

Drawing in a Virtual 3D Space - Introducing VR Drawing in Elementary School Art Education

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ABSTRACT

Drawing is an important part of elementary school education, especially since it contributes to the development of spatial skills. Virtual reality enables us to draw not just on a flat 2D surface, but in 3D space. Our research aims at showing if and how this form of 3D drawing can be beneficial for art education. This paper presents first insights into potential benefits and obstacles when introducing 3D drawing at elementary schools. In an experiment with 18 children, we studied practical aspects, proficiency, and spatial ability development. Our results show improvement in the children's 3D drawing skills but not in their spatial abilities. Their drawing skills also do seem to be correlated with their mental rotation ability, although further research is needed to conclusively confirm this.

CCS CONCEPTS

• **Human-centered computing** → *Human computer interaction (HCI)*; • **Applied computing** → *Education*;

KEYWORDS

Virtual Reality, Painting, Drawing, 3D, Spatial Visualization, Mental Rotation, Spatial Abilities, Children, Art education

ACM Reference Format:

Wendy Bolier, Wolfgang Hürst, Guido van Bommel, Joost Bosman, and Harriët Bosman. 2018. Drawing in a Virtual 3D Space - Introducing VR Drawing in Elementary School Art Education. In *2018 ACM Multimedia Conference (MM '18)*, October 22–26, 2018, Seoul, Republic of Korea. ACM, New York, NY, USA, 9 pages. <https://doi.org/10.1145/3240508.3240692>

1 INTRODUCTION

Brody and Hartman [11] stated that: “Painting in space, unfettered by gravity or a matrix to hold the paint, is like painting in a world

of pure imagination.” Virtual reality (VR) tools enable us to introduce this way of 3D drawing to children at elementary schools. Possible benefits include that they get acquainted with new technologies, new ways to create art, and that it might encourage them to draw more often. This is desirable as drawing has many benefits related to creativity, memory, problem solving skills, and mental health [12, 16, 23, 41]. Furthermore, research suggests that both the drawing of 3D objects and the usage of VR can be beneficial for the improvement of spatial abilities, which are essential cognitive abilities used to interpret incoming visuo-spatial information [32, 33]. Not only are spatial abilities used in everyday activities, such as navigating around the house, they are extremely important in fields such as engineering, science, and technology [7, 21, 33, 35]. This study investigates how drawing in a virtual 3D space can be used beneficially in art education of younger children (ages 10 to 12). We have implemented several drawing exercises in order to teach children how to draw in 3D. In our experiment we evaluate their effect on the participants' VR drawing skills. Furthermore, we study the relationship between the children's spatial abilities and their proficiency in creating a VR 3D drawing. Finally, we examine whether a few VR drawing sessions are enough to increase the children's scores on a spatial ability test. In addition to these findings, we identify and describe potential issues children face when learning to draw in VR. We also provide suggestions based on our experiences and the responses of the children during the experiment.

2 RELATED WORK

VR Painting. VR technologies enable the intuitive creation of 3D drawings, even without experience [39, 40]. Artists are offered the ultimate freedom and the chance to immerse themselves and their audience into their works [8, 17]. Since the only difference between digital painting and drawing is the material that is being simulated, which is not relevant for our research, we will use both terms interchangeably in this paper. Well-known VR painting tools include Tilt Brush [3], Quill [2], and A-Painter [1]. For this study, we use A-Painter, as it is open source and thus allows us to make the changes necessary for our research. Although a lot of research exists on the technologies behind this new form of drawing, there is no research on the act of drawing itself and the teaching of it. Given

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MM '18, October 22–26, 2018, Seoul, Republic of Korea

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ACM ISBN 978-1-4503-5665-7/18/10...\$15.00

<https://doi.org/10.1145/3240508.3240692>

this lack, we study several aspects of introducing 3D VR drawing to children in an exploratory manner. Our aims are to identify opportunities and points of attention and to lay a foundation for future research.

Spatial ability. Spatial abilities have been defined and subdivided in many different ways and there is no one universal definition [22, 35, 36]. For our purpose, we will only distinguish two components: spatial visualization and mental rotation. Linn and Petersen [22] describe spatial visualization as “the ability to perform complicated, multistep manipulations of spatially presented information”. Mental rotation is described as “the ability to rotate two or three dimensional figures rapidly and accurately”. The development of spatial ability is influenced by gender, age and spatial-related experience [33]. Many studies have revealed that the spatial visualization skills of men are better than those of women [13, 19, 33, 36]. Theories aiming to explain this difference include biological factors, such as male cerebral lateralisation and the male sex hormone, and environmental factors, such as gender-typed socialisation [19, 33, 36]. Spatial ability is not fully developed until adolescence is reached [33] and research has shown that spatial activities during childhood are very important to support this development [9, 13]. Activities that have been found to improve spatial abilities include playing with construction toys, participating in some types of sports and playing certain computer games [37]. Another activity that is often mentioned in combination with the development of spatial skills is sketching and drawing (S&D), which is discussed below.

