SCHOOL OF COGNITION

Where students learn from interactive methods

Thesis Project by
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Project guide
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Submitted to
Department of Design
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भारतीय प्रौद्योगिकी संस्थान हैदराबाद
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Enhancing school of cognition through Haptics

-Pratikesh Pundkar-

A Thesis Submitted to
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Approval Sheet

This thesis entitled **Enhancing school of cognition through Haptics** by Pratikesh Vijay Pundkar is approved for the degree of Master of Design in visual design from IIT Hyderabad.

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This is to certify that the work entitled "**Enhancing school of cognition through Haptics**" is a bonafide of thesis work by Pratikesh Pundkar under my supervision for his M.Design degree.

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Abstract

Learning through experience plays a very crucial role in spatial thinking, especially for children with poor progress in understanding concepts and with low memory skill. This study investigated whether the above mentioned problem can be overcome by a training program designed to enhance their cognition. Children with lower understanding of 2D and 3D objects and poor in mathematics were assessed on working memory and their academic performance before and after their adaptive training program. An adaptive training program was designed which enhances the learning experience of children by interacting with 3D objects using force feedback theory. The interaction itself creates a real experience of interacting with physical world and understand its parameters like weight, mass, force, friction, shape, material and viscosity. This finding indicates that the force feedback interaction with the 3D model creates a positive impact on working memory and associates with the cognitive development of children in the age of 8 to 10 years.

Acknowledgement

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CHAPTER 1

PROJECT PROPOSAL

Title : Enhancing school of cognition through Haptics

Background

Students spend most of their time in school. During their elementary school years, children undergo important developmental changes. Their reasoning becomes more logical, their attention gets more adaptable, their perspective becomes more sophisticated, and their linguistic skills blossom. This age span coincides with the time frame in which children are developing an understanding of mental states and process. (Bhaswati Patnayak 2008) During this time period, it is very easy to guide them towards the proper direction of cognitive learning for the better understanding of the logical reasoning in the future.

Objective

The aim of this project is to understand the cognitive development of the children from the age group 7-11 year and create an interactive platform where children can learn science and mathematics using haptics.

Project Brief

The project will proceed in three phase that is Research, Understanding and Execution. In the research phase, I will do literature study on cognitive development, Artifacts and Material Engagement theory. From the research part, I will come up with some findings and develop a concept in the form of executional ideas. From the understanding of my research, I can create a strong philosophy of the design concept. Design Concept will be in the form of interaction platform where children can interact with the interface using haptics and play the game. The interaction system will help children to unconsciously develop his/her 3D orientation memory and logical reasoning ability.

CHAPTER 1

INTRODUCTION

Our country has a very sophisticated education system from kinder garden to post-graduation. The education system plays a very important role in the development of our country. Every year 25.6 million students graduate from different fields and create a big impact on the upcoming Indian economic growth. But the question is - Does our education system do justice to all the 25.6 million students? It is a serious topic while discussing the development of the nation. But the development of students starts from their early childhood itself.

As per the Piaget theory of cognitive development of children, every child goes through the four stages of cognitive understanding that is the Sensorimotor stage, Preoperational stage, Concrete operational stage and Formal operational stage. In the process of cognitive development, it is very important for a child to interact with the real world through senses and experience the world by their own sensory system. It helps them to understand the infinite question of the universe. However, it is very important for a person to build his cognition in the proper sense of understanding for better development and evolve his intelligence. As per the Piaget's theory, children begin to think logically about concrete events in the concrete operational phase. They begin to understand the concept of conservation; that the amount of liquid in a short, wide cup is equal to that in a tall, skinny glass. Their thinking becomes more logical and organized, but still very concrete. So, it is very important for a child in between the age of 7-11 years to have a proper method for developing his thinking skills. This is because the understanding of a child at this age makes a concrete understanding of the concepts which stays concrete throughout life.

But, in the Indian education system, most of the schools have a very theoretical way of teaching, especially in physics, chemistry and mathematics. According to the survey I took in my institute (IIT Hyderabad, 21Jan2018), around 75% of students do not even understand the basic concepts of physics. This is a result of improper development of spatial thinking skills in their childhood. Most of the students lack spatial thinking skills because of lack of cognitive development.

Majority of schools in India from Grade 1 to Grade 8 have a theoretical course without any practical experiments and exploration.

For the proper development of cognition, a student has to go through proper practice of education. In this thesis, an adaptive training program is proposed as a solution to develop a different experience in education. An adaptive training program is an educational platform for a student to interact with theoretical concepts and learn through Haptics (Force feedback). Interaction creates an experience of learning through the force feedback concept where a student will use a haptic pen and interact with the virtual world of education. In the process, I have developed an interactive platform using X3D and Python script. Haptics (Geomagic Touch) tool will be a medium to interact with the virtual world of physics, mathematics and chemistry. Here, one can feel the different properties of physics like mass, texture, shape, force, friction, elasticity and stiffness.

CHAPTER 2

HYPOTHESIS

For an in-depth understanding of physics and mathematics throughout life, it will be beneficial if every student is introduced to physics and mathematics via 3D interactive platform between the age of 7 and 10 years.

Three Dimensional Softwares are widely used in various fields. They have been applied to the industries, research analysis, animation and other areas but there is no implementation of such software for education purpose. The reason for this is that 3D softwares are very complex to understand and are not user-friendly for the children. It is also very difficult for them to understand 3D objects in the 2D workbench. Therefore this study proposes a simple and user-friendly 3D dimensional software for the children with the use of simplified user interaction. In this concept, we are using haptic technology so that children can easily interact with three-dimensional software with the physical touch. Physical touch helps them to memorise geometric shapes and understands actual behaviour of the 3D model. Further, this concept provides a traditional method to create a three dimensional model like clay modelling. Through the developed system, it is possible for the children to easily create 3D forms and obtain the 3D print of the model. It will reduce their effort to visualize complex structure and also help them in effective learning.

CHAPTER 3

THEORY

3.1 What is Cognition?

Cognition is "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses". It is related to processes such as attention, the formation of knowledge, memory and working memory, judgment and evaluation, reasoning and "computation", problem solving and decision making, comprehension and production of language. Cognitive processes use existing knowledge and generate new knowledge.

The processes are analyzed from different perspectives within different contexts, notably in the fields of linguistics, anesthesia, neuroscience, psychiatry, psychology, education, philosophy, anthropology, biology, systemics, logic, and computer science. These and other different approaches to the analysis of cognition are synthesised in the developing field of cognitive science, a progressively autonomous academic discipline.

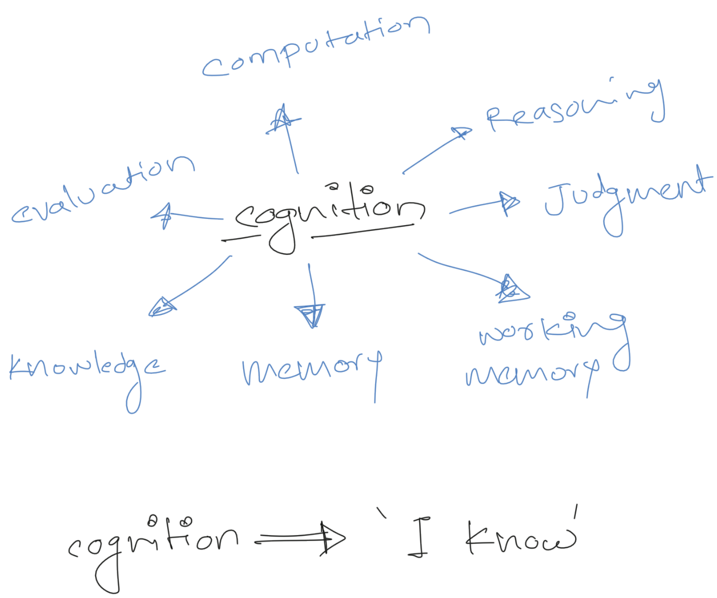

Figure 01 . *Different field of science of cognition classified for the study and their interreletation*

3.2 How is cognition developed ?

Depending on specific field of execution, development of congition can be explained using different terms. But the cognitive development in children might be the most important study considered in human development. The theory of cognitive development is very well explained by a Swiss psychologist Jean Piaget. He is the pioneer of explaining the cognitive development if children. As per the Piaget theory, there are four stages of cognitive development as mentioned in chapter one. Sensorimotor stage, Preoperational stage, Concrete operational stage and Formal operational stage.

Piaget believed that children took an active role in the learning process, acting much like little scientists as they perform experiments, make observations, and learn about the world. As kids interact with the world around them, they continually add new knowledge, build upon existing knowledge, and adapt previously held ideas to accommodate new information.

3.3 Some important concepts of cognitive development

To better understand some of the things that happen during cognitive development, it is important first to examine few important ideas and concepts introduced by Piaget.

- **Schemas**

  A schema describes both the mental and physical actions involved in understanding and knowing. Schemas are categories of knowledge that help us to interpret and understand the world.In Piaget's view, a schema includes both a category of knowledge and the process of obtaining that knowledge.

As experiences happen, this new information is used to modify, add to, or change previously existing schemas.

For example, a child may have a schema about a type of animal, such as a dog. If the child's sole experience has been with small dogs, a child might believe that all dogs are small, furry, and have four legs. Suppose then that the child encounters an enormous dog. The child will take in this new information, modifying the previously existing schema to include these new observations.

- **Assimilation**

  The process of taking in new information into our already existing schemas is known as assimilation. The process is somewhat subjective because we tend to modify experiences and information slightly to fit in with our preexisting beliefs. In the example above, seeing a dog and labeling it "dog" is a case of assimilating the animal into the child's dog schema.

- **Accommodation**

  Another part of adaptation involves changing or altering our existing schemas in light of new information, a process known as accommodation. Accommodation involves modifying existing schemas, or ideas, as a result of new information or new experiences. New schemas may also be developed during this process.

- **Equilibration**

  Piaget believed that all children try to strike a balance between assimilation and accommodation, which is achieved through a mechanism Piaget called equilibration. As children progress through the stages of cognitive development, it is important to maintain a balance between applying previous knowledge (assimilation) and changing behavior to account for new knowledge (accommodation). Equilibration helps explain how children can move from one stage of thought into the next.

