Spatial Ability Reasoning: The Strengths and Weaknesses Between Virtual Reality and Paper Pencil Testing

John Llapa | Graduate Student | North Dakota State University
john.llapa@ndsu.edu

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ABSTRACT

In the United States, many high schoolers are frustrated about sitting through boring classes and not understanding their classes. This research project aims to explore a potential solution to these problems through the use of VR technology. VR technology has taken massive leaps in sophistication over the decades. Now appearing to be a viable option for school districts across the country. The goal of this research project is to study the differences in spatial thinking between two different mediums paper pencil and virtual reality. This would provide insight into how useful this technology can be within an educational environment.

BACKGROUND INFORMATION

VR Technology Evolution

1956: Sensorama, the first VR machine. It was a large booth that could fit up to four people at a time. It combined technologies to stimulate all the senses: there was a combined full-color 3D video, audio, vibrations, smell, and atmospheric effects, such as wind.

1968: The Sword of Damocles, the first virtual reality HMD. These head mounts connected to a computer rather than a camera and was quite primitive as they could only show simple virtual wire-frame shapes.

VR Technology Evolution

1985: DataGlove, EyePhone HMD, and Audio Sphere were developed by VPL Research, Inc. This company is known as the first company to sell VR goggles and gloves.

1991: NASA scientists, designed a VR system to drive the Mars robot rovers from Earth in supposed real-time despite signal delays between the planets. This system is called “Computer Simulated Teleportation”.

VR Technology Evolution

2012: Oculus Rift Kickstarter campaign began to create the first truly immersive virtual reality headset for video games. The product consisted of a VR headset, motion controllers, and sensors. The headset had to be tethered to a computer.

2020: The Oculus Quest 2 was unveiled during Facebook Connect 7 event. The product comes with a VR headset and two motion controllers. The controllers and player location are able to be tracked from the headset and there is no longer a need for a cable to connect the headset to a computer. It can be done wirelessly.

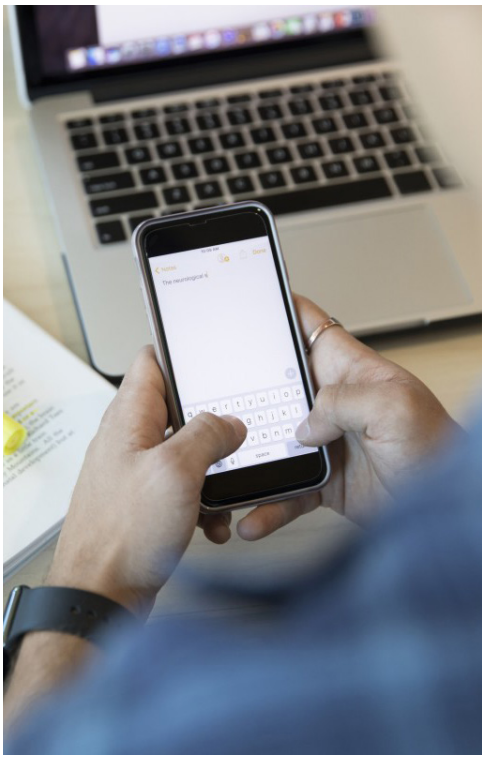
Technology in Schools

Technology has been gradually altering how students may participate in their learning for more than 300 years. Beginning with the hornbook, which was created in the 1450s, this new tool was utilized to aid in the reading and math instruction of young children. Although it began gradually, the employment of new technology in the classroom took up after we entered the 20th century. In the 1920s, radios made their debut, ushering in a new era of education

marked by on-air classes. In the 1930s, overhead projectors started to appear in schools. This made it possible for teachers to prepare lessons in advance by writing them with transparency. In the 1950s, videotapes—a brand-new and innovative technique of instruction—arrived. Before the 1980s, the photocopier and handheld calculator were introduced into the classroom, allowing for instantaneous mass production of materials and quick

Technology in Schools

mathematical calculations. Toshiba introduced its first mass-market consumer laptop in 1985 and in 1993, The World Wide Web had limitations relaxed on commercial usage. Which allowed the world to begin discovering newfound research and communication methods. 93% of classrooms had one or more computers by 2009, and 93% of those PCs had connections to the Internet. Nowadays, it's uncommon for a college student to be without some kind of computer technology: 88% of them have a laptop, and 85% have a smartphone. According to a poll of college students in the United States conducted in 2015.