Spatial abilities and drawing. A considerable number of studies suggest that the sketching or drawing of 3D objects improves spatial visualization skills [6, 21, 28, 33, 38]. However, in these studies the drawing activities are often combined with other spatial visualization improving activities, making it impossible to attribute the performance improvements solely to drawing. This corresponds with Braukmann and Pedras’ statement that not all drawing activities improve spatial skills and that a spatial context is critical [28]. Nevertheless, drawing itself does seem to play a major role in the development of spatial skills; Leopold, Gorska, and Sorby [21, 28] found that courses that relied heavily upon S&D activities were more effective in developing spatial skills than courses that did not. Alias et al. [7] also found the attitude towards S&D to be relevant. Both Rafi et al. [33] and Alias et al. [6] investigated the effect of S&D activities on spatial visualization skills and both found a statistically significant improvement in the spatial visualization ability of their participants. Rafi et al. [33] also found a significant performance gain in mental rotation accuracy but not in mental rotation speed. No significant improvements in mental rotation ability were found by Alias et al. [6]. But they state a lack of shared characteristics between exercises and test and the absence of implicit teaching of mental rotation skills as possible reasons. Although many studies suggest that the drawing of 3D objects is beneficial for the improvement of spatial visualization skills, more research is needed to prove the exact influence of S&D by itself. Furthermore, the existing studies all apply to drawing 3D objects onto a 2D surface using graphical projection. No research exists as of yet evaluating the benefits of drawing 3D objects in a 3D space.

Spatial abilities and VR. Developing spatial skills using VR is a very popular research topic with many promising results [24, 26, 29, 30, 32, 34, 35]. The main advantage of using VR is that it allows

students to observe and manipulate 3D objects directly in 3D space, which helps them understand spatial concepts and relations [20, 32]. Additionally, many of the advantages of VR as an educational tool, such as increased engagement [10, 18, 25, 27], apply here as well. Gutierrez et al. [24] compared the improvement of spatial skills after training with Augmented Reality (AR), VR and PDF3D. Their results showed a significant difference in improvements favoring the 3D virtual technologies over the traditional methods. Yet there are also studies that have not yielded positive results. A notable case being the large-scale study (215 participants) by Dünser et al. [15], who tested the effectiveness of spatial ability training with an AR application. Results did not show significant differences between the AR and non-AR groups. It is hypothesized that traditional spatial ability tests might not be suited very well to detect skills that are required or trained in 3D space. This is a likely cause for the lack of positive results in this study, seeing as students in VR or AR can directly see and manipulate 3D objects without having to interpret or mentally transform 2D representations of these objects, something that is necessary in traditional spatial ability tests. Other studies that did achieve improvements on the traditional tests, generally implemented some association with the 2D representations or used an adapted VR test [34]. Finally it needs to be emphasized that the VR applications in these studies are completely focused on the training of spatial skills. Concerning spatial visualization and mental rotation, no proof exists that an arbitrary VR application will have a positive influence on these abilities. However, given the fact that activities such as playing with construction toys have proven to benefit the development of spatial abilities, we assume that VR applications with suitable activities can achieve this as well without the need to mainly focus on training spatial skills.

3 EXPERIMENT

3.1 Objectives

Our study addresses three main objectives. The first one is taking an initial step towards investigating how VR 3D drawing can best be taught. For this we developed a number of training exercises to see whether they would be effective and how they would be received by the children. The exercises are based on existing drawing exercises, results gathered during a pre-study and advice given by the art teacher involved. We study this objective via the following research question:

Research question 1 – *Are training exercises helpful to improve children’s drawing skills in a virtual 3D space, even with only a small number of training sessions?*

Hypothesis 1 – *We expect that due to the targeted training exercises, children’s drawing skills will improve even after only very few sessions (here: four sessions of 35 minutes).*

Since spatial visualization is used to create mental 3D images, we expect well-developed spatial visualization skills to be an advantage when painting in a virtual 3D space; especially when painting from memory or creating a 3D painting based on a 2D image. The objective to verify this assumption is addressed by the following research question:

Research question 2 – *Is there a connection between a person’s spatial visualization ability and their proficiency in creating a 3D*



Figure 1: The setup during the individual VR drawing sessions (left) and the spatial ability tests (right).

drawing in a virtual 3D space, with a 2D image (2a) or a 3D model (2b) as example?

Hypothesis 2 – We expect that these skills are directly related. That is, children with a high score in the spatial visualization test will have high grades for their 3D drawings and vice versa. Since spatial visualization encompasses the ability to create mental 3D images out of limited information, we expect a bigger influence on 2a than on 2b.

Our third objective is investigating the potential positive impact of VR drawing on spatial skills. Despite the fact that the research in both areas still is quite incomplete, we believe that enough evidence exists to suggest that both drawing and the use of VR, when properly employed, can be beneficial for the development of these skills. Which results in the final research question:

Research question 3a – Can children’s spatial visualization skills (3a) and their mental rotation skills (3b) be improved by 3D drawing in VR, even with only a small number of sessions?

Hypothesis 3 – Already after a small number of sessions (here: four sessions of 35 minutes), we expect that children will score higher on the spatial ability test.