3.4 Artifacts, Virtual artifacts and cognitive artifacts

- **Artifacts**

  Artifacts are those made or given shape to by human, for example a tool or a work of art. Artifacts are usually archaeological objects and the word artifact comes from the Latin phrase arte factum, which means to make.

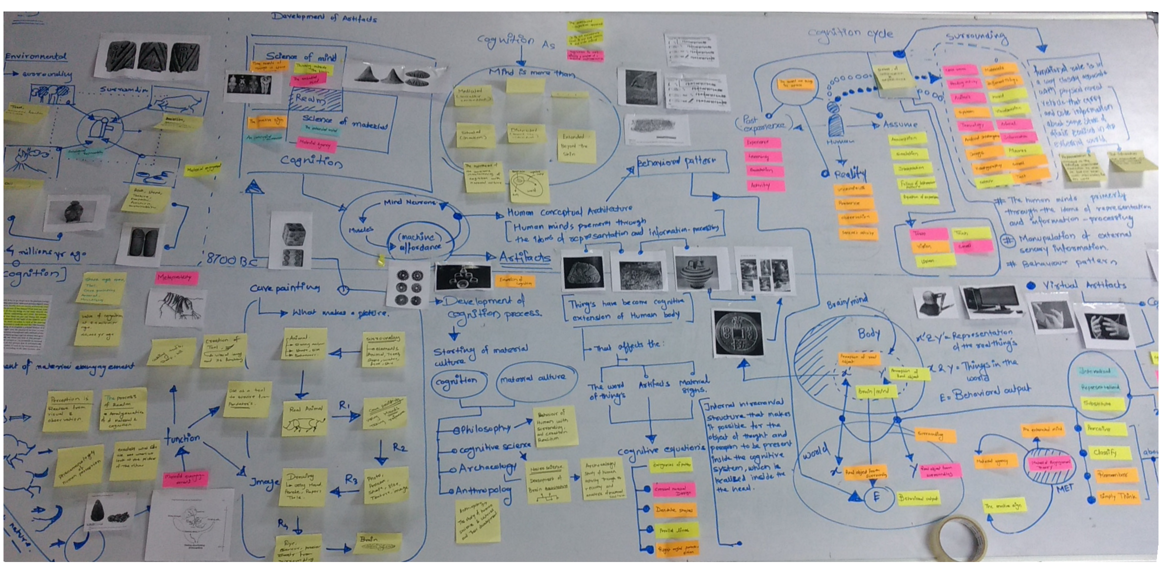

Figure 02. *Study of the development of artifacts from stone age man to cognitive artifacts*

An artifact is the one the most important term for the beginning of cognition in mankind. Creating something from the hands and understanding the shape is the most effective method to improve our cognition. We can learn this from the Stone Age men. They created tools by observing surroundings and used it for hunting. They observed different animals and their lifestyles, their hunting techniques and how they used their tools for protection and survival. This is how humans started adapting their life to surroundings and started learning from it. With passage of time, the meaning of artifacts changed as humans started using it for beautification and cultural things. Human started connecting their emotions with the artifacts and started believing in the spritual world and this is how maybe humans created God. In human history, we have started developing our cognition by making artifacts so it is very important to understand the beginning of a cognitive evolution of human being.

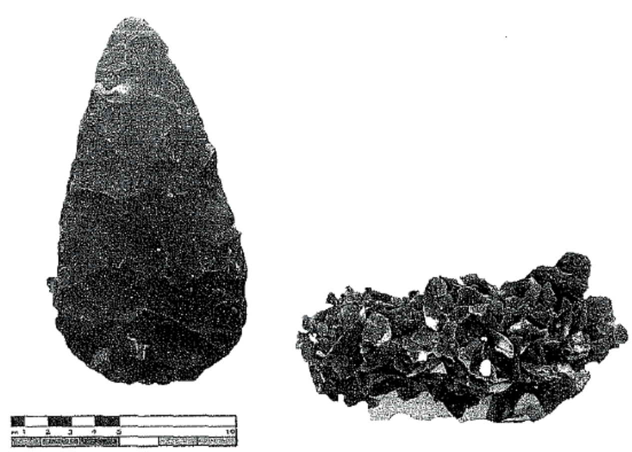

Figure 03: *Stone Age man Making of sharp tool using their surrounding observation and developing cognition.*

- **Virtual Artifacts**

A virtual å(VA) is an immaterial object that exists in the human mind or in a digital environment, for example the Internet, intranet, virtual reality, cyberspace.

Imaginary worlds, characters, items, etc. have been described in stories and tales since the dawn of humanity. In the philosophic discourse, utopias have existed where extensive systems and their components have been depicted in detail. Imaginary artifacts have been described and created in terms of language and visual presentation. The development of the visual presentation techniques (e.g. linear perspective, cinematography) enabled more sophisticated methods to describe these artifacts, events and entities in painting, photography and film. Moreover, virtual artifacts were (and still are) commonly found in environments that require a strong imaginary aspect in order to be experienced, such as radio shows, novels, tabletop role-playing games, etc.

The development of computing enabled the creation of interactive virtual environments that were based on digital technologies and new methods of presentation. In digital environments, virtual artifacts became independent entities that could exist and interact outside the human mind. Even previously unknown, complex forms and imaginary artifacts (e.g. fractals) could be created and represented in these environments.

- **Cognitive Artifacts**

  “ Cognitive artifacts may be defined as "those artificial devices that maintain, display, or operate upon information in order to serve a representational function and that affect human cognitive performance." (Norman 1991, p.17) Cognitive artifacts are in other words man-made things that seem to aid or enhance our cognitive abilities, and some examples are calendars, to-do lists, computers, or simply tying a string around your finger as a reminder.

  An artifact can be though of as a meeting point - an "interface" in today's terms - between an "inner" environment, the substance and organization of the artifact itself, and an "outer" environment, the surroundings in which it operates. If the inner envionment is appropriate to the outer environmnet, or vice versa, the artifact will serve its intended purpose

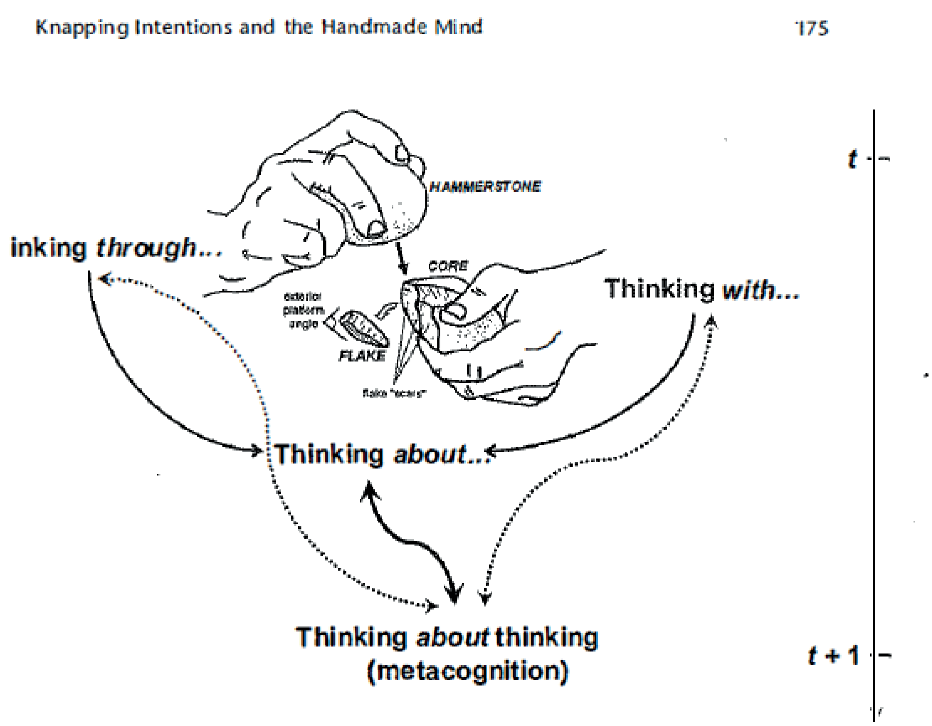

Figure 04. *In the figure we can see the process of how humans think and create something (Image courtecy “How things shape mind”)*

3.5 Haptics

Haptic or kinesthetic communication recreates the sense of touch by applying forces, vibrations, or motions to the user. This mechanical stimulation can be used to assist in the creation of virtual objects in a computer simulation, to control such virtual objects, and to enhance the remote control of machines and devices (telerobotics). Haptic devices may incorporate tactile sensors that measure forces exerted by the user on the interface.

Most researchers distinguish three sensory systems related to sense of touch in humans: cutaneous, kinesthetic and haptic. All perceptions mediated by cutaneous and/or kinesthetic sensibility are referred to as tactual perception. The sense of touch may be classified as passive and active, and the term "haptic" is often associated with active touch to communicate or recognize objects.Haptic technology has made it possible to investigate how the human sense of touch works by allowing the creation of carefully controlled haptic virtual objects.

3.5.1 What is Haptics ?

The somatosensory system is a part of the sensory nervous system. The somatosensory system is a complex system of sensory neurons and pathways that responds to changes at the surface or inside the body. The axons (as afferent nerve fibers), of sensory neurons connect with, or respond to, various receptor cells. These sensory receptor cells are activated by different stimuli such as heat and nociception, giving a functional name to the responding sensory neuron, such as a thermoreceptor which carries information about temperature changes. Other types include mechanoreceptors, chemoreceptors, and nociceptors and they send signals along a sensory nerve to the spinal cord where they may be processed by other sensory neurons and then relayed to the brain for further processing. Sensory receptors are found all over the body including the skin, epithelial tissues, muscles, bones and joints, internal organs, and the cardiovascular system.

3.5.2 How it works ?

Touch is a crucial means of receiving information. This photo shows tactile markings identifying stairs for visually impaired people. Somatic senses are sometimes referred to as somesthetic senses, with the understanding that somesthesis includes the sense of touch, proprioception (sense of position and movement), and (depending on usage) haptic perception.The mapping of the body surfaces in the brain is called somatotopy. In the cortex, it is also referred to as the cortical homunculus. This brain-surface ("cortical") map is not immutable, however. Dramatic shifts can occur in response to stroke or injury.