Technology in Schools

When studying the use of technology for educational or instructional reasons, the following are the top seven crucial principles to comprehend:

1.) Active engagement with the learning material

Due to the participatory nature of technology, students gain knowledge by investigating, and getting input. Students benefit from having a love for what they are learning.

2.) Use of real-world issues

Real-world problems are encouraged to be used in the classroom under this methodology. Students can investigate current events that are relevant to the subject in the classroom by using the Internet.

3.) Simulation and modeling

Through the use of simulation software, real-world activities that would not be feasible without technology are brought into the classroom. Students may observe how a tornado forms, how planets move, or how dinosaurs lived by utilizing the software.

4.) Discussion and debate boards and forums

Students can build online communities, Web sites, and online groups that allow them to communicate in real-time with other students and teachers anywhere in the globe using the Internet or software tools. They may ask questions and voice concerns about their classes, and they can get feedback from their professors.

Technology in Schools

5.)Working groups

Education that emphasizes technology does not entail a class of pupils studying by themselves while fixating on a book. Working groups facilitate the development of democratic group dynamics and stimulate group activities, discussions, and debates.

6.) Coaching

These days, teachers take on more of a coaching role. They are more than just teachers who impart knowledge. Instead, they act as coaches do and direct student activities. In order to ensure that students receive the proper information and academic training, they offer feedback and coaching to the class. Teachers assist pupils in acquiring problem-solving, research, and judgment abilities.

7.) Formative assessment

Teachers make sure that students are learning how to use the available digital resources as well as ideas. Activities centered on technology primarily call for critical thinking and problem-solving abilities. Teachers serve as facilitators, giving continuous feedback to help pupils comprehend concepts at a deeper level.

Methodology

This project investigates human subjects and data analysis. The human subject study consists of conducting two spatial thinking tests. One test will be completed on a traditional paper-pencil medium. The second test will be carried out in a virtual reality environment. The preliminary study data will contribute to the collection of quantitative data pieces. Taking into account human responses in addition to quantitative data will allow us to determine whether virtual reality is a viable educational tool.

Research Results

Research Results - Protocol

Each participant was required to complete two spatial thinking tests. There would be a 5-minute introduction where any questions a participant had would be answered. Then the first test would begin, and participants had 10 minutes to complete the test. Next, a 5-minute intermission would occur where participants could get water, go to the bathroom, or stretch. Then the final test would begin which also had a time limit of 10 minutes. Resulting in 30-minute sessions.

The first test given alternated between the paper and virtual reality test. This allowed half the participants to start with the paper/pencil test and half to start with virtual reality. This would allow for a deeper analysis of the results at the end.

Each test consisted of six problems that activated spatial ability reasoning. Each of the six problems was a different type of spatial ability reasoning question. There were group rotation, visual comparison, combining shapes, maps/ plans, block counting, and reflection types of questions. Both tests had one of each type of question. This would allow for analysis of each question. This would allow for insight as to what type of question was performed the best between the two mediums.

There was a total of nine participants that varied in their enrollment level and gender. Four of the participants identified as female and five identified as male.

Two programs were used to create the tests. For the paper and pencil, Adobe Illustrator was used. For the virtual reality test, Unreal Engine was used.

Research Results - Paper Test

Participants were given instructions that they were not allowed to draw or write on the test in order to help them solve the questions. This is because the test is suppose to activate spatial thinking abilities.

Question 01:

The group rotation question. Participants had to select two figures that had the same composition of shapes.

Question 02:

The visual comparison question. Participants had to select the two figures that were the exact same.

Question 03:

The map and plan question. Participants had to place themselves on the map and follow the instructions to arrive at the correct building.