Besides these experimental research questions, we investigate multiple aspects of learning to draw in VR in an exploratory manner. This includes observing the children during the drawing sessions, having an interactive conversation with them and letting them fill out questionnaires. Related findings are discussed in Section 5.

3.2 Materials, Implementation, and Subjects

3.2.1 Hardware. The VR hardware consisted of an HTC Vive, which is a VR set with a head mounted display (HMD) and two handheld controllers (see Fig. 1, left). The headset was used in Extended Mode, with the HMD showing the painting environment and a separate screen showing both the view of the participant and additional controls. This allowed the experimenter to follow and manage the experiment.

3.2.2 Software. The main software used for this experiment was an adapted and expanded version of A-Painter [1], an open-source, web-based VR painting tool. The adaptations include the addition of a menu to enable the experimenter to control the experiment, and the implementation of several drawing exercises. Section 3.2.3 discusses these in more detail.

3.2.3 Drawing exercises. Based on a pre-study and advice of the art teacher involved, it was decided to implement two kinds of drawing exercises: basic shapes and step-by-step (SBS) exercises. During the basic shape exercises, a 3D model of a shape is shown in the virtual environment. The children are asked to copy this shape. If they find this difficult or do not know where to start, they are able to ask for help by pressing a button. This button starts step-by-step instructions that show a possible way to create that shape (see Fig. 3 for an example). The children are able to control the steps themselves by pressing the ‘previous step’ and ‘next step’ buttons. The included basic shapes are: a cube, a pyramid, a sphere, a cylinder, and a cone. The SBS exercises make use of the same mechanics as the help function of the basic shapes. The exercises start with a simple shape that is expanded every time the child presses the ‘next step’ button. The main goal of these exercises is to show the children that they can create complicated figures by combining the basic shapes they practiced earlier. Three SBS exercises were created: a tree, a church and a chicken (see Fig. 2 for the latter).

3.2.4 Spatial ability test. Despite concerns about the suitability of traditional spatial ability tests for this kind of research, they are still the standard. This, combined with the lack of established tests for VR acquired skills, led to the decision to use these traditional tests as a first step. A spatial ability test consisting of two parts was created. The first part contains the questions of 123test’s Spatial Reasoning Test (SRT) [5] to test the spatial visualization skills of our participants. This test is very similar to the well-known DAT:SR; it also consists of mentally folding 2D patterns into 3D objects. The SRT from 123test was chosen based on its scientific foundation [4], the simplicity and clarity of the questions, its length (only 10 questions) and its free use policy. The second part, which tests mental rotation skills, contains ten questions of the redrawn Vandenberg and Kuse Mental Rotations Test created by Peters et al. [31]. The Vandenberg and Kuse MRT was chosen due to its popularity and known reliability. Due to the original version of this test being difficult to obtain and of poor visual quality, it was decided to use a redrawn version. Both tests were performed twice; once before and once after the experiment. To avoid the possibility of children remembering their previous answers, the order in which questions and answers appeared was randomized.

3.2.5 Subjects. 18 elementary school children (seven boys, eleven girls, ages 10-12, all in the same grade) participated in this experiment. They had no prior knowledge of the experiment, participated voluntarily, and did not receive any form of compensation. Both the children and the teacher responsible for them signed a consent form ahead of the experiment. Given the nature of this research and the fact that it was during school hours, it was not legally necessary to obtain consent from the parents as well. The participants were divided into three groups of six (see Table 1). Gender is an important factor in spatial abilities (see Section 2), therefore groups were created with boys and girls divided as evenly as possible. Besides gender, the division was completely random.

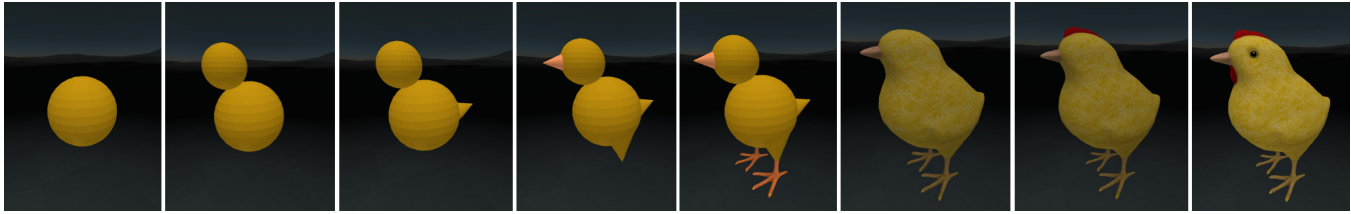


Figure 2: The steps of the step-by-step chicken exercise.

Group	Description	Gender distribution
Experiment group (A)	Participated in the VR painting training sessions with exercises.	4 female, 2 male
Training control group (B)	No training session, but free painting in VR for same amount of time.	4 female, 2 male
Spatial control group (C)	No participation in any VR painting activities.	3 female, 3 male

Table 1: The different participant groups.

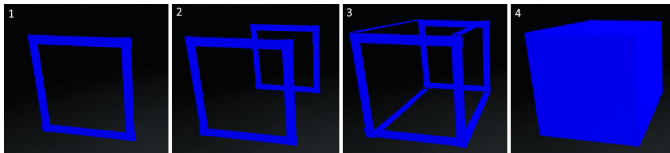


Figure 3: The optional extra steps that show a possible way to construct a cube.