3.5.3 Neurophysological part of haptics

The four mechanoreceptors in the skin each respond to different stimuli for short or long periods. Merkel cell nerve endings are found in the basal epidermis and hair follicles; they react to low vibrations (5–15 Hz) and deep static touch such as shapes and edges. Due to a small receptive field (extremely detailed info) they are used in areas like fingertips the most; they are not covered (shelled) and thus respond to pressures over long periods.

Tactile corpuscles react to moderate vibration (10–50 Hz) and light touch. They are located in the dermal papillae; due to their reactivity they are primarily located in fingertips and lips. They respond in quick action potentials, unlike Merkel. They are responsible for the ability to read Braille and feel gentle stimuli.

Lamellar corpuscles determine gross touch and distinguish rough and soft substances. They react in quick action potentials, especially to vibrations around 250 Hz (even up to centimeters away). They are the most sensitive to vibrations, and have large receptor fields. Pacinian reacts only to sudden stimuli so pressures like clothes that are always compressing their shape are quickly ignored.

Bulbous corpuscles react slowly and respond to sustained skin stretch. They are responsible for the feeling of object slippage and play a major role in the kinesthetic sense and control of finger position and movement. Merkel and bulbous cells - slow-response - are myelinated; the rest - fast-response - are not. All of these receptors are activated upon pressures that squish their shape causing an action potential.

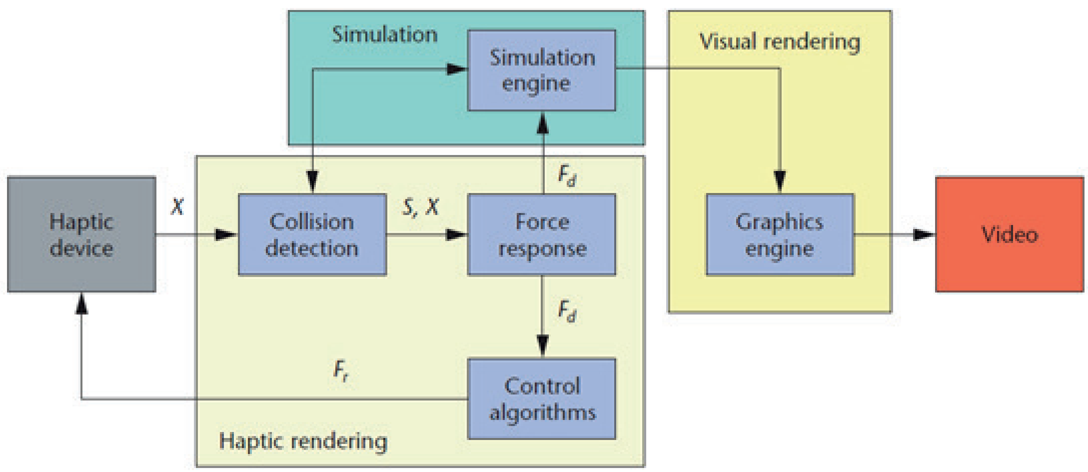

Figure 05: *This diagram linearly (unless otherwise mentioned) tracks the projections of all known structures that allow for touch to their relevant endpoints in the human brain.*

3.6 What is spatial thinking ?

So far, we have been casual in using the term “spatial thinking.” But what do we really mean by it? Spatial thinking concerns the locations of objects, their shapes, their relations to each other, and the paths they take as they move. All of us think spatially in many everyday situations: when we consider rearranging the furniture in a room, when we assemble a bookcase using a diagram,when we relate a map to the road ahead of us. We also use spatial thinking to describe nonspatial situations, such as when we talk about being close to a goal or describe someone as an insider.

3.6.1 Importance of spatial thinking

Spatial thinking--such as visualizing the earth rotating--is crucial to student success in science, technology, engineering, and mathematics (STEM). Since spatial thinking is associated with skill and interest in STEM fields (as well as in other areas, such as art, graphic design, and architecture), the immediate question is whether it can be improved. While some students are better at spatial thinking than others, everyone can improve. The need to develop students' spatial thinking is currently not widely understood. The educators already have some excellent techniques for developing it, through practice, language, gesture, maps, diagrams, sketching, and analogy. Systematically building these techniques into the curriculum could yield important dividends for Indian education. In this thesis, I am exploring the new platform to improving spatial thinking by using haptics in 3D environment.

3.6.2 Geometry and spatial thinking in children

Geometry and spatial reasoning are inherently important because they involve "grasping ... that space in which the child lives, breathes and moves ... that space that the child must learn to know, explore, conquer, in order to live, breathe and move better in it" (Freudenthal, in National Council of Teachers of Mathematics [NCTMI, 1989, p. 48). In addition, especially for early childhood, geometry and spatial reasoning form the foundation of much learning of mathematics and other subjects. Although ourknowledge ofyoung children's geometric and spatial thinking is not as extensive as that of their numerical thinking, it has grown substantially and can be used as a basis for curriculum development and teaching. Here, we briefly review these two main areas of this research: shape and

3.6.3 Why children struggel to identify 3D shapes.

Students do not perform well with 3-D shapes. Most intermediate-grade students have difficulty naming solids (Carpenter, Coburn, Reys, & Wilson, 1976). South African first grad- ers used different names for solids (such as "square" for cube) but were capable of understanding and remembering features they discussed (Nieuwoudt & van Niekerk, 1997). U.S. students'
reasoning about solids was much like that about plane figures; they referred to a variety of char- acteristics, such as "pointyness" and comparative size or slenderness (Lehrer et aL, 1998). Students also treated the solid wooden figures asalleable, suggesting that the rectangular prism could be transformed ,oto a cube by "sitting on it. "Use of plane figure names for solids may indicate a lack of discrimination tween two and three dimensions (Carpenter et aI., 1976). Learning only Ilane figures in textbooks during the early primary grades may cause some ·tial difficulty in learning solids. Construction activities involving nets (fold- ut shapes of solids) may be valuable as they require children to switch be- een more-analytic 2-D and synthetic 3-D situations (Nieuwoudt & vaniekerk, 1997).

CHAPTER 4

METHODOLOGY

4.1 Children psychology towards 2D and 3D Object

In the current education system, there is not even one subject to understand 3D forms through 3D software for children. Hence, it is very difficult for them to visualize 3D objects. Therefore, the first phase of a design process is to visit schools to understand their psychology and behaviour to make 3D forms. For that, it is important to involve them in the task of drawing, clay modelling and Origami to observe their approach to make 3D objects.

In the process of understanding how students perceive 2D and 3D objects, we did one experiment. In the experiment, there were 22 students were involved between the age of 7 to 9 years. In the first round of experiment, students had to draw a 2D object like a square, circle or triangle. The first round is to understand how the student perceives 2D objects. Most of the students easily drew the given objects without any obstacle.

Figure 06: *Students are drawing 2D objects as per given instructions in the first round of the experiment.*

Figure 07: *Students are trying to identify the difference between 2D and 3D object.*

In the second round of the experiment, students were given a task to draw the same 2D objects into 3D objects. However, most of the students were not aware of the 3-dimensional perspective. When asked to differentiate between the 2D and 3D physical objects, most could easily do so. But, surprisingly, 95% students failed to draw 3D sketches. From this interaction session, we understood that students observe their surroundings but are unable to understand the nomenclature of nature. As a result, most students succeeded in identifying 2D and 3D objects but failed to explain the difference between them.

From the experiment, we have identified that the observation of students is much stronger than their cognitive rate. Due to the poor academic course structure, most of the students are unable to understand the concepts of nature merely from textual knowledge. Though the study of 3D objects has been included in Grade 3 syllabus, most students failed in the second round of our experiment. This due to improper development of spatial thinking in the academic course.

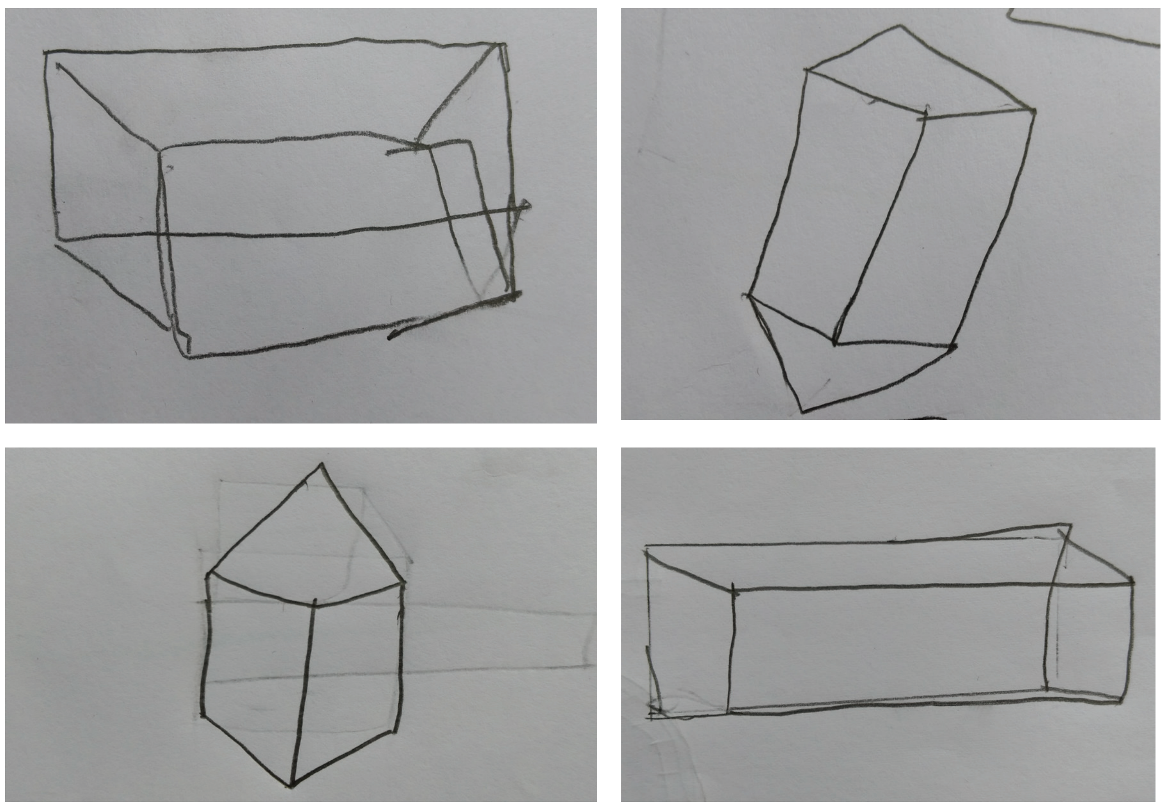

Figure 08: *Some of the drawing of students who were struggling to draw 3D objects*

4.2 Contextual Enquiry

We visited the school to understand their activities in their own environment so that we could learn their natural behaviour. In this process, we gave them a task of creating a 3D form with the help of clay. In this activity, we observed their hand gestures, uses of tools, the way they held the tools and their visualization.

