A Serious Game with Data Analysis to Diagnose and Treat Children with Visual Sequential Memory Deficit

A thesis submitted to the
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by

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degree of Master of Science

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Data Science.

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"There exists no clustering function that simultaneously satisfies scale invariance, consistency and richness."

Jon Kleinberg

A Serious Game with Data Analysis to Diagnose and Treat Children with Visual Sequential Memory Deficit

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Abstract

Visual Sequential Memory (VSM) allows a person to perform tasks such as remembering letters, numbers, objects or shapes in the correct order. Its deficit can lead to challenges in one's personal life, including dyslexia and dyscalculia. Detecting Visual Sequential Memory Deficit (VSMD) is essential for those who suffer from its related consequences. But current clinical methods don't have a high rate of diagnosis, and also treatment is limited to the few hours the person spends in the clinic. In this thesis, we propose an Origami based Serious Game, called *Memori*, for the diagnosis and treatment of children with VSMD. We illustrate the rationale behind using Origami, the design process of our game, its implementation, data construction, data analysis methods and their comparison.

For this work, we chose 3D graphics to give the user a realistic feeling about the game environment. To be easily accessible on any device and platform, we chose WebGL since it supports 3D graphics on any web browser. For the analysis of the data gathered by our system, we compared different clustering methods to achieve better diagnosis of children with VSMD. Our preliminarily performance evaluations with 24 adults revealed a 13% improvement of memory and 1.00 score increase in performance while a slight decrease occurred in attentiveness from 2.33 to 2.02 for people who used our tool. We also experimented with children in 2 schools. They were exposed to two different methods of testing in diagnosis and treatment. The data collected from these two experiments was analyzed using 3 variant clustering methodologies in order to verify the performance of the game.

Keywords: Visual Sequential Memory, Game Design, Serious Games, Play Therapy, Data Science, Clustering, K-means, Hierarchical, Spectral.

Sıralı Görsel Hafıza Eksikliği Olan Çocuklara Tanı Koyan Ve Tedavi Eden Veri Analizi Olan Bir Uygulamalı Oyun

Ayşe Rümeysa Mohammed

Öz

Sıralı Görsel Hafıza kişilerin harfleri, sayıları, nesneleri ve şekilleri doğru sırada hatırlamalarını sağlar. Eksikliği ise kişinin hayatında disleksi ve diskalkuli gibi zorluklara yol açar. Sıralı Görsel Hafıza Eksikliği'nin tanısının koyulması bunun sonuçlarından muzdarip olanlar için önemlidir. Ama mevcut klinik yöntemlerin tanı koyma oranı çok düşük ve tedavi ise klinikte geçirilen bir kaç saat ile sınırlı. Bu tezde, origamiyi temel alan Sıralı Görsel Hafıza Eksikliği olan çocuklara tanı koyan ve tedavi eden *Memori* isimli bir oyun tasarladık. Origami kullanmanın gerekçelerini, oyunun tasarım aşamalarını, oyunun uygulanmasını, veri yapılanmasını, very analizin yöntemlerini ve bunların karşılaştırılmasını detaylı bir şekilde anlattık.

Bu çalışmada, oyun ortamının daha gerçekçi bir his vermesi için 3D grafik tasarımını kullandık. Her cihazdan ve platformdan erişim kolaylığı sağlanması için bütün internet tarayıcılarını destekleyen WebGL'i seçtik. Sistemimizin topladığı verinin analizi için Sıralı Görsel Hafıza Eksikliği olan çocuklara daha iyi tanı koymak adına farklı kümeleme yöntemlerini kıyasladık. 24 yetişkin ile yaptığımız ilk performans testlerimizde hafızada 13% ilerleme ve skorda 1.00 artış görürken oyunumuzu kullananlarda dikkatlilikte 2.33'ten 2.02'ye düşüş gördük. Ayrıca 2 farklı okulda çocuklarla da oyunumuzu test ettik. Çocuklar tanı koyma ve tedavi etmede iki farklı yöntemle karşılaştılar. Bu iki deneyden toplanan veriler oyunun performansının tasdik edilmesi için 3 farklı kümeleme yöntemi kullanılarak analiz edildi.

Anahtar Sözcükler: Sıralı Görsel Hafıza, Oyun Tasarımı, Uygulamalı Oyunlar, Oyun Terapisi, Veri Bilimi, Kümeleme, K-ortalamalar, Sıradüzenli, Spektral.

To my mom; without her I would not be here.

To my husband; for his devotion and support.

To our little surprise gift; amare et sapere vix deo conceditur.

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Last but not the least, I would like to salute my dear husband Shady Mohammed for holding my hand during my work and always supporting me to perform better. His patience, motivation and enthusiasm were stairs to perfectness. My success is a part of his commitment and belief in me.

Contents

List of Figures

List of Tables

Abbreviations

VSM	**V**isual **S**equential **M**emory
VSMD	**V**isual **S**equential **M**emory **D**eficit
SG	**S**erious **G**ames
ITPA	**I**llinois **T**est of **P**sycholinguistic **A**bilities
KCIT	**K**nox **C**ube **I**mitation **T**est
CBTT	**C**orsi **B**lock **T**apping **T**est
USA	**U**nited **S**tates of **A**merica

Chapter 1

Introduction

Ever increasing value of interactive and indirect learning led the researchers to focus their efforts to develop more target-oriented games with an explicit educational and/or medical purposes and are not intended to be playable principally for enjoyment. Serious Games come in various types and specialized for different competencies, so that they attract many users. There are many benefits to be gained from gaming that traditional training methods don't offer. Serious games improve individual motivation and knowledge retention during training. The interactive nature of gaming requires greater involvement and attention than a typical training lecture. Serious gaming is a versatile, low cost, high ROI, training solution that can be adapted to meet specific learning requirements. The flexibility allowed by serious gaming makes it a more cost effective option, especially in areas of training that involve dangerous or complex tasks. Organizations can effectively increase training frequencies and more efficiently tailor training sessions for maximum learning benefits. Serious games, if designed and used properly, can help create a very powerful training experience.