Question 04:

The block counting question. Participants had identified how many blocks there are in the image.

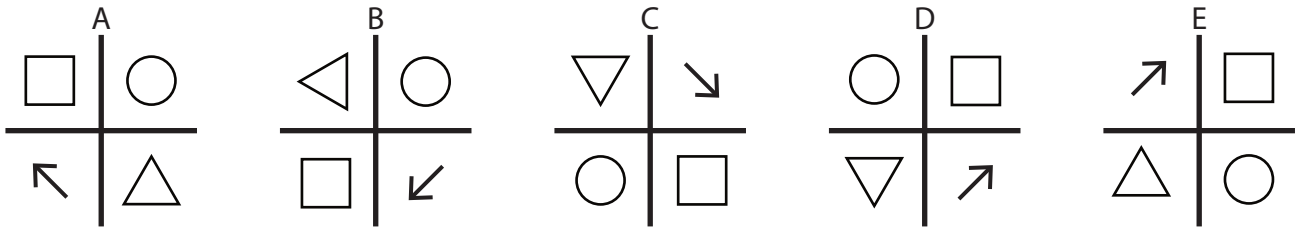
Question 05:

The reflection question. Participants had to select the two figures that were reflections of one another.

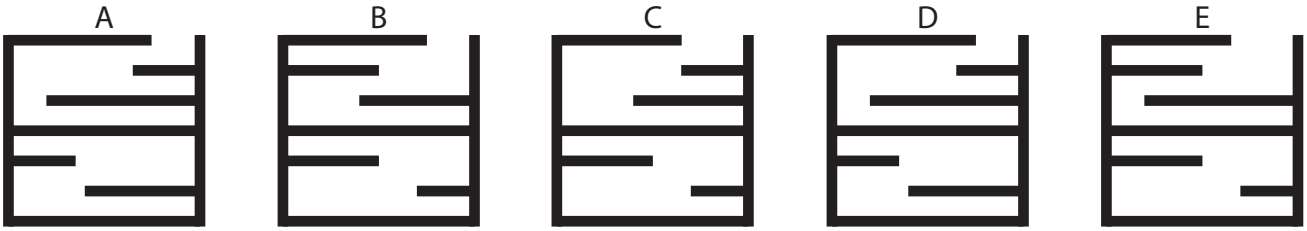
Question 06:

The combining shape question. Participants had to determine what shape is possible given three 2D shapes.

Question 01: Circle the two identical figures.



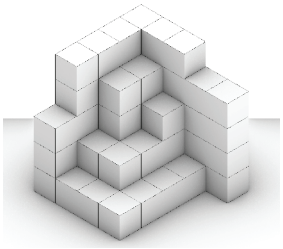
Question 02: Which two figures are identical?



Question 03: Identify what building Lisa is in front of on the map.

Lisa is standing on Mount Street facing south. She then proceedes to walk to her left until she reaches an intersection. Upon reaching the intersection she begins walking along Oak Park the same way she has been until she reaches another intersection. From here she decided to walk a block south toward South Road. She then proceedes to walk west for three blocks. At the new intersection she begins heading north until she finds the first building to her east. What building is she in front of? _____

Question 04: How many blocks are there?