Figure 09: *Students were answering the question about 3D objects and their properties*

Behavorial Observations

In the process of interacting with students, most of the students were very enthusiastic as it opened up a new world of imagination in 3D space which made them curious about the study. We also observed some specific children and chose them for a more detailed study. We chose three students from the 42 students who were very curious about geometry but were poor at understanding it. In the task, the performance of those three students was very low. So, we decided to observe them in different situations - in isolation, in a group and in the classroom. After studying each of them in three different situations, we identified their socio cognition and their observation patterns.

We also told them to do various activities. First, we asked them about their favourite object and asked them to draw it on paper. The object they mentioned was a bicycle. In the second task, we took them near a bicycle and asked again to draw it. In the first task, the student could very well explain the structure of the bicycle but was struggling to draw it on paper. However, when we showed them a bicycle and asked to draw by observing, he managed to draw it fundamentally correct. In this process, we understood that students can observe the fundamental properties of 3D objects but they struggle in drawing it fundamentally correct. The possible reason would be that students mostly learn the fundamental properties from a theoretical book without experiencing it in real. As a result, they fail at developing their cognition to understand the function and fundamental properties of any 3D object.

4.3 Validation Study

The data which we have collected from the survey is analyzed to conclude out objectives for the product. We identified the common hand gesture, 3D forms and the use of tools to study the common behaviors of children in the task. It helped to find out the simplified way to design the 3D model.

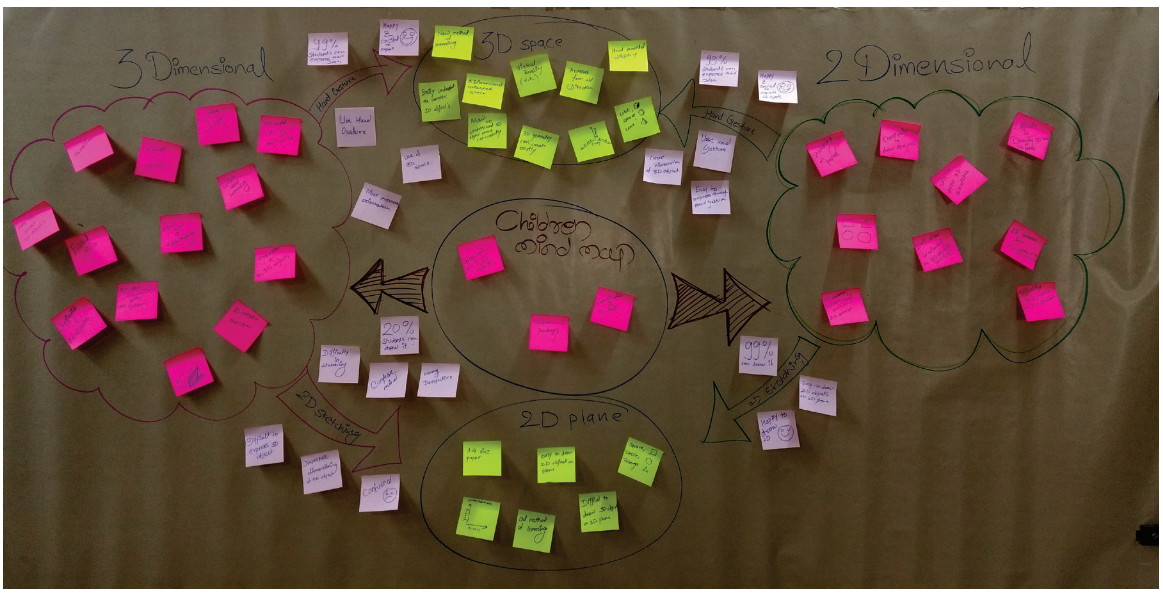

Figure 10: *In the figure, data is classified to create a mind map of students to understand the touch points.*

The data is collected from the task and observation is collected in four categories. 2D space, 3D space, 3dimensional and 2 dimensional. The classified data is gathered from the different student's behaviour and the performance of the task. From the classification, we have created a mind map of students in the different dimensions. From the diagram given in the above image, we can correlate the connection between the children emotion and their behaviour in the different situation and identify the interactive touch point for the platform.

4.4 Designing User Interface

From overall study, we will use color theory, graphic icons, basic geometric shapes and animation to create more user friendly interface for 3D software. In the user interface these elements will help them to become familiar and even it is very easy for them to interact with the system.

In the process of designing an interactive platform for children, we took a reference from their textbook. In the first part of the interactive platform, we focus only on geometric shapes which are given in the textbook. There is a chapter in the textbook about shapes, basically, the chapter focuses on the study of different geometric shapes and understand their properties. By taking consideration of the exercise given in the chapter we created an interactive platform using X3D and Python script where students can solve the same exercise using interactive Geomagic tool. In the platform, the student has to interact with the cube and count the number of faces on cube by using the Geomagic pen. During the interaction, the student can feel the touch force of the cube in the Geomagic pen.

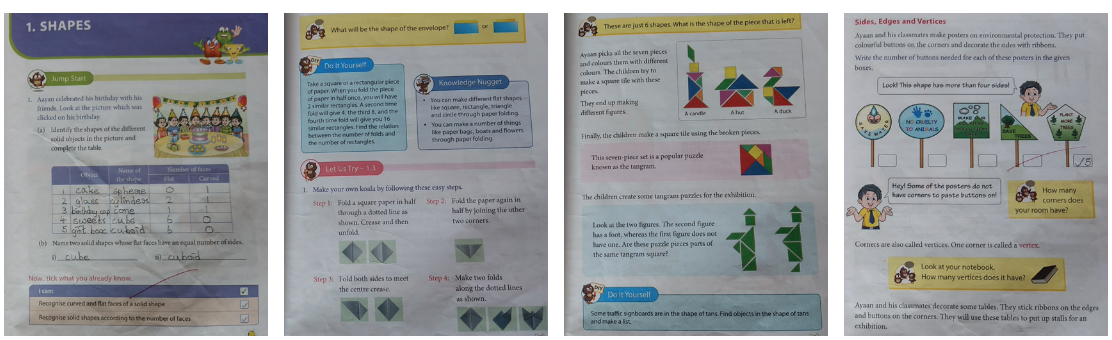

Figure 11: *In the figure, Chapter in the 3rd standard textbook on shape is shown.*

4.4.1 Technology used

With a rapid advancement in technology, a new domain called Haptics has opened up. The world is moving towards Virtual Reality and extensive Human-Machine interaction is now a key point for any successful technology. Keeping this in mind, it is important to explore various applications of such a technology which promises to bring thoughtful changes to the way humans interact with information and communicate ideas.

4.4.2 Haptics technology

The word “haptics” is derived from a Greek word 'haptikos' which means pertaining to sense of touch. According to Wikipedia, Haptic or kinesthetic communication recreates the sense of touch by applying forces, vibrations, or motions to the user. With the help of Haptic device people get a sense of touch with computer generated environments, so that when virtual objects are touched, they seem to be real and tangible. Haptic technology enables the user to interface with a virtual environment via the sense of touch. Haptics has collectively brought biomechanics, psychology, neurology, engineering and computer in study of human touch and force feedback.

Figure 12 : *Haptics force feedback tool*

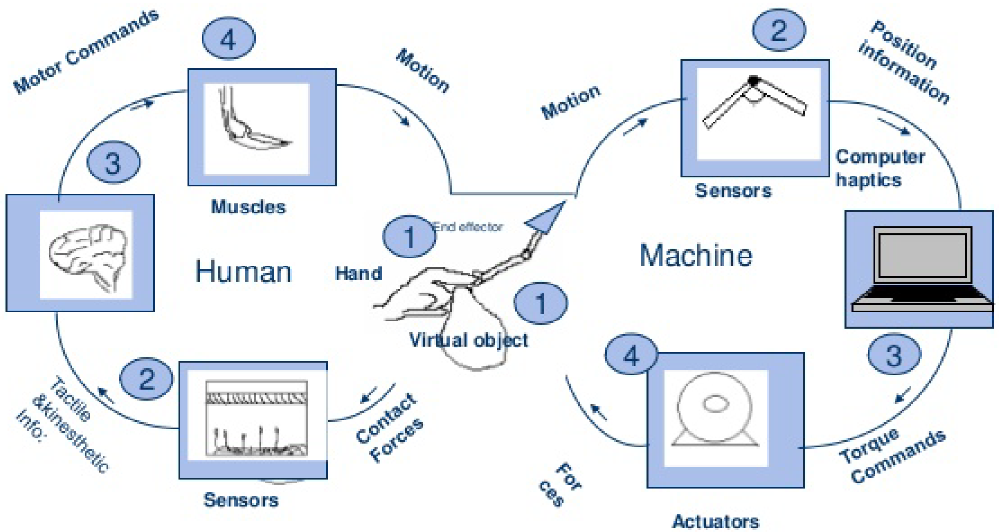

Figure 13: *Haptic system define the interaction between human and brain*

4.4.3 Haptic System

Basically a Haptic system consists of two parts namely human part and the machine part. In the Figure 2, left part is human part and right part is machine part. The human part senses and controls the position of the hand and machine part exerts forces from the hand to simulate contact with a virtual object.