Serious games can help individuals specially children and young adults in many fields to manage vital aspects of life such as health and medical care. For instance, it aids young adults to control diabetes or teaching children about food safety. While, it is observed that there is a rare number of games can help in diagnosing or treating psychological and brain disorders such as anxiety, depression, and VSM disorders. These disorders can be treated if it is diagnosed in early stage in children. VSM is the capability of remembering visual details and information in sequence. For instance, a child cannot spell or write a word correctly since he/she cannot remember the sequence of its letters due to the lack of VSM skills. This makes the individual's life will be more challenging and hard leading to dyslexia and dyscalculia. Classical clinics offer limited hours to persons being treated since the person needs to be present in the clinic every therapy session. This lead to demotivation of most of the children. Combining serious games with the therapy adds more entertainment to children and young adults. Moreover, it is portable and flexible. It can be performed from home. That is why we created *Memori*, where it is a synthetic instrument for the diagnosis, performance measurement, and treatment of people with VSMD. The game is designed to be played on any platform, since it is an html, so it can run on laptops, mobile phones. Memori's purpose is to diagnose VSMD, measure performance, and offer a therapy.

As a conclusion, serious games are both games-and not games. They are games that provide fun and amusement to the person but with a specific purposes. They can be used to asses the educational and clinical processes. They are games that set rules, simulate individual's behaviors, and accept input from the player.

1.1 Motivation

Psychologists encounter several problems in dealing with children with special needs. These children may easily get distracted and cannot focus on the therapy for long time. This usually results in discontinuation of the treatment. And also, the treatment is confined to the therapy sessions received in the clinics. The tasks that they are doing during the sessions are not always very appealing for children and they lack motivating the children.

Serious gaming offers a solution in this avenue since it is portable, it attracts children with its entertainment and its gamification features motivate children to continue further with their treatment.

Combining a clinical problem with a serious game, we were motivated to create a game that can solve this issue and with the aid of data science methods, we were able to analyze and offer another way for psychologist to benefit in the clinics and for parents to use at home as a continuation for the treatment.

1.2 Research Contributions

This thesis presents a novel approach to diagnose and treat VSMD. It demonstrates an Origami-based serious game specially for children along with a novel methodology of testing the game, defining its data features, and the way of collecting the data. Data analysis techniques, clustering methods, were applied to the collected data to evaluate the game performance. Finally, the game results were compared and verified by a well-known psychology test "Corsi Block Tapping Task" used specially for VSM related problems.

1.3 Research Publications

The publications linked to this thesis are given below.

Conference Publications:

Paper 1: A. R. Mohammed, A. Rashed, and S. Shirmohammadi, "*Memori*: A Serious Game for Diagnosing and Treating Visual Sequential Memory Deficit," in *Proceedings of 5th Conference on Serious Games and Applications for Health, IEEE SeGAH 2017 (SeGAH'17)*, Perth, Australia, April 2017 [1].

Paper 2: A. R. Mohammed, A. Rashed, and S. Shirmohammadi, "A Synthetic Instrument for Diagnosis and Performance Measurement of Individuals with Visual Sequential Memory Deficit," in *Proceedings of the 12th Annual IEEE International Symposium on Medical Measurements and Applications (MeMeA 2017)*, Rochester, MN, USA, May 2017 [2].

Other Conference Publications:

This publication is not directly related to the topic of this thesis but it was published during the author's Master studies.

A. E. AlChalabi, A. R. Mohammed, O. Guzey, "Bringing Engineering and Management Education Together in the Age of Big Data," in *Proceedings of Portland International Center for Management of Engineering and Technology (PICMET'17)*, Portland, OR, USA, July 2017 [3].

Chapter 2 is reused from **Paper 1:**.

Sections 5.1 is reused from the **Paper 2:**.

1.4 Thesis Outline

This thesis includes the design and evulation of the serious game *Memori* for diagnosing and treating VSMD. The rest of the thesis is structured as follows:

Chapter 2. Related Work: covers relevant games and approaches for VSM, while discussing related psychological tests.

Chapter 3. Background: gives information on the analysis of psychology tests and clustering algorithms.

Chapter 4. Proposed Game: details the design of the game, provides explanation about how to play the game and collect the data.

Chapter 5. Performance Evaluation: presents the results, evaluation, comparison of clustering methods, and psychology tests carried out during the experiments to determine the diagnosis and treatment.

Chapter 6. Conclusion and Future Work: concludes and specifies the important parts of the thesis, and highlights the possible areas to further work on.

Chapter 2

Related Work

We discuss the related work in the following subsections: Current Clinical Methods, Serious Games for Visual Memory, Serious Games for Dyslexia, Serious Games for Dyscalculia, and Origami in Therapy and Education.

2.1 Current Clinical Methods

VSMD can be diagnosed by Visual Sequential Memory subtest of the Illinois Test of Psycholinguistic Abilities (ITPA) [4], Knox Cube Imitation Test (KCIT) [5] or Corsi Block Tapping Task (CBTT) [6]. KCIT is a very efficient way that serves as diagnosing and treating. The problem with these methods is that they are restricted to clinical settings, and cannot be used at home. So their effectiveness is limited to the clinical exposure the child has.