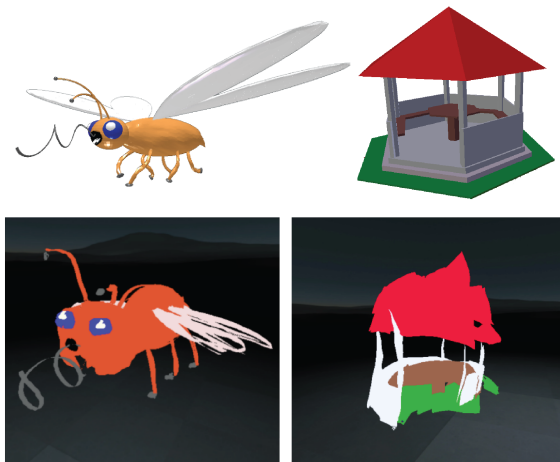


Figure 4: Example figures for the graded drawings (top) and drawings by two participants (bottom).

3.3 Setup and Procedure

The whole experiment ran over the course of five weeks. It started and ended with a 40 minute classroom session with all participants. In between, groups A and B had individual VR drawing sessions once a week, except for one holiday week in the middle. The duration of each individual drawing session was 35 minutes.

3.3.1 Classroom sessions. During the classroom sessions (see Fig. 1, right), the participants made the spatial ability tests, filled out

the questionnaires and received information about the experiment. Ahead of the first spatial ability test, the children were asked to form pairs and solve four example exercises. Additionally, each pair received printed 2D patterns of the example SRT questions. These could be folded into cubes, helping them to understand the SRT exercises. Their answers were jointly discussed and more explanations were given where necessary. When everyone understood the example exercises, the spatial ability tests were made individually.

3.3.2 Individual drawing sessions. At the beginning of the first session, each participant received instructions on the controls and was given time to try out everything. Once they had mastered the controls and were familiar with the virtual environment and painting software, an example scene was started. It contained both a 2D image and a 3D model of a polar bear to help explaining the purpose of the first assignment and the concept of 3D. The first assignment was the creation of the first part of the so-called graded drawings (GDs). These drawings were made during the first and last session with the purpose of rating the participants' VR 3D drawing skills. To be able to measure progress, the subjects received the same examples in the last session as in the first one.

The examples are shown in Fig. 4; each subject saw one of them as a 2D image and the other as a 3D model. The distribution of 2D/3D is based on the Latin square design. Orders of the graded drawings were mixed across and within groups. The main reason for having two graded drawings, one with a 2D example (GD2D) and one with a 3D example (GD3D), is the expectation that spatial visualization will play a more important role when drawing from memory or creating a 3D drawing based on a 2D image than when copying a 3D model. Since a drawing from memory is more difficult to grade than one based on an example, it was decided to study the difference between 2D and 3D examples. Also for the exploratory part of our research it is quite interesting to see how children deal with the task of creating a 3D drawing while only provided with a 2D example. Since they themselves have to imagine what the figure would look like in three dimensions, we expect this to be more difficult than copying a 3D model.

During the second and third sessions, group A made the drawing exercises while group B received the same amount of time to draw

freely. As VR is relatively new, not much is yet known about the long-term effects. Therefore, this study was carefully designed to take the maximum amount of precautions possible in order to assure that it would not negatively affect the children's visual development. The VR sessions were divided into two time slots of 15-20 minutes in between which we asked the children to take the headset off for a few minutes. The settings of the headset were adjusted carefully for each child to ensure that the image was clear for each of them. Additionally, they were regularly asked how they were feeling and it was emphasized that they should let us know as soon as they felt any discomfort.

The participants in group A all completed the exercises within the scheduled session times, although some needed to be told to draw faster and less precise in order to finish in time. When participants in group A finished their exercises before the scheduled ending time of their session, they were allowed to draw freely until their time was over. The children were asked to not discuss the VR drawing sessions with each other and to not use VR painting software anywhere else for the duration of the experiment.

3.3.3 Grading. Grading of the GDs was done separately by the experimenter and the art teacher. When the two grades were relatively close (difference of 1.5 or less), the mean of the two grades became the final grade. Drawings with a bigger difference were discussed and graded collectively. The grades of the graded drawings are based on the following aspects, which were established in discussion with the art teacher:

- Usage of the 3D space (0 - 5 points)
- Correctness of the proportions (0 - 5 points)
- How it looks from different perspectives (0 - 5 points)
- Overall appearance (0 - 5 points)

Subsequently, the grade was calculated by $\text{Grade} = (a+b+c+d)/2 + \text{process points}$. In line with the school's grading system, the maximum grade was 10 points. Process points are bonus points with a maximum of 1.5 that could be awarded when the participant showed remarkable insight during the process of drawing. They were included after the trial run, when it was noted that some students started off very promising with the creation of a well-constructed skeleton of the 3D figure, but then proceeded to color it in a messy way, causing their skills to not be reflected in the final drawing.