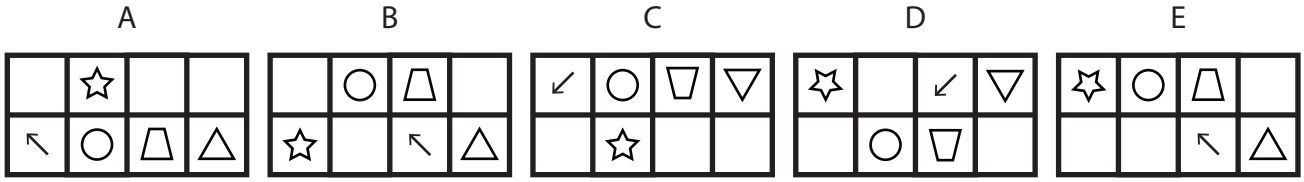
A.) 62

B.) 64

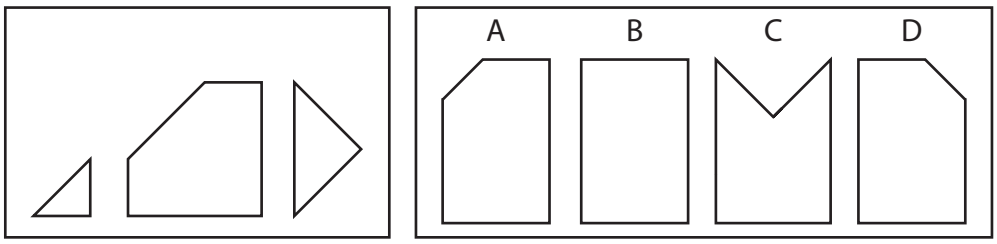
C.) 68

D.) 70

Question 05: Which two figures are the reflection of one another?



Question 06: From the given shapes what is the possible solution?



Research Results - Virtual Reality Test

Prior to the test starting a short explanation on how to properly put on the headset, adjust the eye distance, and how to maneuver/interact within the virtual environment.

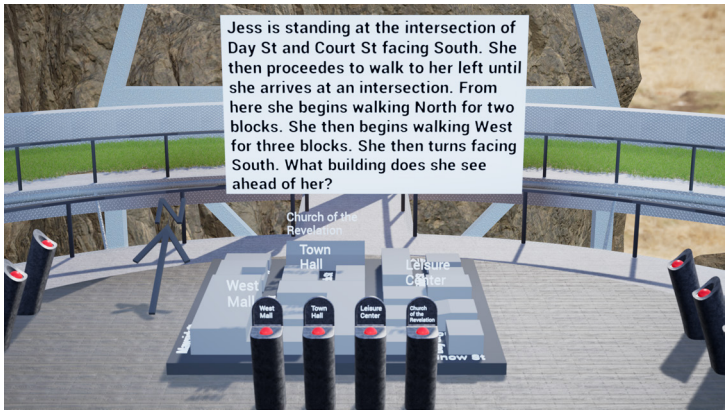
All six of the different types of spatial ability reasoning questions were present, the same as in the paper test.

For five of the questions, participants would press the button for the answer they believed. Participants were also allowed press the button again which would reset the answer.

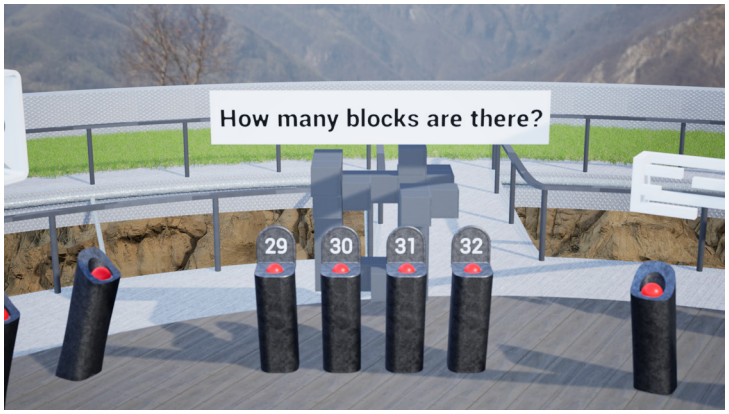
For the combining shape question participants were able to use the motion controllers to manipulate the 3D objects. Attempting to re-create the figure displayed above.