2.2 Serious Games for Visual Memory

Nagle *et al.* [7] designed a memory training game for measuring the effects of different task difficulty levels and user control choices in a serious game. The memory training game takes place in virtual environment, a room, and players receive a list of some objects they need to locate in the room. Objects are numbered and then placed in the room. The challenge was to memorize the list items and their location numbers, to place them in corresponding locations.

Illanas, *et al.* [8] developed a mini-game, *MemOwl*, for memory stimulation. In this game, participants are shown some pictures for a specific time. Pictures consist of owls of different colors. When the time is over, users need to pick the correct picture, see Figure 2.1. The number of owls increases and the time duration of picture display decreases by level difficulty. *MemOwl* targets to improve attention, visual memory and short-term memory skills.

FIGURE 2.1: Game scene from *MemOwl*.

2.3 Serious Games for Dyslexia

Rello, *et al.* [9] developed a browser-based game, *Dytective*, to detect risk of dyslexia. The game is designed to have linguistic tasks that are shaped according to the typical mistakes done by dyslexic people. It can diagnose English and Spanish speaking school age children with dyslexia.

Rello, *et al.* [10] created a game, *DysEggxia*, to improve the spelling of children with dyslexia. Its exercises have misspelt words for players to correct them, see Figure 2.2. The words are gathered from texts written by dyslexic children. The experiment was held for 8 weeks. During the first 4 weeks, 48 children played the game *DysEggxia*. Then they are switched to another word game, *Word Search* and played it for 4 weeks. At the end of the experiment, the results were compared and children who played *DysEggxia* had less mistakes in word spelling.

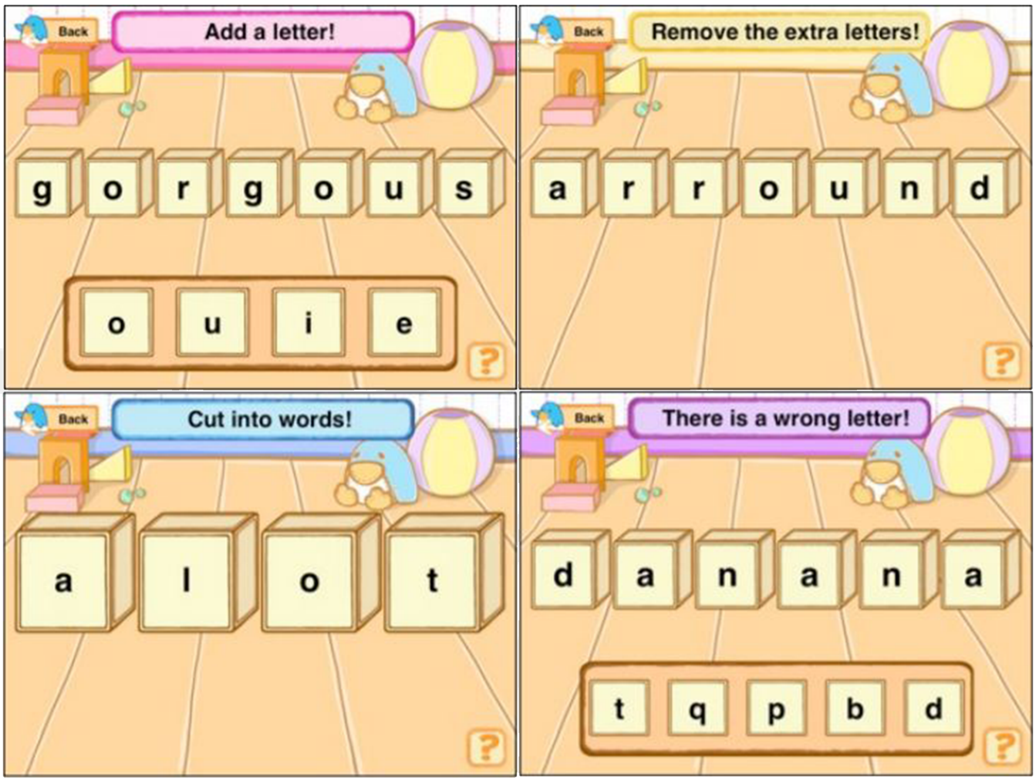

FIGURE 2.2: Game scenes from *DysEggxia*.

2.4 Serious Games for Dyscalculia

Kuhn and the research team at the University of Münster developed *Meister Cody - Talasia* for diagnosing and treating children with dyscalculia. It is an educational game consisting of 20 therapeutic exercises [11]. The game and difficulty levels are shaped according to the user profile on daily basis. *Meister Cody* is designed in a way to improve working memory, number processing and calculation skills.

Lányi, et al. [12] proposed a mini game, *Cheese Factory* dedicated to people with learning disabilities under Game On Extra Time (GOET) project. Its main goal is to introduce and practice percentages, fractions, and decimals. The game design is similar to well-known *Tetris Game*. Players are asked to complete a full circular shaped cheese by falling cheese slices which has fractional numbers written on.

2.5 Origami for VSM in Therapy and Education

While playing Origami, a child will invoke his/her VSM quite heavily. Gross suggests that while doing Origami, one needs use the following skills: following a sequence of directions, listening skills, reading skills, language skills, writing skills, social skills, mathematics, spatial relationships, memory and concentration [13]. According to Kaplan, performing a folding act requires following instructions, solving problems, learning the steps in the proper order, thinking skills, self-image, and success experience [14]. Other studies have come to similar conclusions, that Origami requires skills that are directly related to VSM [15] [16] [17] [18] [19] [20].