Specialized hardware is used in haptics applications to provide sensory feedback. A common haptic interface configuration uses mechanical linkages to link a person's finger to computer interface. When the user's fingers moves, the sensors translate those motions into actions on a screen. Thus motors transmit feedback through the linkages to the fingers of the user. The process used by software to perform its calculation is called haptic rendering.

4.4.3 Haptic Devices

Mechanical devices that mediate between the user and the computer are referred to as haptic devices. Haptic devices are input-output devices. They are able to track the user's physical manipulation which is input and provide realistic touch sensations coordinated with the on – screen events as output.
The haptic device used in this project is Geomagic Tool shown in Fig 3. The device has in-built servo motors used to provide force feedback for a sense of touching a virtual object.

Figure 14: *Haptic touch tool which is used to interact with the virtual 3D model using force feedback.*

4.4.4 Applications of haptic

The applications of Haptic technology are numerous and ever ending. Future applications of haptic technology cover a wide spectrum of human interaction with technology. Current research focuses on the mastery of tactile interaction with holograms and distant objects, which if successful may result in applications and advancements in gaming, movies, manufacturing, medical, and other industries.The medical industry stands to gain from virtual and telepresence surgeries, which provide new options for medical care. The clothing retail industry could gain from haptic technology by allowing users to "feel" the texture of clothes for sale on the internet.Future advancements in haptic technology may create new industries that were previously neither feasible nor realistic. Haptic technology can also be used for virtual learning to create a 3D interactive platform.

4.4.5 Use of haptic in the project

As mentioned above, Haptics technology can be extensively used in learning and teaching. It will be elemental in the enhancement of cognitive understanding of subjects like physics and mathematics. With the help of 3D interactive platform like Geomagic Haptic Device, students will have an experience like none other. Studies show that introduction of 3D interaction at the age of 7 to 10 years should help in creating an in-depth understanding of physics and mathematics. Physics and mathematics are often feared by students and this technology will be instrumental in removing this fear.

With this motivation, the project is aimed for creating a 3D interaction platform for Grade III students. The project also provides a platform for getting started with developing their cognition and includes step-by-step instructions from basic to higher examples. At the end of the platform, one will be able to create various objects and environments which can be interacted with GeoMagic Device for the sense of touch.

4.5 Technical Specifications

Other than the GeoMagic Touch Haptic Device, creating a 3D interactive platform requires various software tools and programming languages.

4.5.1 H3D and H3D Viewer

H3D API is an open-source, cross-platform, scene-graph API (Applications program interface) . H3D is written entirely in C++ and uses OpenGL for graphics rendering and HAPI for haptics rendering.
H3DViewer is an application for displaying x3d-files with haptic content using H3D API. It provides an additional feature of being able to change settings for haptic and graphic rendering while the scene is being rendered. At the same time H3DViewer works as any normal X3D-viewer which lets the user navigate the scene, change navigation type etc.

For installation and basic initial instructions, follow the official manual available on the website.

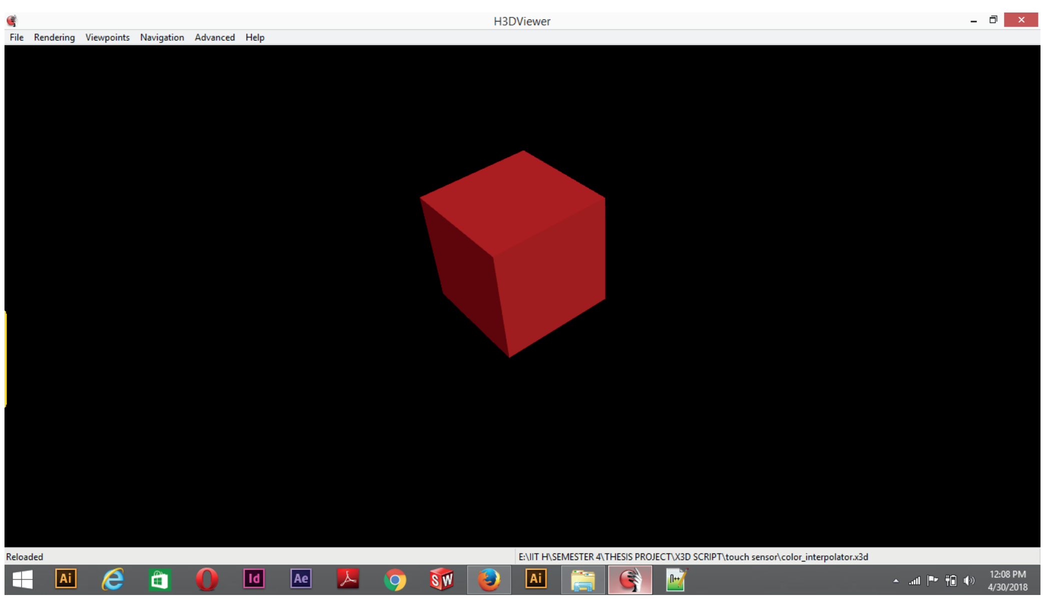

Figure 15: *It is an H3D viewer where we can interact with the 3D object. As shown in the figure we can interact with the cube using geomagic haptic tool.*

4.5.2 X3D

The X3D file format is used by H3D as an easy way to define geometry and arrange scene-graph elements such as a user interface. H3D has a full XML enabled X3D parser and automatically supports predefined X3D nodes as well as any new nodes developed for the required objects and environment.

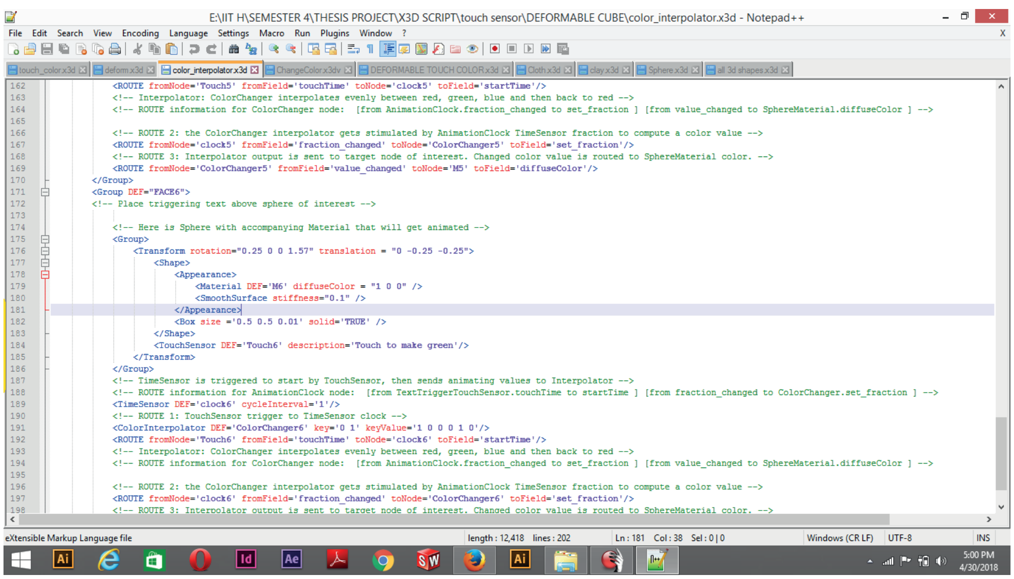

Figure 16: *It is a script written for the interactive cube where we can count the faces of cube. The script is written in X3D and python.*

4.5.3 Python

Python is an interpreted language meaning that you do not need to compile your python scripts to run them. Python is ideal for defining fields that control simple non-time-critical behavioral properties such as managing a user-interface. Python also has an extensive library of extensions to simplify tasks such as file management, network communication and database access. Python provides additional functionalities and helps to create complicated 3D interactions in X3D.

There are elementary examples to get acquainted with Python and few examples with X3D.

4.5.4 The H3DInterface Python module

All H3D specific types, like fields and types like Vec3f, Matrix3f, etc, are included in a Python module called H3DInterface. In order to get access to these types and functions from your python script one has to import the module. The H3DInterface module is a bridge between X3D and Python. It is imported like any other python module.

4.5.1 GeoMagic Touch Haptic Device

The Touch haptic device by 3Dsystems enhances productivity and efficiency by enabling the most intuitive human-computer interaction possible, the ability to solve problems by touch. The Touch model is a cost-effective haptic device. The Touch system's high fidelity force feedback senses motion in 6 degrees of freedom providing the best, most realistic 3D Touch sensation for any application. One can feel the point of the stylus in all axes, and track its orientation (pitch, roll and yaw). The Touch's portable design, compact footprint, and an USB interface ensures quick installation and ease-of-use.

CHAPTER 5

EXPERIMENT

5.1 Pattern of experiment

The experiment is done for the 20 students - 12 boys and 8 girls. In the process, we have considered 20 students as a subject who attended an adaptive training program as per the process. Before and after the adaptive training program, all student went through three tests -Purdue Rotations test, Maths test and Short form Paper Folding test. As per the before and after the performance of the student in the test, a mean value and standard deviation were calculated to identify the result. On the basis of these statistics, we could identify the accuracy and analyze the performance of students in each of the 3 tests. This greatly helped us to understand the impact of the adaptive training program.

Before the adaptive training program, all student attended the three tests which were of 2 hours duration each. Each test carried 30 marks having three questions of 10 mark each. The first two tests were theoretical and third test that was a paper folding which had to be done practically. On the basis of performance of each student before and after the adaptive program, we could observe substantial changes in the performance. The questions could be different before and after the test but they tested the same concept in physics and mathematics.

Figure 17: *Students solving the test before adaptive training program.*

5.1.1 Purdue Rotations test

The Purdue Spatial Visualization Test-Visualization of Rotations (PSVT:R) is a test of spatial visualization ability published by Roland B. Guay in 1977. Many modifications of the test exist.

This paper probes the relationship between the psychometric construct known as 'spatial ability' and students' performance in Geometry courses. It examines some of the early literature on the evolution of the concept of spatial ability, reviews the results of research on the relationship between success (or failure) in introductory Geometry course and students' spatial ability, and describes a spatial ability test known as The Purdue Visualization of Rotations (ROT) test that has been shown to be among the spatial ability tests whose results are least likely to be complicated by analytical processing.