4 RESULTS

4.1 Research question 1

To answer the first research question, a mixed design setup was used with between-subjects factor *group* and within-subjects factor *time*. *Group* has two categories: group A, the group that made the exercises, and group B, the group that did not make the exercises. Categories for *Time* are before and after the VR drawing sessions. Multiple two-way mixed ANOVAs were conducted to determine whether the exercises influenced the grades. Multiple tests were needed because all subjects made two graded drawings; one with a 2D example and one with a 3D example. The dependent variable *grades* in the first test is the mean grade of GD2D and GD3D combined (MGD). Thereafter, we test for GD2D and GD3D separately as well. Mean grades for all selections can be found in Figure 5.

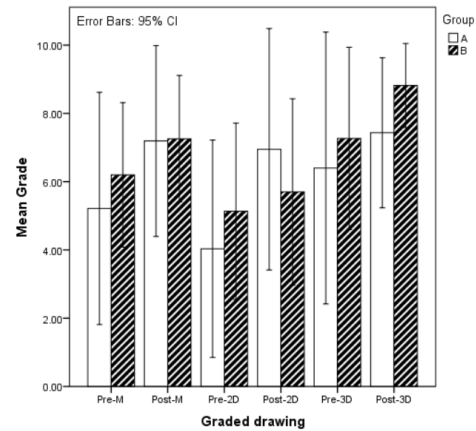


Figure 5: The mean grades for GDs. M = Mean grade of GD2D and GD3D combined, 2D = GD2D and 3D = GD3D.

Effect of exercises on MGDs. There was no statistically significant interaction between *group* and *time* on grades ($F(1, 10) = .770, p = .401, \text{partial } \eta^2 = .071$). The main effect of *time* did show a statistically significant difference in grades before and after sessions, $F(1, 10) = 8.430, p = .016, \text{partial } \eta^2 = .457$. The main effect of *group* showed that there was no statistically significant difference in grades between groups, $F(1, 10) = .154, p = .703, \text{partial } \eta^2 = .015$.

Effect of exercises on GD2Ds. There was no statistically significant interaction between *group* and *time* on the grades ($F(1, 10) = 3.187, p = .105, \text{partial } \eta^2 = .242$). The main effect of *time* did again show a statistically significant difference in grades before and after the sessions, $F(1, 10) = 7.003, p = .024, \text{partial } \eta^2 = .412$. The main effect of *group* showed that there was no statistically significant difference in grades between the different groups, $F(1, 10) = .002, p = .962, \text{partial } \eta^2 = .239 \cdot 10^{-3}$.

Effect of exercises on GD3Ds. Again, there was no statistically significant interaction between *group* and *time* on the grades ($F(1, 10) = .129, p = .727, \text{partial } \eta^2 = .013$). The main effect of *time* showed that there was no statistically significant difference in grades before and after the sessions, $F(1, 10) = 3.215, p = .103, \text{partial } \eta^2 = .243$. The main effect of *group* showed that there was no statistically significant difference in grades between the different groups, $F(1, 10) = .744, p = .409, \text{partial } \eta^2 = .069$.

Effect of dimension of example on the grades. To test our assumption that drawing a 3D figure based on a 2D image is more difficult than copying a 3D model, we used a within-subjects design to test whether the participants performed better on the GD3Ds than the GD2Ds. The dependent variable is *grade* and the independent variable is *dimension* with levels 2D and 3D. A paired-samples t-test was used to determine whether there was a statistically mean difference between the grades for the GD2Ds and the GD3Ds. Data are mean \pm standard deviation, unless otherwise stated. There were no extreme outliers in the data, as assessed by inspection of a box-plot (see Figure 6). After ensuring that the mild outliers found in this and other analyses did not affect the results, it was decided to continue without excluding them. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test ($p = .101$). The

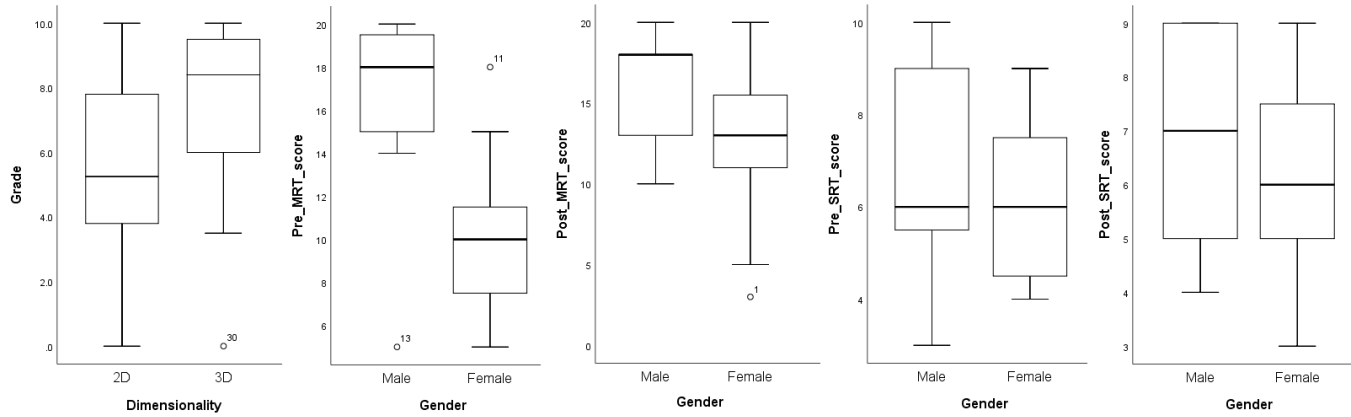


Figure 6: Division of data shown by boxplots. They show a few mild outliers (o) but no extreme ones (*).