Origami has been used for therapeutic and educational purposes by many researchers in the past. Origami has also been shown to benefit learning disabled, dyslexic, physically or emotionally handicapped students [21]. Origami also helps with fine motor control and hand writing, attentiveness, sequential memory, and specifically helps children with learning disorders to develop fine motor skills, observation skills, and VSM [22]. A child suffering from dyscalculia who cannot comprehend or manipulate numbers, forms or anything related to those can also benefit from Origami by learning to follow the sequence and order of things [23]. For diagnosis, Origami can evaluate which basic difficulties a child might have in the acquisition of topological concepts and spatial orientation [24] [22]. Origami is also utilized in pediatrics for mental health, clinical fine/visual motor skills, memory, and sequencing [25].

The above work all show very promising effects that Origami applications can have on VSM, for both diagnosis and treatment. In this thesis, we are revisiting such applications of Origami, in the context of today's technology and gaming environments. We design a platform-independent mobile serious game called *Memori* that shows to a child the step-by-step order of making various Origami shapes. Using the child's performance, one can then diagnose the child for VSMD, as well as treat children with VSMD at clinics and homes.

Chapter 3

Background

3.1 Psychology Tests

Several tests are used for testing VSM [26] and intelligence testing. However, in our experiments, we preferred the following two:

3.1.1 The Knox Cube Imitation Test

Howard A. Knox, was a medical doctor who designed methods for intelligence testing on immigrants with mental deficiencies. His test consists of one small black cube and four one-inch cube blocks of color red, blue, green and yellow. The large cubes are positioned 4 inches apart. 5 different line sequences are practiced with increasing difficulty level as shown in Figure 3.1. Acording to Knox's study, high grade imbeciles can resemble only line (a), feebleminded can resemble till line (b), likewise morons or higher feebleminded resemble till line (c), normal persons can resemble till line (d), and only bright persons can resemble all, i.e. till line (e) [5].

3.1.2 The Corsi Block-Tapping Test

Corsi Block-Tapping Test (CBTT) includes nine blue square blocks. On each trial the blocks get marked in order, see Figure 3.2. The subject is required to remember and mimick. The test starts with sequence of two and two tries are given for each sequence

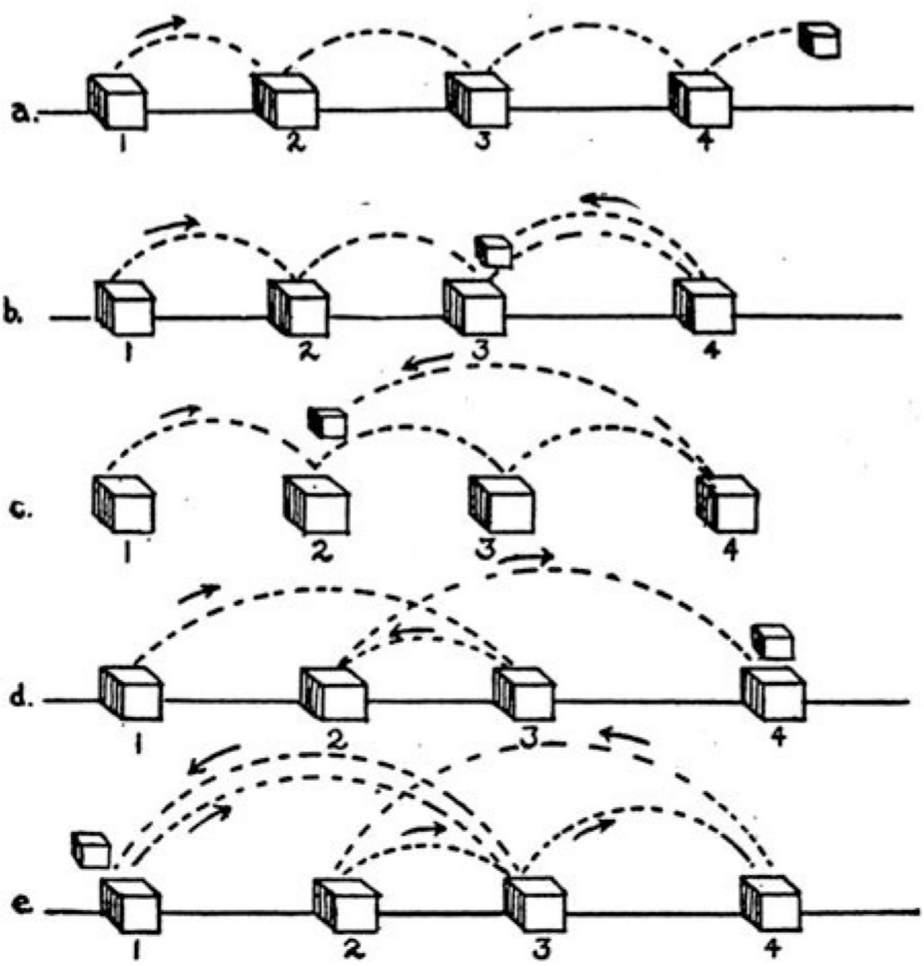

FIGURE 3.1: Knox Cube Imitation Test: a, high grade imbecile; b, feebleminded; c, moron; d, normal; e, bright.

length. In order to proceed, the subject should get at least one sequence correct. Additionally, three practice trials are offered at the start for subject to become familiar with the test. Complexity of the sequence increases until the subject's performance is insufficient. The performance is called *Corsi Span* and its value is 5 on average [27].

3.2 Clustering Methods For Data Analysis

There are several statistical methods to extract knowledge from data. Depending on the data we gathered during our experiments, our analysis can benefit from clustering methodologies.