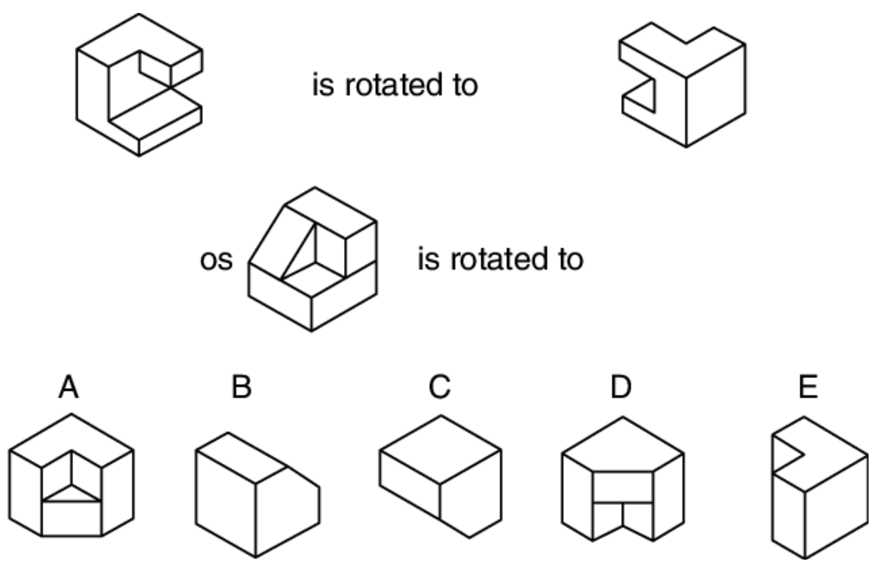

Figure 18: *In the figure the sample of Question asked in ROT is given*

This test can identify the spatial thinking ability of student by solving the problems. In the test, a student has to identify the next orientation of the 3D object and imagining the 3D object in mind. From the test, we can also identify the 3D orientation memory of students.

5.1.2 Conservation test

The test is given to identify the skill of student to identify the properties of different 3D shapes. In the test, students have to solve some basic geometry question depend on the shape and their properties. From the test, we identified the ability of the student to understand different properties of the 3D world. Basically, we can identify how the student perceives objects from surrounding from their day to day life and explain it in the paper.

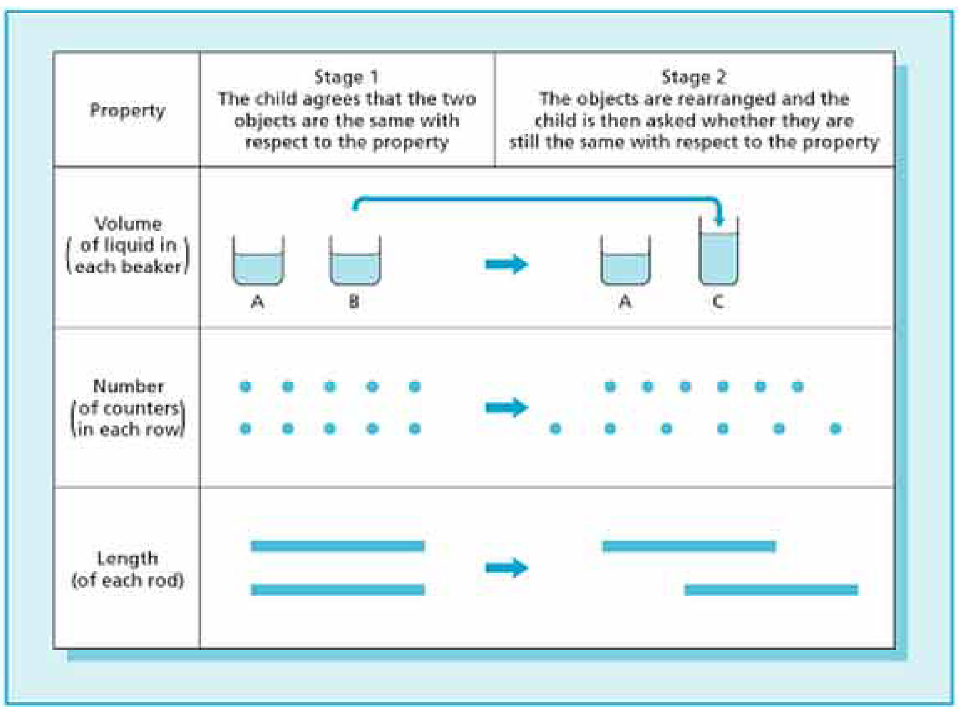

Figure 19 : *Sample of Question asked in Conservation test*

5.1.3 Short form Paper Folding test

Mental paper folding is a complex measure of visuospatial ability involving a coordinated sequence of mental transformations and is often considered a measure of mental ability. The literature is inconclusive regarding the precise neural architecture that underlies performance.

Mental paper folding is a complex visual transformation task. Mental transformation of visual stimuli is a component of spatial ability, which has been considered a form of general intelligence or a “global measure of mental ability” (Uhlaner and Bolanovich 1952, p. 11; Lohman 2000). Mental paper folding involves mentally imagining the folding of a 2-dimensional pattern into a mental representation of a 3-dimensional box, or mentally unfolding the 3-dimensional box into a 2-dimensional pattern. To complete a mental paper folding task, each fold requires a simple mental rotation of a square, from 2-dimensionality to 3-dimensionality creating a sequence of coordinated manipulation of the mental rotation and transformation components (Milivojevic et al. 2003).

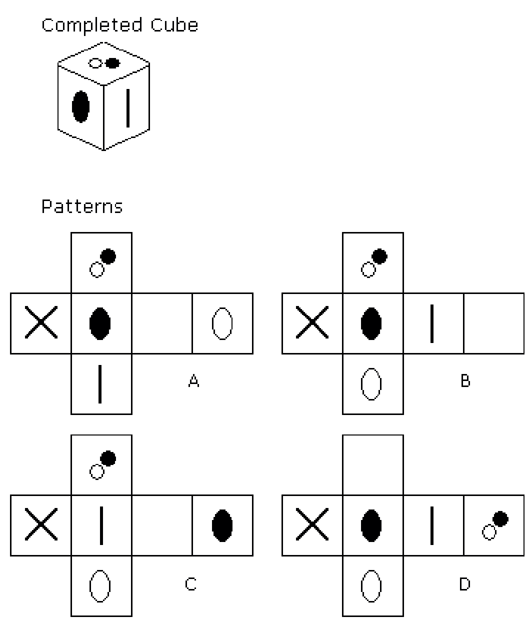

Figure 20: In the figure the sample of Question asked in paper folding test

Both visual representation of the pattern and transformation in 3-dimensional space is essential to correctly answer a mental paper folding question. Mental rotation is a widely studied visuospatial measure; however, there is a continued lack of consensus regarding the precise neural structures that correlate with performance. Both mental rotation and mental paper folding are the subtypes of objective imagery control or spatial transformations, the ability to manipulate mental representations (Ekstrom et al. 1976; Lequerica et al. 2010). Mental rotation involves encoding internal spatial relations and correctly mentally transforming a visual stimulus.

Figure 21: *Student solving short form Paper Folding test after adaptive training program*

5.2 Test Results

Children completed the first pre-training assessments. Training commences within a one week of this assessment. Children completed a set of post-training assessments within one week of finishing their training. The data are reported for 20 students (12 boys and 8 girls) with a group of 7-10 yrs. Participants scored in pre and post-training.

- **Purdue Rotations test**

  Data reported for 20 students (12 boys and 8 girls) from third standard class. Who completed pre-Purdue Rotations test and post-Purdue Rotations test. Participants scored as per the test from 30 marks having three quests of 10 mark each. The mean value was 14.3 and standard deviation 6.87 for pre-Purdue rotation test and The mean value was 24.65 and standard deviation 4.715 for post-Purdue rotation test.

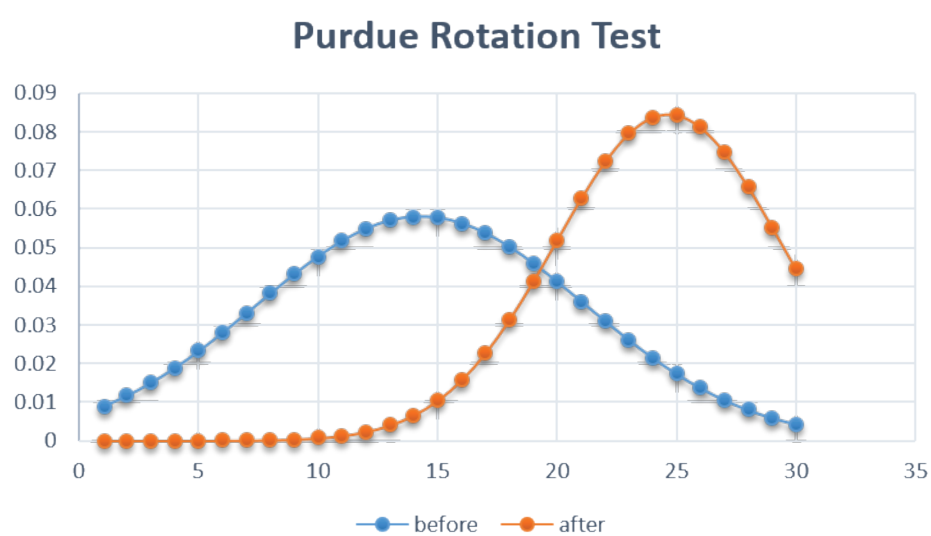

Figure 22: *The result of Purdue Rotation test*

- **Conservation test**

Data reported for 20 students (12 boys and 8 girls) from third standard class who completed pre-**Conservation test** and post-**Conservation test** . Participants scored as per the test from 30 marks having three quests of 10 mark each. The mean value was13.85 and standard deviation 7.548 for pre-Purdue rotation test and The mean value was 19.7 and standard deviation 5.87 for post-Purdue rotation test.