Group Rotation

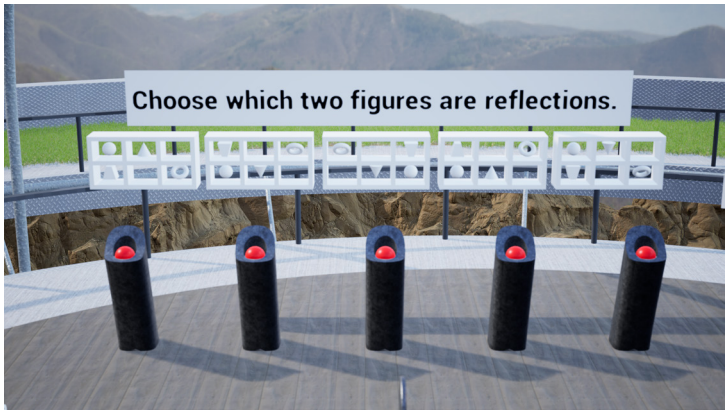
Visual Comparison



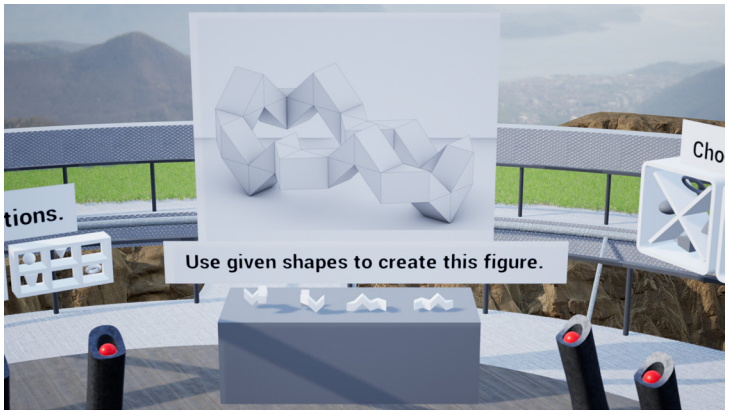
Map and Plan



Block Counting



Reflections



Combining Shapes

Research Results - Participants

Alpha Code	Gender	Enrollment Level	First Test
zjd5ovmrxx5lv8s	Male	4th year	VR
1sszn6xelywf3uj	Female	5th year	Paper
alimjuklabfy1hi	Female	5th year	VR
l8p7d84l6u5lyvv	Female	2nd year	VR
t63do9ordew6968	Female	5th year	Paper
3eo4b9e1k1avmft	Male	5th year	VR
apqa6cklh7murw6	Male	5th year	Paper
liw9k15xysmhz3e	Male	5th year	VR
v3mvhflrdd0nvhj	Male	2nd year	Paper

Research Results - Overall Scores

Due to unequal questions in the combining shapes category. The combining shape question has been omitted. The paper test dealt with three 2D shapes, while the virtual reality consisted of four 3D shapes. This will be discussed further in the report.

Paper Test Score	Virtual Reality Test Score
3/5	2/5
4/5	3/5
2/5	2/5
4/5	3/5
5/5	4/5
3/5	3/5
5/5	4/5
2/5	4/5
4/5	3/5

Six of the nine participants scored better on the paper test, regardless of which test was given first.

Those who took the paper test first had higher scores on the virtual reality test when compared to participants that took the virtual reality test first.

Those that took the paper test first had higher scores on the virtual reality test when compared to participants that took the virtual reality test first.

Research Results - Paper Results

GR = Group Rotation
VC = Visual Comparison
MP = Map and Plan
BC = Block Counting
RF = Reflection
CS = Combining Shapes

	GR	VC	MP	BC	RF	CS
zjd5ovmrxx5lv8s	1	1	1	0	0	1
1sszn6xelywf3uj	1	1	1	0	1	1
alimjuklabfy1hi	0	1	0	1	0	1
l8p7d84l6u5lyvv	1	1	0	1	1	1
t63do9ordew6968	1	1	1	1	1	1
3eo4b9e1k1avmft	1	1	0	0	1	0
apqa6cklh7murw6	1	1	1	1	1	1
liw9k15xysmhz3e	0	1	1	0	0	1
v3mvhflrdd0nvhj	1	1	0	1	1	1
Totals:	7	9	5	5	6	8
Sum:	32					

Research Results - Virtual Reality Results

GR	VC	MP	BC	RF	CS
1	0	1	0	0	0
1	1	0	0	1	0
0	1	0	1	0	0
1	0	1	0	1	0
1	1	1	0	1	0
1	1	0	0	1	0
1	1	1	0	1	0
1	1	1	0	1	1
1	1	0	0	1	0
8	7	5	1	7	1