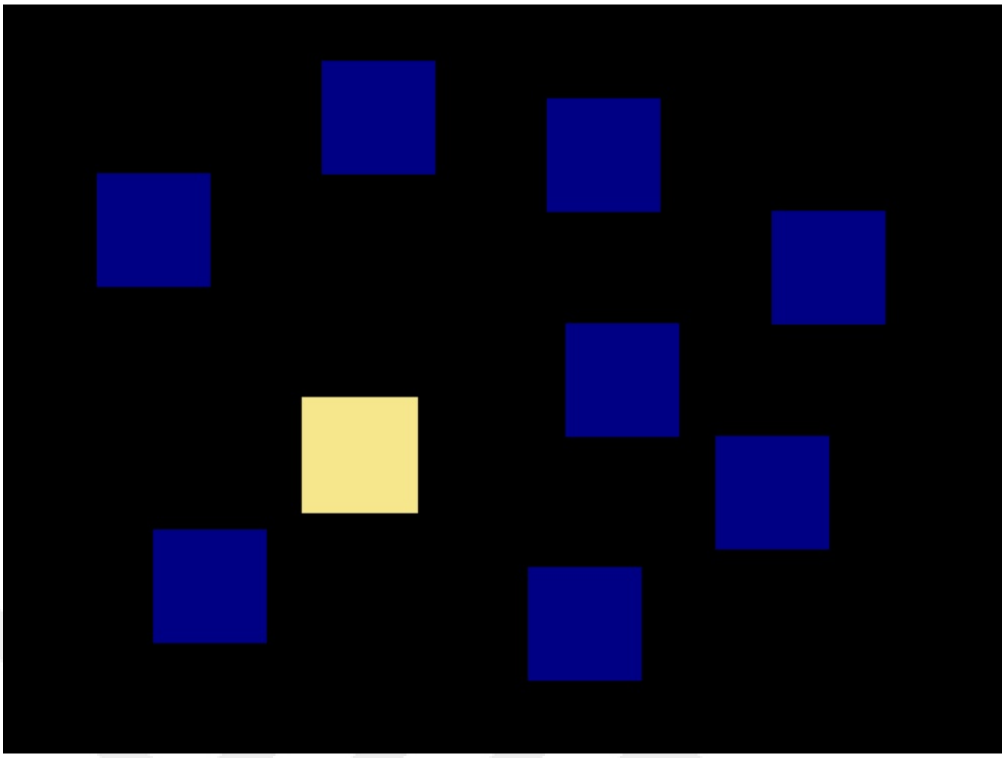

FIGURE 3.2: The Corsi Block-Tapping Test: Square blocks are lit up in order.

Clustering is an unsupervised learning technique. It deals with finding a structure within a set of unlabeled data and congregating data in distinct groups, i.e., clusters [28]. Therefore it can be inferred that intra-cluster similarity is high and inter-cluster similarity is low. Clustering methods are often used when the cluster labels are not or for some reasons cannot be defined.

Typical clustering models are k-means, hierarchical, distribution based, density based, and mixture of Gaussian. In the following section, we describe them theoretically.

3.2.1 K-means Clustering

In k-means algorithm, the cluster number is told to the system in advance. K-means algorithm settles k centroids randomly, see Figure 3.3, then partitions the data into k clusters and designates the data points to clusters so as to minimize the distance between the points and centroids,i.e. variance.

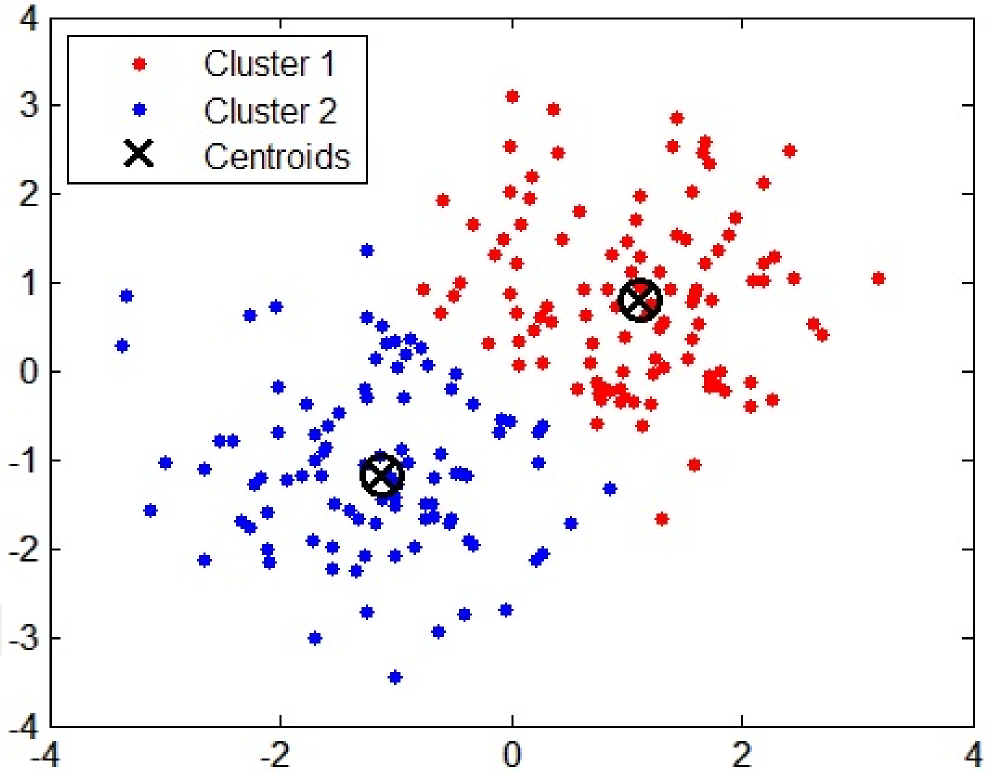

FIGURE 3.3: An example of K-means clustering diagram.