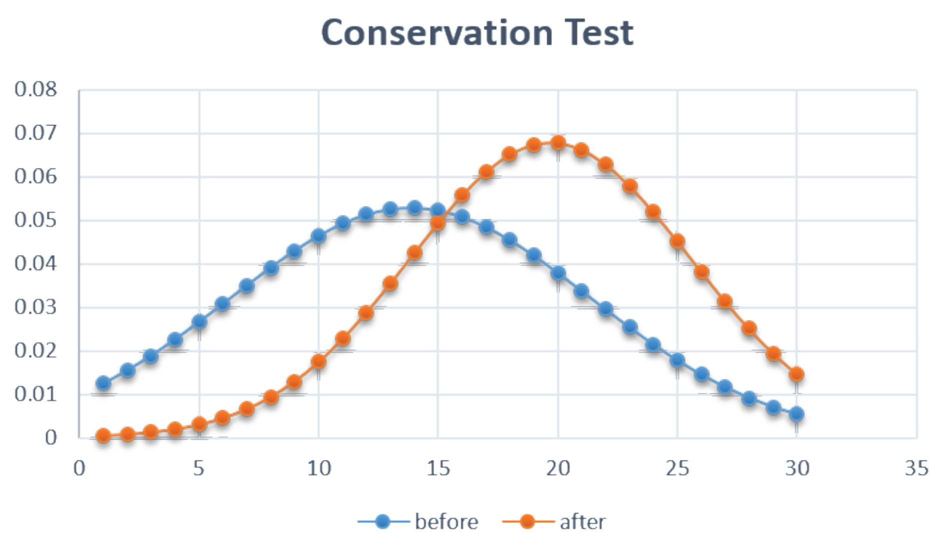

Figure 23: *The result of Conservation test*

- **Short form Paper Folding test**

  Data reported for 20 students (12 boys and 8 girls) from third standard class. Who completed pre-**Short form Paper Folding test** and post-**Short form Paper Folding test**. Participants scored as per the test from 30 marks having three quests of 10 mark each. The mean value was 14.25 and standard deviation 7.785 for pre-Purdue rotation test and The mean value was 22.15 and standard deviation 6.149 for post-Purdue rotation test.

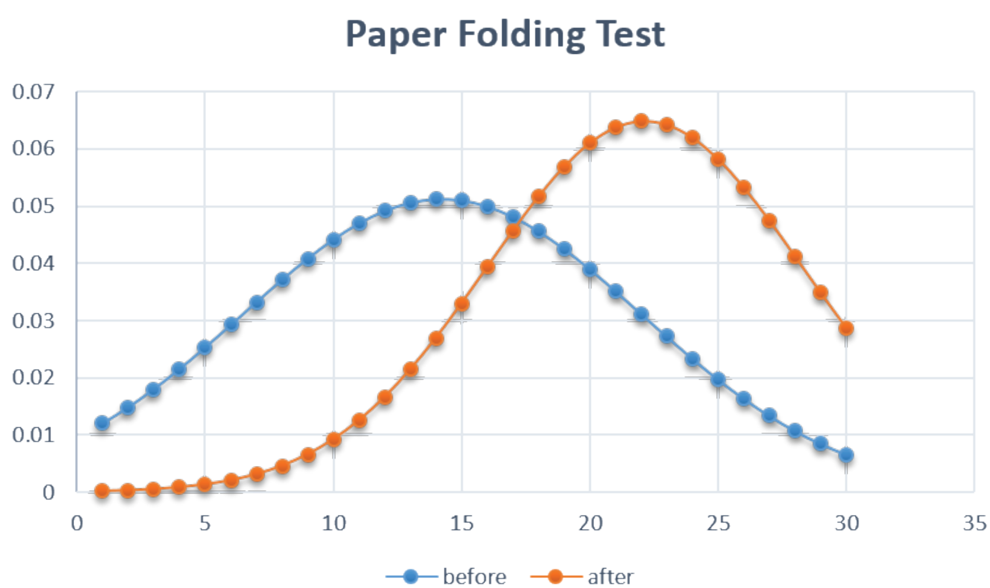

Figure 24: *The result of Paper folding test*

5.3 Impact of adaptive training program

An adaptive training program is a one-week training program where students have to interact with the virtual 3D objects like cube, sphere, cone and cylinder. Students interacted with the 3D object using Geomagic Touch haptic tool which is basically an interactive tool used for force feedback during interaction with virtual objects. The touching scene with the object creates a real experience for the students which gives them an enhanced opportunity to learn about different geometric shapes. The 3D orientation of the objects helps them to develop their 3D orientation memory.

In the program, students have to repeatedly interact with the 3D object by understanding their orientation about all axes. Moreover, students can also feel other properties of solid like friction, weight, inertia, elasticity, and damping. Because of these properties, students can experience a real touch of interaction with the object which helps them to build their cognition and improve their spatial thinking ability. Force feedback theory of Geomagic Touch haptic tool will improve the working memory of students as it gives a practical experience of the solid properties. Students also interacted with the different dimension of 3D world as they played with the moving solar system which they had never experienced before. The interactive moving solar system made them curious and motivated them to imagine beyond there limits.

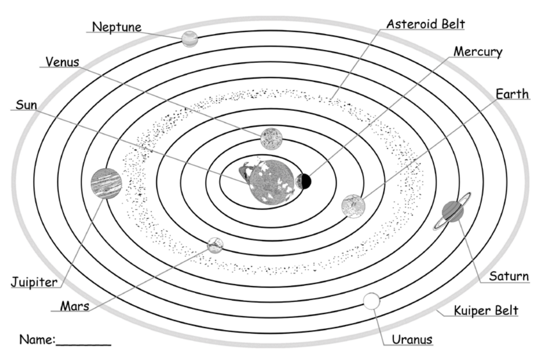

Figure 25: *Diagram of a solar system given in the third standard book*

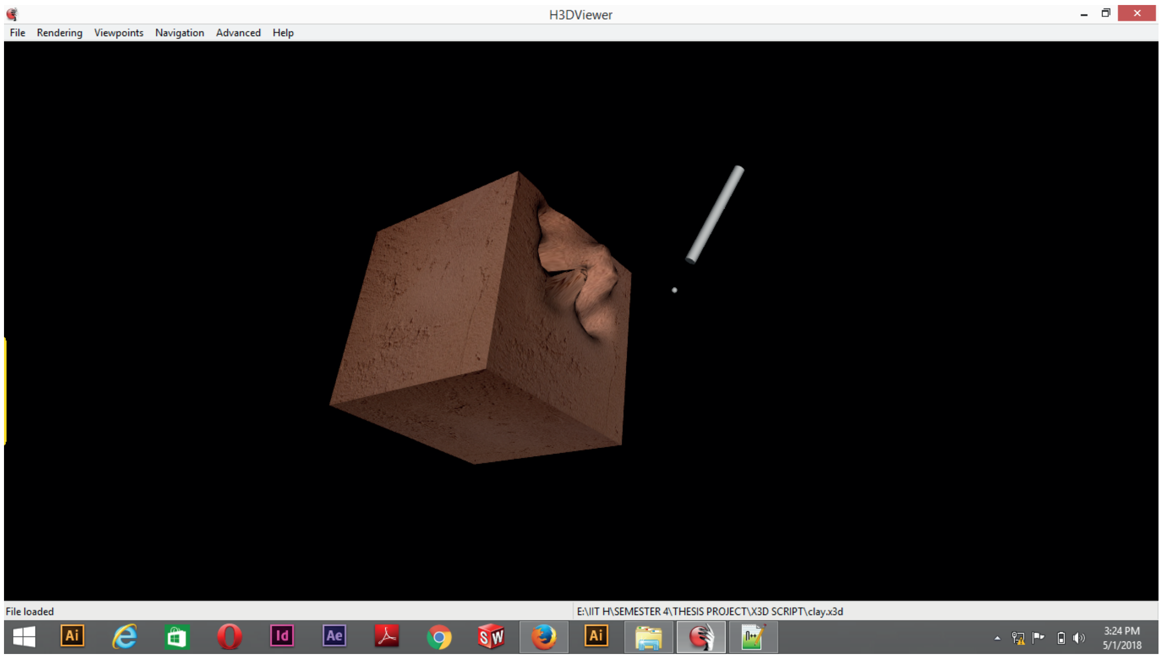

Figure 26. *Interacting with 3D clay model using Geomagic Touch*

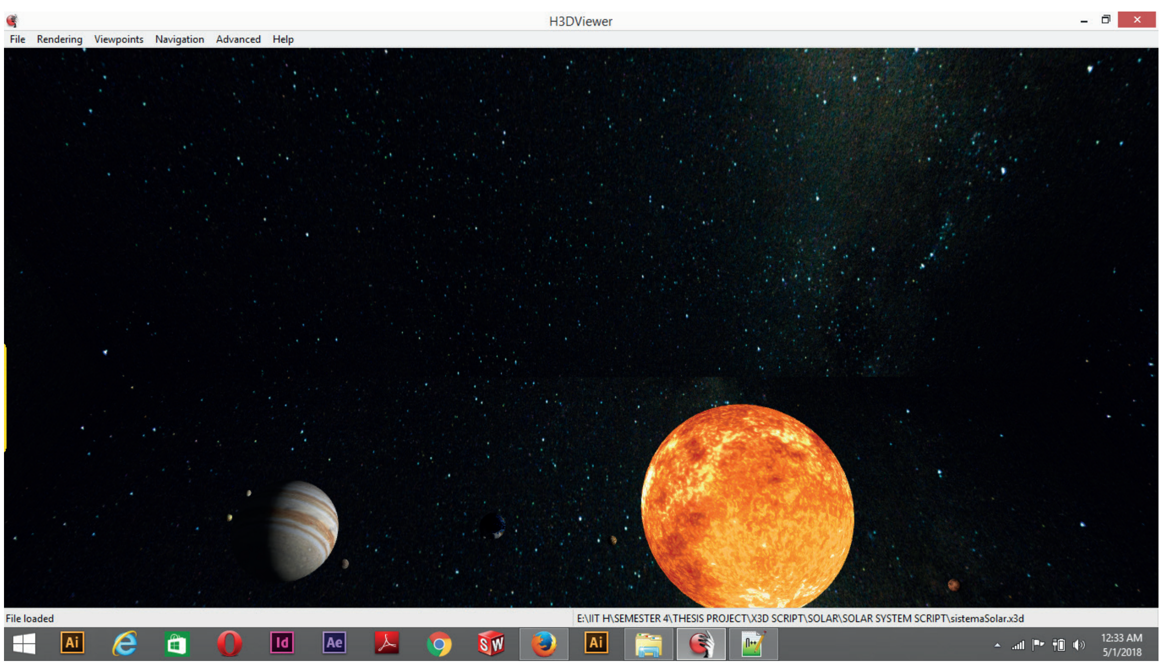

Figure 27: *Interactive moving solar system in H3D viewer*

CHAPTER 6

CALCULATIONS

The calculation is used to identify the accuracy of the result. It helps to analyse data of the experiment to find the probability of the hypothesis. In the experiment, we have calculated the mean value of 20 students from their pre-training and post-training results. Mean value helps us to calculate the standard deviation of the output result in the pre-test and post-test result. The accuracy of the performance calculated by the standard deviation. Lesser the standard deviation greater will be the accuracy of the performance in the test of 20 students.