grades for the GD3Ds (7.48 ± 2.56) were higher than the grades for the GD2Ds (5.45 ± 2.90); a statistically significant difference of 2.025 (95% CI, 1.0341 to 3.0159), $t(23) = 4.227, p < .0005, d = .86$.

4.2 Research question 2

A Pearson's product-moment correlation was run to assess the relationship between spatial ability test scores and grades of the drawings. Preliminary analyses showed the relationships to be linear. All variables were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$), and there were no outliers. There was a strong, positive correlation between the post-MRT scores and the grades for the post-GD3D, which was statistically significant ($r(10) = .600, p = .039$). Aside from this, no statistically significant correlations were found between spatial test scores and drawing grades.

4.3 Research question 3

Two two-way mixed ANOVAs were conducted to determine the effect of VR painting on the subjects' spatial ability test scores. The within-subjects factor is *time*, with the categories pre-test and post-test. The between-subjects factor is *painted_in_VR* with the categories yes and no.

Effect on SRT scores. There was no statistically significant interaction between *painted_in_VR* and *time* on the SRT scores, $F(1, 16) = .152, p = .701, \text{partial } \eta^2 = .009$. The main effects of *painted_in_VR* and *time* showed that there are also no significant differences in SRT scores between groups, $F(1, 16) = .150, p = .703, \text{partial } \eta^2 = .009$, or pre- and post-tests, $F(1, 16) = .017, p = .898, \text{partial } \eta^2 = .001$.

Effect on MRT scores. There was a statistically significant interaction between *painted_in_VR* and *time* on the MRT scores, $F(1, 16) = 5.785, p = .029, \text{partial } \eta^2 = .266$. The simple main effects for *painted_in_VR* on the pre-MRT scores, $F(1, 16) = .469, p = .503, \text{partial } \eta^2 = .028$, and post-MRT scores, $F(1, 16) = 1.293, p = .272, \text{partial } \eta^2 = .075$, are both not significant. There was a statistically significant effect of *time* on MRT score for the group that did not paint in VR, $F(1, 5) = 10.210, p = .024, \text{partial } \eta^2 = .671$. For the group that did paint in VR, the MRT score was not statistically significantly different between the pre- and posttest, $F(1, 11) = .005, p = .943, \text{partial } \eta^2 = .482 \cdot 10^{-3}$.

4.4 Effect of gender

Effect of gender on spatial ability test scores. Our spatial ability test was made by seven male and eleven female participants. An independent-samples t-test was run to determine if there were differences in scores between males and females. There were no extreme outliers in the data, as assessed by inspection of boxplots (see again Figure 6), and the scores for each test were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$). There was homogeneity of variances, as assessed by Levene's test for equality of variances ($p > .05$). The pre-MRT scores of the male participants (16.00 ± 5.32) were higher than the pre-MRT scores of the female participants (10.09 ± 3.91), a statistically significant difference of 5.91 (95% CI, 1.31 to 10.51), $t(16) = 2.721, p = .015, d = 1.32$. The mean scores of the other tests were also higher for the male participants, although these differences were not found to be significant.

Effect of gender on VR drawing skills. Four male and eight female subjects participated in the VR drawing sessions. Since the grades, grouped by gender, violated the outlier and normality assumptions of the independent-samples t-test, it was decided to use the non-parametric alternative: the Mann-Whitney U test. Distributions of the pre-grades for males and females were not similar, as assessed by visual inspection. The pre-grades of the females (mean rank = 8.00) were statistically significantly higher than the pre-grades of the males (mean rank = 3.50), $U = 28, z = 2.038, p = .048$, using an exact sampling distribution for U [14]. Distributions of the post-grades for males and females were similar, as assessed by visual inspection. Median post-grade for females (7.58) and males (7.10) was not statistically different, $U = 17, z = .170, p = 1.000$.

The results above suggest that the male participants improved more than the female participants. A two-way mixed ANOVA was conducted to determine whether gender indeed influenced the improvement of the participants. A mixed design setup was used with between-subjects factor *gender* and within-subjects factor *time*.

There were no outliers, as assessed by examination of studentized residuals for values greater than ± 3 . The pre-grades of the female participants were not normally distributed, as assessed by Shapiro-Wilk's test ($p = .007$). As all other data was normally distributed and since ANOVAs are considered to be fairly robust to deviations

from normality, it was decided to run the test regardlessly. There was homogeneity of variances ($p > .05$) and covariances ($p > .05$), as assessed by Levene's test of homogeneity of variances and Box's test, respectively.