3.2.2 Hierarchical Clustering

Hierarchical clustering builds a binary tree of data by progressively combining two similar data points, see Figure 3.4. The algorithm calculates the similarities between each points and then merges the best pair. After merging, the average of the data for these two clusters becomes the assigned value for the new cluster. This iteration is done until it reaches one supreme cluster. This algorithm could be computationally expensive.

The y-axis on the graph is named as *height* and it represents the similarity of the two data points, smaller the height more similar the points.

3.2.3 Spectral Clustering

For performing spectral clustering, a similarity matrix along with its eigenvalues and k clusters are needed to be introduced. Spectral clustering uses these eigenvalues of the similarity matrix of the data and applies them for dimensionality reduction. Then it clusters the points with the k-means or any desired algorithm.

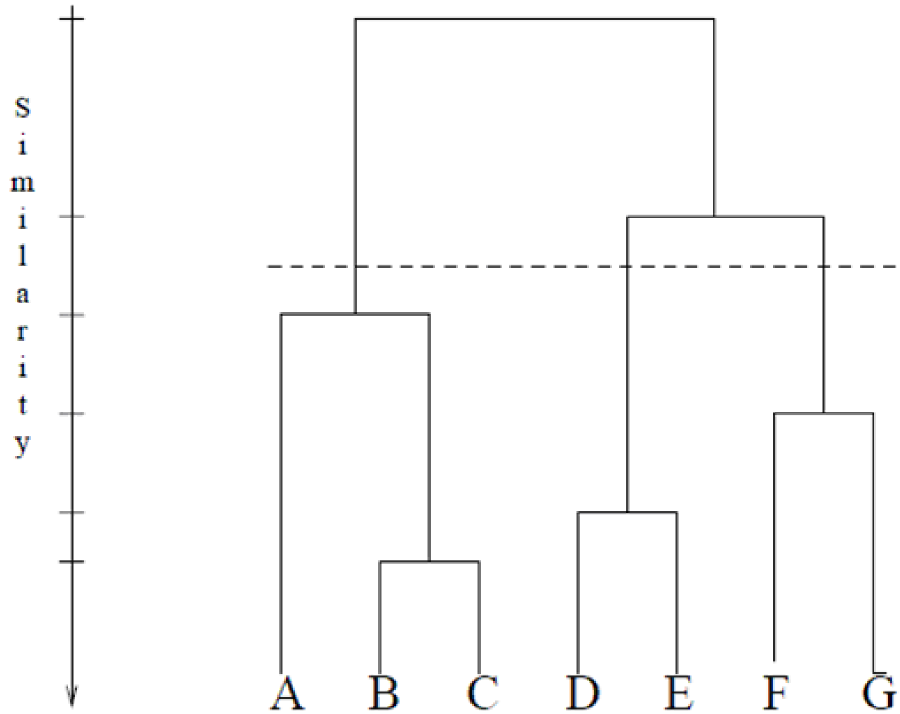

FIGURE 3.4: An example of Hierarchical clustering diagram.

Spectral Clustering is very efficient when we have high dimensional data. It projects the data points into a lower-dimensional eigenvector space where grouping requires less effort.

Chapter 4

Proposed Game

4.1 Game Play

The design of the game is shown in Figure 4.1. As demonstrated, the game will start by inquiring whether it is the first time the child is playing or not. If it is the first time, then the player will start with the tutorial. Tutorial is designed to make the user become comfortable with the game environment and the game flow. It also helps eliminating the training effect.

At the end of the tutorial, if the child feels his/her performance is not satisfactory, then the child will repeat the tutorial. As soon as the child determines that his/her performance is sufficient, the child will start playing the game. Diagnosis will be based on the first time playing with 3 origami shapes; Basic House, Sailboat, and Duck. On the other hand, treatment will be based on the progress of the child playing with all the shapes. In tutorial, T-shirt origami is set along with the instructions of how to play and navigate through the game. Other origami shapes like Heart, Windmill and Plane are also on the main menu to give the player more options to play with. In Figure 4.2, all the origami shapes are presented.

4.2 Game Design

Since the game must be played by children at home, we decided to make it very portable; i.e., accessible on laptops, smartphones and tablets, running on any operating system.