In mathematics, a Gaussian function, often simply referred to as a Gaussian, is a function of the form: Gaussian functions are often used to represent the probability density function of a normally distributed random variable with expected value $\mu = b$ and variance $\sigma 2 = c 2$.

The p-value is used in the context of null hypothesis testing in order to quantify the idea of statistical significance of evidence. The alternative hypothesis is the one you would believe if the null hypothesis is concluded to be untrue. The null hypothesis, H0 is the commonly accepted fact; it is the opposite of the alternate hypothesis. Researchers work to reject, nullify or disprove the null hypothesis. Mathematically, p-value is defined as the as the probability, under the null hypothesis, of obtaining a result equal to or more extreme than what was actually observed.

The p-value lies between 0 and 1 and interpreted in the following way:

A small p-value (typically ≤ 0.05) indicates strong evidence against the null hypothesis, so the null hypothesis can be rejected.
A large p-value (> 0.05) indicates weak evidence against the null hypothesis, so one fails to reject the null hypothesis.
p-values very close to the cutoff (0.05) are considered to be marginal (could go either way).

Cohen's d is an effect size used to indicate the standardised difference between two means. It is calculated for finding correlation between two sets of data and a larger absolute value always indicates a stronger effect. Cohen's d-value is defined as the difference between two means divided by a standard deviation for the data, i.e.

$$\text{Cohen's } d = \frac{M_1 - M_2}{SD_{pooled}}$$

M1= Mean of data 1

M2= Mean of data 2

SD= Pooled standard deviation

For the experiment conducted in the this thesis, hypothesis is formulated as :

Null Hypothesis - Adaptive training program has no effect on student’s cognition and does not increase the performance in the 3 tests conducted.
Alternate Hypothesis - Adaptive training program enhances student’s cognition and increases the performance in the 3 tests conducted.

Figure 25 contains the statistical analysis of the data obtained from the experiment. For all 3 tests, p-value and Cohen’s d effect size value is calculated for mathematically validating the experiment. It is observed that p-value for all 3 tests is less than 0.05, which means we can reject the null hypothesis. This provides statistical evidence for the alternate hypothesis. Higher values of Cohen’s d effect size indicates that there is large difference in pre-training and post-training marks for all 3 tests.

	Adaptive training program					
	Pre-training		Post-training		Pre to post training	
	Mean	SD	Mean	SD	p	d
Purdue Rotations test	14.3	6.8	24.6	4.7	0.0186	1.757
Conservation test	13.8	7.5	19.7	5.8	0.0391	0.864
Paper folding test	14.2	7.7	22.1	6.1	0.0306	1.126

Figure : 28 *Impact of training on cognitive measurement*

6.1 Formulas used for the calculation

- Mean value $$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$
- Standard deviation $$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}}$$
- Gaussian curve $$y = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

$$\mu = \text{Mean}$$
$$\sigma = \text{Standard Deviation}$$
$$\pi \approx 3.14159\cdots$$
$$e \approx 2.71828\cdots$$

CHAPTER 6

RESULTS

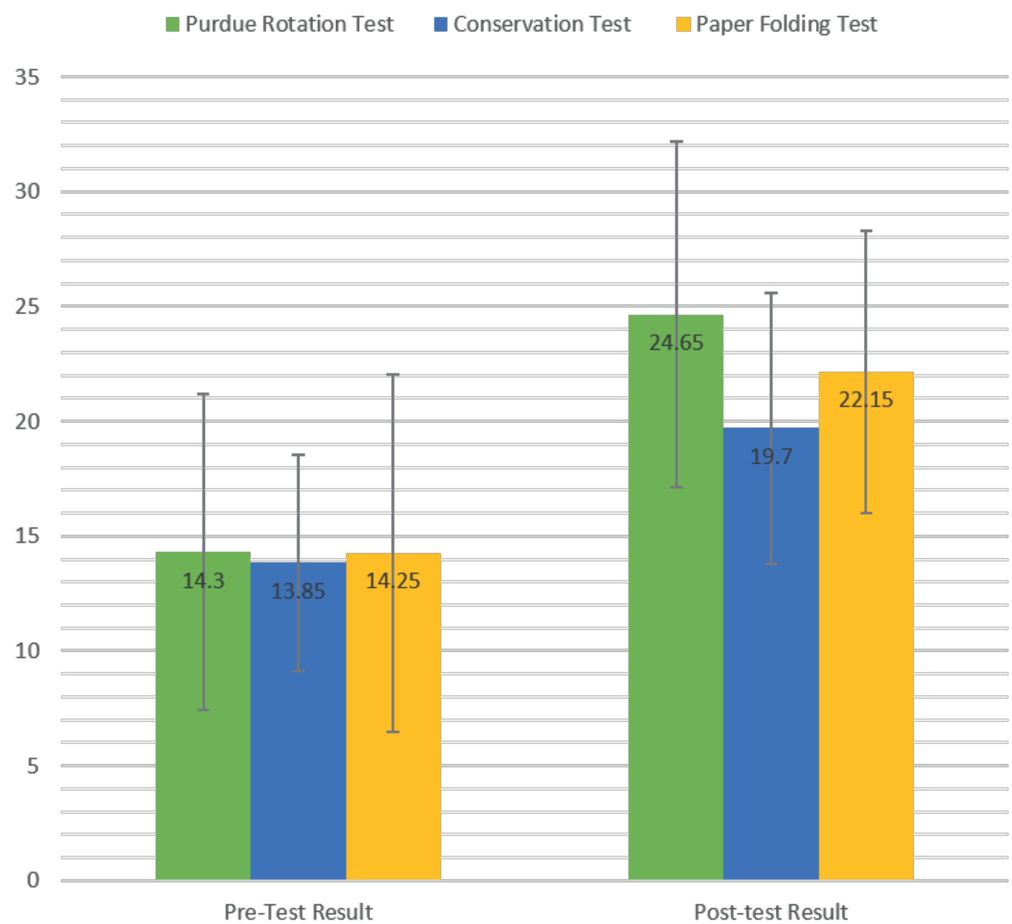

Figure 29: *Impact of training on spatial thinking*

Figure 29 shows the training gains (in standard scores) for the three aspects of spatial thinking in geometry, averaged in each case over all relevant test scores taken before, immediately after the training. Mean scores, **p-values** and **Cohen's d** effect size values showing the pre- to post- training gains and pre- to follow-up gains for spatial thinking are shown for the adaptive groups.

CHAPTER 8

CONCLUSION

On average, there will be four or five pupils in a class of 20 who have geometric spatial thinking abilities as low as the children participating in this study, and they will typically be making poor academic progress (Gathercole & Alloway, 2008). This study provides the first demonstration that these commonplace deficits and associated learning difficulties can be ameliorated, and possibly even overcome, by intensive adaptive training over a relatively short period: just 1 week, typically. The majority of the children who completed the adaptive program, which involved intensive training of 35 minutes a day in school for at least 8 days, improved their spatial thinking scores substantially over this period. The gains generalized to independent and validated spatial thinkling assessments that were not trained, and were greatest for the tests involving either Purdue Rotations test,Conservation test and Paper folding test. Importantly, it is these tasks that are most strongly predictive of children's learning abilities.

Adaptive training had little detectable impact on measures of the children's academic skills immediately following completion of training. This is unsurprising, as any improved cognitive support for learning caused by training would be expected to take some time to work its way through to significant advances in performance on standardized ability tests. And indeed, a significant boost to mathematics performance was found 6 months following adaptive training. Training gains therefore appear to extend to at least some of the learning difficulties associated with poor spatial thinking ability. Interestingly, IQ did not show a comparable boost with training, indicating that although spatial thinking and IQ are undoubtedly related (Kane & Engle, 2002; Jaeggi, Buschkuel, Jonides & Perrig, 2008), its contribution to learning can be distinguished in struggling learners (Cain et al., 2004).

This adaptive spatial thinking training program meets the criteria we set in advance of the study for educational significance: its benefits extend to the many children whose low spatial thinking abilities are accompanied by poor academic learning but who often fall below the radar of recognition for special assistance in learning.

CHAPTER 8

FUTURE SCOPE

The future scope of the project is very vast. From the experiment, we can identify the improvement in spatial thinking of students. Extension of this project might become very elaborate. It is possible to create a big server for many schools and design an online adaptive training program for them. Execution of this project can break the limit of our thinking.

In future, we can use technologies like virtual reality, augmented reality, ultra haptics, etc to extend the scope of the project. These technologies can create a more immersive experience for children and will help to improve the impact of an adaptive training program. Moreover, advanced technology can create a new dimension of the haptic world where the limitation of haptic can be minimised and student can interact with the digital world with more immersive experience.

Implementation of the project can be used in different subjects like chemistry, physics, biology and material science. Moreover, we can use it in graduate school to enhance the experience of technical learning for students. A student can create his own profile on the server to analysis his own growth from childhood to graduation.

CHAPTER 9

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