There was a statistically significant interaction between *gender* and *time* on the grades, $F(1, 10) = 12.540, p = .005, \text{partial } \eta^2 = .556$. The simple main effects for *gender* on the pre-grades, $F(1, 10) = 3.065, p = .111, \text{partial } \eta^2 = .235$, and post-grades, $F(1, 10) = .009, p = .926, \text{partial } \eta^2 = .001$, are both not significant.

There was a statistically significant effect of *time* on grade for the male participants, $F(1, 3) = 18.118, p = .024, \text{partial } \eta^2 = .858$. This effect was not statistically significant for the female participants, $F(1, 7) = 2.524, p = .156, \text{partial } \eta^2 = .265$.

5 DISCUSSION

Our research was aimed at investigating how drawing in a virtual 3D space can be used beneficially in art education of younger children. Several aspects were investigated including how to improve drawing skills in VR, the effect of certain spatial skills on the ability to draw in VR, whether drawing in VR might improve spatial abilities and issues that may arise when learning to draw in VR.

5.1 Research Questions and Hypotheses

In our *first hypothesis*, we expected that due to the targeted training exercises, children's drawing skills will improve even after very few sessions. The results show that the grades of the graded drawings have indeed improved; the post-grades are on average 1.52 points higher than the pre-grades. Although the children in group A had a mean improvement of 1.98 and the children in group B a mean improvement of 1.06, this difference was not statistically significant. Therefore we cannot attribute these improvements to the training exercises. We do however expect the aforementioned difference to become statistically significant with a larger sample size.

In the *second hypothesis* we suspected a person's spatial visualization ability and their proficiency in creating a 3D drawing in a virtual 3D space to be directly related. We also assumed one's spatial visualization to have a bigger influence on creating a drawing with a 2D image as example than a drawing based on a 3D model. The results nevertheless do not show a clear relationship between spatial visualization ability and VR drawing skills; all correlations between SRT scores and GD grades were small and not found to be statistically significant. Looking at the results, we also do not expect significant correlations to be found in experiments with a larger sample size. A possible explanation is that our hypothesis is invalid and that there is no relation between a person's spatial visualization and their VR drawing skills. Alternatively, the relation could be too small compared to other factors to be able to test it without knowing the other variables. Another possible explanation is that our SRT test was inadequate to measure the kind of spatial visualization that is used when drawing in a virtual 3D space.

We did find a strong, positive correlation between the post-MRT scores and the post-GD3D grades that was statistically significant. The correlation between the post-MRT scores and the post-GD2D grades was strong and positive as well, although not statistically significant. Since the p-value of .088 is close to being statistically significant, further research with a larger sample size is necessary

to validate if this correlation indeed exists. The correlations with the pre-MRT scores are both small and not significant. We suspect that during the pre-drawings, other factors, such as getting used to the controls, influenced the drawings too much to be able to identify a potential correlation, which may or may not exist.

Our results fail to reject the original null hypothesis but seem to suggest that a relation between mental rotation skills and proficiency to draw in a 3D virtual space does exist, although only detectable after a few sessions. The correlation coefficient of the correlation with the GD2D grades is smaller than with the GD3D grades, which means the correlation between the MRT scores and the drawings with a 3D example is stronger. This contradicts our hypothesis. Yet, due to the lack of significance of the correlation with the GD2D grades, it is too early to draw a conclusion from this.

Our *third research question* verified whether a small number of 3D drawing sessions in VR could improve children's spatial visualization and mental rotation skills. The results show that the children who participated in the drawing sessions did not improve at either the SRT or MRT. Thus we fail to reject the null hypothesis and cannot accept our hypothesis. It may however be that the sessions were too few to result in measurable effects, or that the tests we used are not suited to detect skills that are trained in a 3D space. An unexpected finding is that the children who did *not* participate in the VR drawing sessions, did significantly improve at the MRT. An obvious explanation would be that the results were exchanged, but this was double checked afterwards. Another explanation could be that group C did mental rotation ability improving activities in class, while groups A and B participated in the drawing sessions. However, the participants from groups A and B were taken out of the classroom one by one and spread over several days, thus this seems highly unlikely. Due to the lack of other explanations and given the small sample size, we can only attribute this result to chance. Finally, since *gender* is proven to be an important factor in spatial abilities, we also expected it to affect our results. This expectation was justified, as our results show that the boys scored on average 5.91 points higher on the pre-MRT, which is a statistical significant difference. Furthermore, the girls performed significantly better on the pre-GDs, while the boys significantly improved more during the sessions. This improvement of the male participants led to almost equal mean post-grades for both genders.

5.2 Qualitative Results

This study served as exploratory research into teaching elementary school children to draw 3D objects in VR. In addition to the formal results presented in 5.1, our and the school's main interest was to see if 3D drawing can be used in art education; along with possible guidelines or recommendations on how to use it.