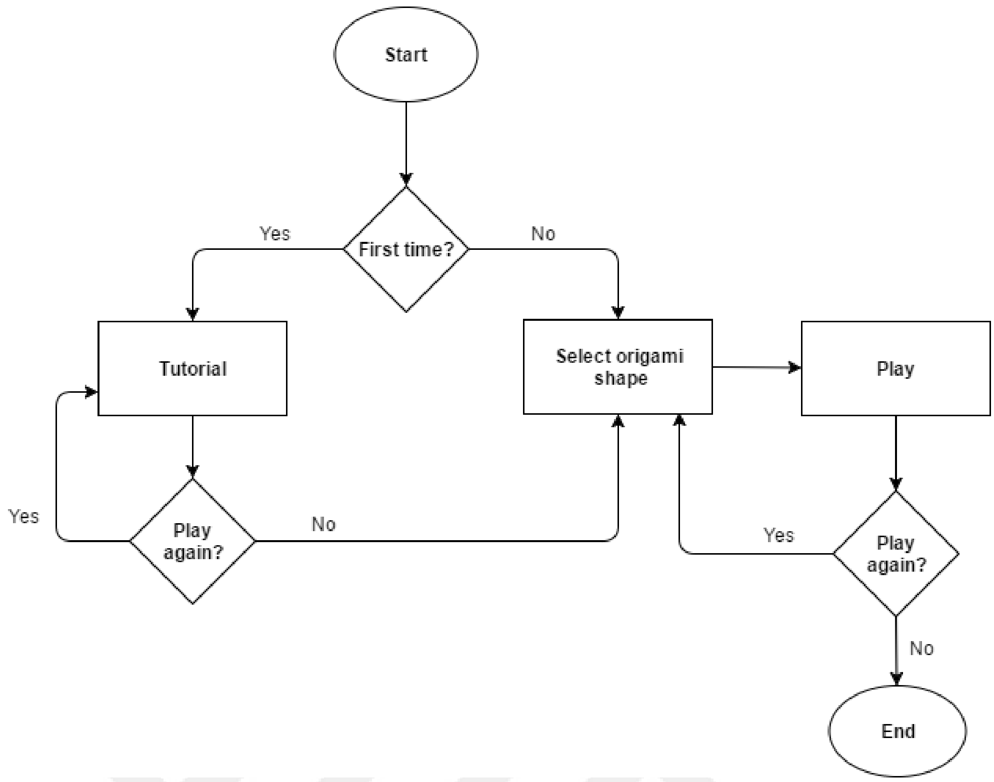

FIGURE 4.1: The flow chart illustrating the game design.

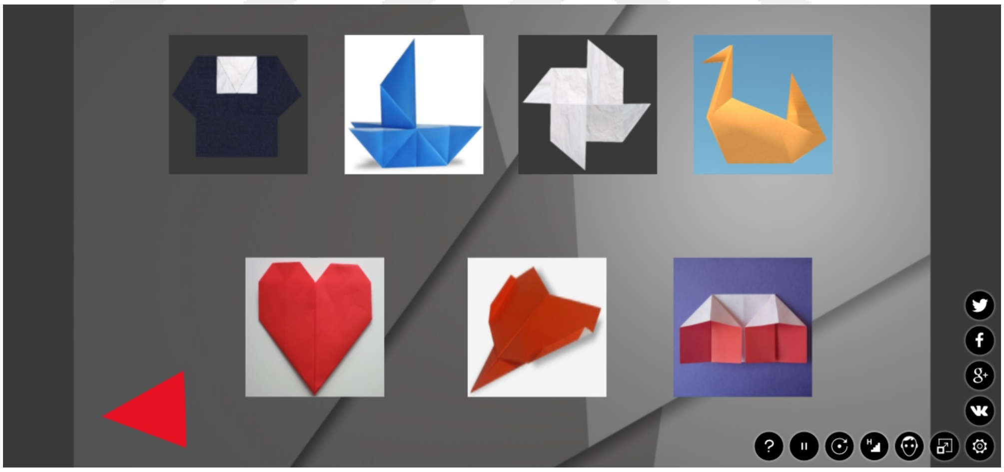

FIGURE 4.2: Main menu of *Memori*.

We also decided to use 3D graphics in order to give the game a realistic feeling. To meet these requirements, we need a platform that supports 3D on various operating systems. For that, we chose WebGL which supports 3D and runs on any web browser [29]. This makes our game very accessible. In the following sections, we elaborate our choice of platform and serious of decisions we made in the process of game design.

4.2.1 Platform

Even though there are quite powerful game engines exit such as Unity3D [30] and Unreal Engine 4 [31], we preferred to go with a simple, yet brand new platform, which is Blend4Web [32]. Blend4Web is a plugin for the famous Blender 3D Simulation Software [33] that allows the option of compiling the scene as an HTML file and export it to a specific web player, embedded with compilation, and render the game scene via any web browser.

4.2.1.1 Strengths & Weaknesses

Advantages & disadvantages of the preferred platform are listed below:

- Blend4Web comes with its own Logic Editor, i.e. B4WLogicNodeTree. Even though it is neither as efficient nor as powerful as using C# in Unity or C++ in Unreal Engine, it is fairly enough for simple logic editing such as playing an animation on clicking a button or jumping to an instance in the animation timeline.
- Blend4Web has a Vertex Animation Baking system, which is typical for simple simulations, such as origami. So once animations are defined and marked on the timeline, a single click on "Bake" button in the Blend4Web toolbox compiles the scene animation and the scene gets ready for rendering.
- Blend4Web also introduced a Fast Preview option, which allows the designer to render the scene in a web browser and to tweak its features, such as Lightning, Wind and materials while checking the frame rate and loading time, let alone to be able to preview the game from the player's perspective who can navigate through the scene just as s/he can navigate through a 3D-viewer.
- One of the most significant limitations of Blend4Web is its lack of exporting multiple animation types. So the designer has to choose among Shape Keys, Vertex Animation, Modifiers and Scale & Modifier. The ways to animate Shape Keys using Vertex Animation, i.e. linking a vertex group to an armature and animating the armature instead of animating the vertex group itself with shape keys, adds to the total scene size and loading time due to the extra objects, such as armatures, that need to be added.

- In case the designer prefers not to deal with Blend4Web Material Node Editor, Blender has no problem with switching back and forth between Cycles Render, and use its full power in Material editing, and Blend4Web. That is typical for basic materials like paper, and simple texture editing such as drawing a line or even a smiley face.

Blender has remarkably powerful variety of object generators, shape deformers, simulators and modifiers. In fact, we used Lattice Modifier as one of the approaches to simulate a realistic folding behaviour as mentioned in the next section.

4.2.2 Simulation

4.2.2.1 Paper

One typical way to simulate a paper is a plane object which is subdivided to 20 cuts. However, a plane is only one-sided in Blender. In order to get over this, we just duplicated the plane with the duplicate facing the opposite direction. That also allows us to use different textures for each face. Then, we set the duplicate plane as a child of the original one, so that any changes in position or scale of the original plane will be also applied to the duplicate. For better visualization a *Subdivision Surface Modifier* can be added to smooth out the paper.