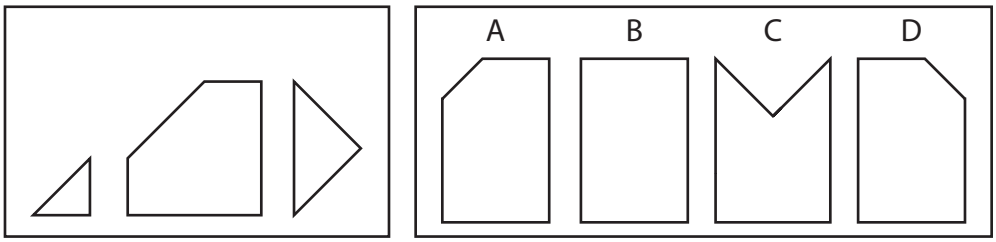
28

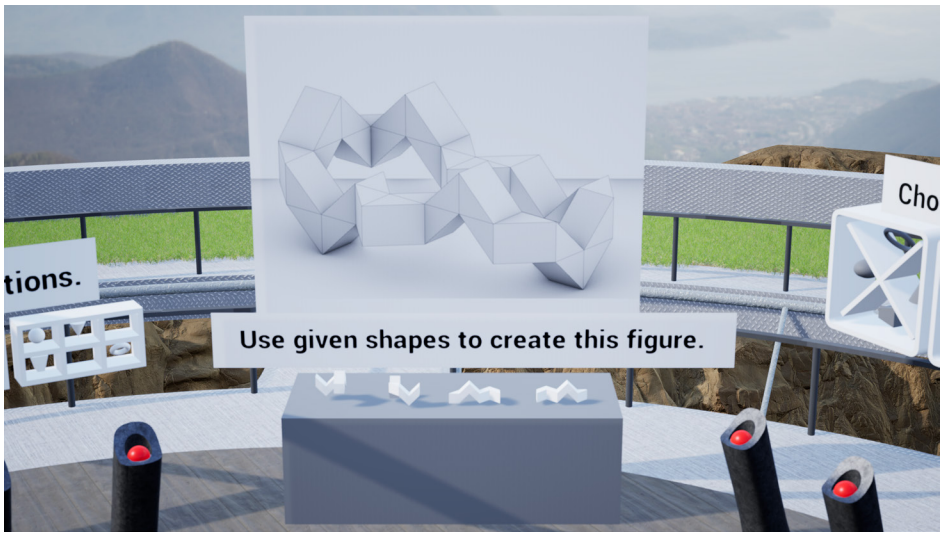
Overall, the paper test proved to have higher scores for most participants than the virtual reality test.

Research Results - Observations

Upon examination of the test as a whole. There appears to be an unbalance of question composition for the type of combining shape. The paper test consisted of three simple 2D shapes that participants had to manipulate in their minds and select the possible figure. In the virtual reality, test participants were given four complex 3D shapes that they had to try and manually arrange to create a given image. Had the questions been designed a bit more similarly, within the virtual reality environment a total of three 3D objects would be used and consisted of simpler shapes (ex. pyramid, rectangular prism, cylinder, etc.). Or the paper test could have consisted of three 3D objects that would have to be mentally arranged.

Question 06: From the given shapes what is the possible solution?





Research Results - Observations

Paper Test						VR Test					
GR	VC	MP	BC	RF	CS	GR	VC	MP	BC	RF	CS
1	1	1	0	0	1	1	0	1	0	0	0
1	1	1	0	1	1	1	1	0	0	1	0
0	1	0	1	0	1	0	1	0	1	0	0
1	1	0	1	1	1	1	0	1	0	1	0
1	1	1	1	1	1	1	1	1	0	1	0
1	1	0	0	1	0	1	1	0	0	1	0
1	1	1	1	1	1	1	1	1	0	1	0
0	1	1	0	0	1	1	1	1	0	1	1
1	1	0	1	1	1	1	1	0	0	1	0
7	*9*	*5*	*5*	*6*	*8*	*8*	*7*	*5*	*1*	*7*	*1*

Participant "alimjuklabfy1hi" noted that she has dyslexia. Which made it hard for her to answer some questions. This is apparent when you look at the types of questions she got right and wrong. On both tests, she got the same kind of questions correct and wrong. The map and plan question consisted of a good amount of reading which made the question much more difficult for her. The group rotation and reflection questions also proved to be challenging.