The main obstacle encountered by the children when asked to draw a 3D object was not knowing where to start. Especially at the beginning, they were not sure how to deal with the extra dimension and how to create the more difficult 3D shapes. A cube was simple for most. An ovoid, however, caused quite some problems. When drawing in 3D for the first time, the children generally used one of two strategies. Some started drawing a 2D image from one side, then walked around it to another spot in order to extend it to 3D. This often produced inferior results compared to children using

the second approach: starting with a 3D skeleton, then filling it in with colors. The step-by-step drawing approach developed with the art teacher was motivated by this observation. After teaching the children some basic shapes step-by-step and showing them how to create more complex figures by combining these basic shapes, the first strategy was almost never used anymore. This resulted in higher quality drawings that were built up more logically. We noted major differences in 3D drawing skills between the children. Some were truly talented and did not need any help or instructions, while others had great difficulties. Therefore we would suggest to implement several difficulty levels or optional help buttons. This way, every child can receive the instructions they need, without making it tedious for the talented students. As we already expected, creating a 3D drawing based on a 3D model was found to be much easier than creating one based on a 2D image. This was also supported by the grades, which were on average 2 points higher for the GD3Ds than for the GD2Ds. Overall, the children became familiar quickly with the controls and software. In most cases, only brief instructions in the first session were needed. Few children had more difficulties getting used to the controls, but they had also mastered everything before the last session. We also noticed that the children desired to create environments that they could play and interact with. They liked drawing houses that they could 'enter', making up stories about their drawings and sometimes making accompanying sounds. In the questionnaire, participants from group A all answered that they liked freestyle drawing best, but were divided over the best way to improve at VR drawing. During sessions, however, there seemed to be a preference for basic shapes. They often mentioned how helpful they were and that it was convenient that they could reuse them for the more complicated ones. The cone was chosen most often as hardest basic shape by far. The children were really enthusiastic about the VR drawing sessions. Most of them did not want their sessions to end. Although they were 35 minutes long, only one participant assessed the duration of the sessions as 'too long'. Two children answered 'too short' and all others answered 'exactly right'. When asked how often they would like these sessions, 42% answered 'every week' and 33% even answered 'every day'. Before and after the sessions, the children were asked to write down their favorite method(s) of drawing. After the sessions, two children changed their answer to include VR and five children even completely changed their answer to VR only. While some of this enthusiasm might be attributed to the newness of the tools, the answers clearly reflect a potential in increasing an interest in drawing and art education in general.

6 CONCLUSIONS AND FUTURE WORK

The work presented in this paper was motivated by the goal to a gain better understanding of the benefits and obstacles that drawing in VR might bring when introducing it to elementary school children. Our experiment shows that children quickly improve at drawing 3D figures in a virtual 3D space. The participants that made the training exercises improved more than the participants that did not. However, since this difference was not statistically significant, the effect of our training exercises is inconclusive. We assume that the effect size was too small to be significant for our sample size, as we only had six participants per group. Therefore,

further research should be conducted with more participants.

Our results also show that gender is indeed an important factor to take into account when conducting research in this area. Not only was a significant difference found in the spatial ability test scores, it also seems to influence the initial proficiency in VR drawing and the rate of improving at VR drawing. However, our research was not aimed at investigating gender differences. Further research with a larger sample size and a more equal male-female ratio should be conducted in order to draw final conclusions on this subject.

The children indicated that they considered the training exercises incredibly helpful. Especially for teaching them the basic shapes, which they could later reuse in more complicated figures. The biggest obstacles encountered by the children were not knowing where to start and how to handle the extra dimension. The step-by-step exercises were experienced as helpful in these situations.

A strong, positive correlation was found between scores on the post-MRT and grades for the post-drawings with a 3D example. It seems that a direct relation between mental rotation skills and proficiency to draw in a virtual 3D space does exist, although only detectable after a few sessions. The correlations between SRT scores and grades were all small and a significant effect could not be discovered. Although these results are not conclusive, they do suggest that this is indeed a promising direction for further evaluation.

The VR drawing sessions did not improve spatial visualization or mental rotation abilities in our participants, at least not the kind that is measurable with traditional tests. This seems to support Dünser et al.'s [15] hypothesis that traditional spatial ability tests might not be suited very well to detect skills that are required or trained in 3D space. Therefore it is planned to examine this further in the follow-up research, creating a spatial ability test in VR and involving a cognitive scientist.

Although additional experiments are needed to conclusively answer our research questions, this study has laid an important foundation for future research in this area. Our results point out opportunities, points of attention, and interesting follow-up research. It is worth repeating this experiment with a larger sample size and more training sessions. Additionally, it is promising to combine and compare VR drawing with other activities such as standard 2D drawing on paper, building blocks and VR gaming. Furthermore, the involved teachers and children both expressed a vast interest in this new technology. Even after several sessions, the children are still motivated and wishing for more sessions. These observations, together with the feedback provided by the involved art teacher, suggest that VR drawing can make a good and beneficial complement for traditional art classes, even if further evaluations will not confirm expected benefits such as the assumed increase in spatial ability.

ACKNOWLEDGMENTS

The authors would like to thank ING Bank N.V. and KLEURin-CULTUUR for enabling this research and making sure that all the necessary hardware was available. Assistance provided by Amanda de Gast during the experiments and her valuable insights as an art teacher were indispensable and greatly appreciated. We also thank Bastiaan van Meerveld from Sterrenschool de Ruimte for allowing the participation of his students in this study, and of course the students for their cooperation.

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