	0.071	−0.440	−0.232
10	–	–	C	0.077	−0.461	−0.250
–	–	–	D	0.053	−0.327	−0.157
–	–	–	E	0.212	−0.504	−0.358

**Correct answer*

Appendix B. (M3D & S3D Animation rubric)

Rubric for the Evaluation of the Learning Environment and Process Constructed by the Monoscopic 3-Dimensional (2D) and Stereoscopic 3-Dimensional Animations

High quality		**Medium quality**		**Low quality**	
3		**2**		**1**	
The monoscopic 3D / stereoscopic 3D animation I viewed was related to “The Shape and the Movements of the Earth” unit.	□	The monoscopic 3D / stereoscopic 3D animation I viewed was partly related to “The Shape and the Movements of the Earth” unit.	□	The monoscopic 3D / stereoscopic 3D animation I viewed was not related to “The Shape and the Movements of the Earth” unit.	□
The monoscopic 3D / stereoscopic 3D animation I viewed reinforced my learning.	□	The monoscopic 3D / stereoscopic 3D animation I viewed partly reinforced my learning.	□	The monoscopic 3D / stereoscopic 3D animation I viewed was not reinforced my learning.	□
The monoscopic 3D / stereoscopic 3D animation I viewed facilitated my learning.	□	The monoscopic 3D / stereoscopic 3D animation I viewed partly facilitated my learning.	□	The monoscopic 3D / stereoscopic 3D animation I viewed was not facilitated my learning.	□
	□		□		□

High quality		**Medium quality**		**Low quality**	
I was able to comprehend the content of the monoscopic 3D / stereoscopic 3D animation I viewed.		I was able to partly comprehend the content of the monoscopic 3D / stereoscopic 3D animation I viewed.		I was not able to comprehend the content of the monoscopic 3D / stereoscopic 3D animation I viewed.	
The monoscopic 3D / stereoscopic 3D animation I viewed engaged my attention / aroused my interest towards the course.	□	The monoscopic 3D / stereoscopic 3D animation I viewed partly engaged my attention / aroused my interest towards the course.	□	The monoscopic 3D / stereoscopic 3D animation I viewed was not engaged my attention / aroused my interest towards the course.	□
The duration of the monoscopic 3D / stereoscopic 3D animation I viewed was sufficient for me to comprehend the subject.	□	The duration of the monoscopic 3D / stereoscopic 3D animation I viewed was partly sufficient for me to comprehend the subject.	□	The duration of the monoscopic 3D / stereoscopic 3D animation I viewed was not sufficient for me to comprehend the subject.	□
I was able to relate the monoscopic 3D / stereoscopic 3D animation I viewed with my daily life.	□	I was able to partly relate the monoscopic 3D / stereoscopic 3D animation I viewed with my daily life.	□	I was not able to relate the monoscopic 3D / stereoscopic 3D animation I viewed with my daily life.	□
The monoscopic 3D / stereoscopic 3D animation I viewed was close to reality.	□	The monoscopic 3D / stereoscopic 3D animation I viewed was partly close to reality.	□	The monoscopic 3D / stereoscopic 3D animation I viewed was not close to reality.	□
The quality / legibility of the text used in the monoscopic 3D / stereoscopic 3D animation I viewed was suitable.	□	The quality / legibility of the text used in the monoscopic 3D / stereoscopic 3D animation I viewed was partly suitable.	□	The quality / legibility of the text used in the monoscopic 3D / stereoscopic 3D animation I viewed was not suitable.	□
The colours used in the monoscopic 3D / stereoscopic 3D animation I viewed were coherent.	□	The colours used in the monoscopic 3D / stereoscopic 3D animation I viewed were partly coherent.	□	The colours used in the monoscopic 3D / stereoscopic 3D animation I viewed were not coherent.	□
The quality of the sound of the monoscopic 3D animation I viewed was high.	□	The quality of the sound of the monoscopic 3D / stereoscopic 3D animation I viewed was partly high.	□	The quality of the sound of the monoscopic 3D animation I viewed was not high.	□
The sound used in the monoscopic 3D / stereoscopic 3D animation I viewed was appropriate.	□	The sound used in the monoscopic 3D / stereoscopic 3D animation I viewed was partly appropriate.	□	The sound used in the monoscopic 3D / stereoscopic 3D animation I viewed was not appropriate.	□
The graphics used in the monoscopic 3D / stereoscopic 3D animation I viewed were appropriate.	□	The graphics used in the monoscopic 3D / stereoscopic 3D animation I viewed were partly appropriate.	□	The graphics used in the monoscopic 3D / stereoscopic 3D animation I viewed were not appropriate.	□
The image transitions in the monoscopic 3D / stereoscopic 3D animation I viewed were appropriate.	□	The image transitions in the monoscopic 3D / stereoscopic 3D animation I viewed were partly appropriate.	□	The image transitions in the monoscopic 3D / stereoscopic 3D animation I viewed were not appropriate.	□

Appendix C. (Student interview form)

Student Interview Form Intended for Monoscopic 3D (Dimensional) and Stereoscopic 3D (Dimensional) Animation and the Learning Environment

1) Was it enjoyable to learn with the monoscopic 3D / stereoscopic 3D (dimensional) animation about "The Shape and the Movements of the Earth" prepared for the geography course?
2) Did the monoscopic 3D / stereoscopic 3D (dimensional) animation about "The Shape and the Movements of the Earth" prepared for the geography course increase your motivation?
3) Do you think that the monoscopic 3D / stereoscopic 3D (dimensional) animation about "The Shape and the Movements of the Earth" prepared for the geography course contributed to your learning? Why?
4) Do you think that learning the subject was easier thanks to the correlation between the monoscopic 3D / stereoscopic 3D (dimensional) animation about "The Shape and the Movements of the Earth" prepared for the geography course and daily life?
5) Do you think that the monoscopic 3D / stereoscopic 3D (dimensional) animation about "The Shape and the Movements of the Earth" prepared for the geography course contributed to making more complex and difficult subjects easier to comprehend? Why? Explain.
6) Do you think that the monoscopic 3D / stereoscopic 3D (dimensional) animation about "The Shape and the Movements of the Earth" prepared for the geography course was helpful in converting abstract concepts into concrete ones?
7) Could you write down the strengths and weaknesses of the monoscopic 3D / stereoscopic 3D (dimensional) animation about "The Shape and the Movements of the Earth" prepared for the geography course?
8) In which other courses do you think the monoscopic 3D / stereoscopic 3D (dimensional) animation about "The Shape and the Movements of the Earth" prepared for the geography course may be utilized?
9) Would you like to be taught your future courses with the monoscopic 3D / stereoscopic 3D (dimensional) animations? Why? Explain.

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