Between the two tests. Only the paper test was able to achieve a perfect score. This happened on two separate occasions with participants, "t63do9ordew6968" and "apqa6cklh7murw6". Both participants received *5/5* on the paper test and *4/5* on the virtual test. Both also answered incorrectly the block counting question in the virtual reality test.

Research Results - Observations

Participant "l8p7d84l6u5lyvv" began experiencing nausea during the virtual reality test. This was visually apparent while observing her take the test. After she began feeling nauseous she began answering the remaining questions quickly. She was one of two participants who finished the virtual reality test before the 10-minute timer went off.

The second-year participants "l8p7d84l6u5lyvv" and "v3mvhflrdd0nvhj" both received the same overall score for both tests. In the paper test, they both got the map and plan questions incorrectly. While on the virtual reality test they had different incorrect answers. Both had the block counting incorrect, but "l8p7d84l6u5lyvv" answered the visual comparison incorrectly while "v3mvhflrdd0nvhj" answered the map and plan incorrectly.

Of all the participants only "liw9k15xysmhz3e" scored higher on the virtual reality test. He was the only participant to immerse himself in the virtual environment. This means he was standing up, walking around, and crouching. This was different from other participants who remained seated for the virtual portion.

Participants that took the virtual reality test first stated after the tests were completed that they felt they would have performed better on the virtual reality test had they taken the paper test first. However, the data shows that individuals who took the paper test first generally still had a lower score on the virtual reality test.

Research Results - Observations

Participants who completed the paper test first generally received a higher score on the paper test and a lower score on the virtual test. However, participants who completed the paper test first also did slightly better on the virtual test when compared to those that started with the virtual reality test.

When examining each question type individually between the two tests there are certain questions that performed better in each medium.

The visual comparison and block counting types of questions were answered correctly the most on the paper test.

The group rotation and reflection types of questions performed the best in the virtual reality environment.

The map and plan type of question received the same correct answers on both the paper and virtual reality test.

Male	4th year	VR	3/5	2/5
Female	5th year	Paper	4/5	3/5
Female	5th year	VR	2/5	2/5
Female	2nd year	VR	4/5	3/5
Female	5th year	Paper	5/5	4/5
Male	5th year	VR	3/5	3/5
Male	5th year	Paper	5/5	4/5
Male	5th year	VR	2/5	4/5
Male	2nd year	Paper	4/5	3/5

Research Results - Observations

A rather counterintuitive piece of data emerged relating to the block counting type of questioning. On the paper, test participants had to maintain a mental count from an isometric view of blocks. Whereas, in the virtual reality test they had the ability to approach, walk around, and crouch around the question. The virtual reality test initially appeared to be the superior medium to answer this type of question. However, the test results for that question showed that it did not help. Of the nine participants, five answered correctly on the paper test and only one in the virtual reality environment.

The combining shape question presented some difficulty between the two tests. Nevertheless, there was still an initial belief that the virtual reality test would prove to have the upper hand. Within the virtual reality environment, participants were able to approach these 3D objects with their controller's "hands" capable of flipping, rotating, and/or twisting these objects. They were aided in the regard that they did not have to mentally rearrange the objects as they did on the paper test.

Within the survey portion of the preliminary study. A majority of participants claimed that they felt the virtual reality environment activated their spatial thinking abilities the most. However, the test data shows a different story. with six of the participants scoring higher on the paper test, two scoring equal points, and one scoring higher on the virtual reality test.

Research Results - Participant Survey

What are the main differences between the two mediums that affected your spatial thinking abilities?

01: Moving around in the VR was the biggest difference. It helped in some of the test and was a little difficult in others.
02: Controls of VR game.
03: ...
04: My ability to control my maneuvering in the VR. VR allowed a more 3D/tangible approach.
05: I enjoyed experiencing the spatial puzzles in VR and felt I could better answer them with percieving depth.
06: Had to ovisualize in my mind for the paper. VR allowed me to "physically" look & crouch.
07: Being able to walk around the blocks to count.
08: For the map portion just understanding my sense of place. I was thinking where I currently was instead of placing myself.
09: The digital test is more fun. You have more around, actually press things, etc.

Research Results - Participant Survey

Which of the two mediums do you feel activated your spatial thinking abilities more?

01: Definitly the VR. Looking at objects that are 3D is very different than seeing them in 2D.
02: VR.
03: Shape and the map both.
04: VR.
05: VR.
06: VR.
07: Paper.
08: Which shapes match, reflections, and puting blocks/ shapes together
09: It was pretty similar I think.

Research Results - Participant Survey

Which of the two mediums were the most comfortable for the test and why?

01: I personally like the paper more but I think that is because that is. I feel like if I had more experience with VR my answer might be different.
02: Paper, not used to taking a test and being able to walk around the questions and see from a 3D versus 2D viewpoint.
03: Find the want that is similar. Find of the location how things fit or work together.
04: Written - I have little experience with VR, so I wasn't as confident.
05: VR was more fun and more intuitive. I felt most comfortable there. Pen and paper was more familiar so I felt more control over my time in that environment.
06: VR - the goggles were warm.
07: VR - I felt more confident being able to see things in person.
08: The map and which shapes where the same. Even though I failed the map, I just felt more certain with those types.
09: Paper, because I am more used to it.

Research Results - Participant Survey

Of the six types of questions presented, which ones were the most challenging in each medium?

01: VR - making of the shape one
Paper - counting blocks

02: VR - building puzzle
Paper - identical pictures

03: VR - map of direction
Paper - map of direction

04: VR - similar shapes on VR - the white made it hard to see, but I should've just adjusted my view to be above the pieces.
Paper - block counting - VR allowed me to look at the whole thing, but I also got nauseous.

05: VR - Building a 3D model from shapes was the most challenging.
Paper - counting blocks in 2D paper was hardest there.

06: VR - block counting, hard to keep track.
Paper - block counting, hard to keep track.

07: VR - shape building.
Paper - block counting.

08: VR - putting the blocks together.
Paper - putting the shapes together.

09: VR - "make the shape."
Paper - "make the shape."

Research Results - Participant Survey

Which of the two mediums allowed you to comprehend the questions easily?

01: Paper because it is what I am used to.
02: VR, I felt I needed to try and ask less questions about each problem.
03: The reflection.
04: It's hard to say because my nauseousness limited part of my VR experience. Disregarding it, the VR did help my questions be more tangible and allow me to view them from different angles. If I'd had more experience with VR so that I would not experience nausea, I feel like VR would be much more comfortable.
05: VR.
06: VR.
07: VR.
08: Reflection of the shapes and the map.
09: The VR medium.

Conclusion

The average American adult has fulfilled their general education requirements. That is, they have dedicated almost 13 years of their lives to learning. In the United States, around 49.9 million children attend public schools. It is in our best interests to provide the younger generations with all of the tools they need to succeed in life.

This preliminary study was on the smaller side with nine participants, only six spatial thinking questions, and unbalanced question. It does still provide valuable information. To further this research a study that has a much larger sample size and more spatial thinking questions will provide additional data.

The examination of spatial thinking ability data from traditional pencil/paper and virtual reality mediums was derived from this exploratory investigation.

It is hard to conclude definitely the result of this preliminary study. The paper test received a higher overall score of 32 points and the virtual test had an overall score of 28. Both tests had different types of questions which excelled in performance. Not many of the participants had experience with virtual reality. While they all have had years of exposure to traditional testing methods. Empirically from the small sample size, the paper test appears to be the best option, but further testing is required to make a definitive statement.

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