4.2.2.2 Folds Type

There are two types of folding behaviour in Origami, outer and inner. The outer fold is the one that does not include folding a part of the paper if this part has another part below or above it which is not to be folded. In other words, it is a fold which can be done without having to put a thump between two parts of the paper as if you are clapping and the paper is between your two hands. An example is shown in Figure 4.3.

The origami shapes without any inner folds could be simulated more realistically using Lattice Modifier. In Lattice Modifier, the scene size is significantly bigger, about four folds, than of a scene created by using armatures which is our second approach for origami simulation.

FIGURE 4.3: Outer folds (steps 1,2 and 4) vs. Inner fold (step 3).

4.2.2.3 Folding

Lattice Modifiers. As mentioned above, there are two types of folds. For shapes with only outer folds, such as the heart shape, see Figure 4.4, we used the Lattice Modifier.

A lattice is basically a cube without faces. The default dimensions for a lattice are U,V,W=2,2,2. By setting the W axis to 1 and the U or V to 20 (or more), we get a plane-shaped mesh with 20 edges ready to fold a paper, see Figure 4.5. However, the lattice is still flat. In order to make it mimic the folding behaviour, we apply to it a Simple Deform Modifier. The Simple Deform Modifier has four modes; Twist, Bend, Taper and Stretch. The typical deform we need to simulate a fold is in Bend mode with limits 0.67 and 1.00, and angle 200°. For the axis of bending we created a Plain Axes

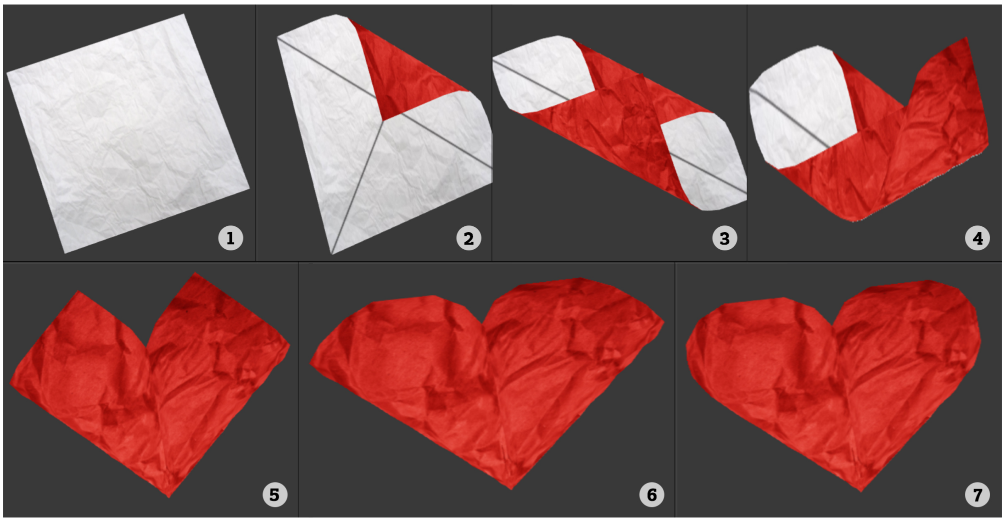

FIGURE 4.4: Origami Heart made by only outer folds and thus simulated by a Lattice Modifier.

object and position it at one end of the lattice which we also set it as the Plain Axes object's parent, so when we move the lattice, its axes move with it, see Figure 4.6.

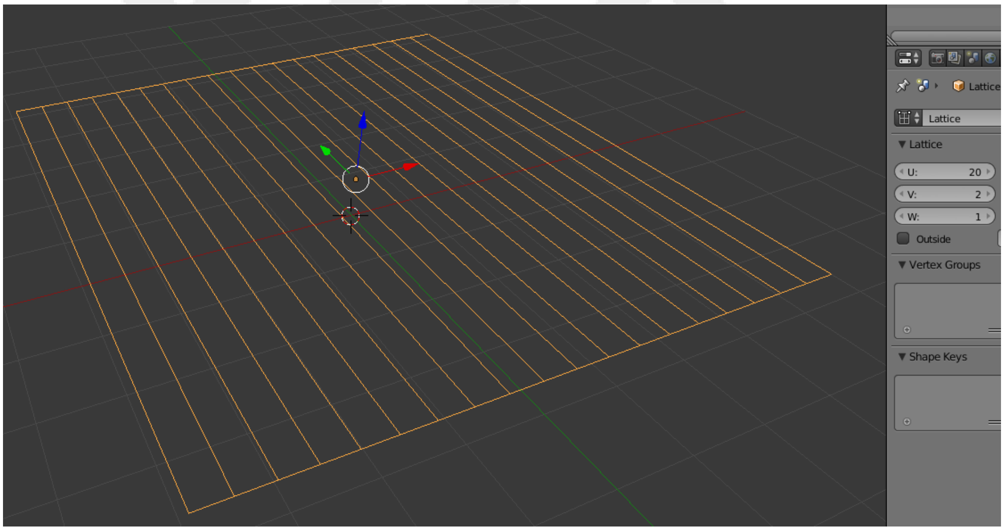

FIGURE 4.5: A Lattice object after changing its dimensions to appeal to a plane object.

Now that we have the lattice object ready to fold paper, we can just go ahead and apply a Lattice Modifier to the paper objects. By moving the Lattice object towards the paper, the outer fold starts taking place, see Figure 4.7.

Armatures. One important drawback of Lattice Modifiers is that it cannot handle inner folds. So we have to use the most common way in animating rigid objects, armatures.

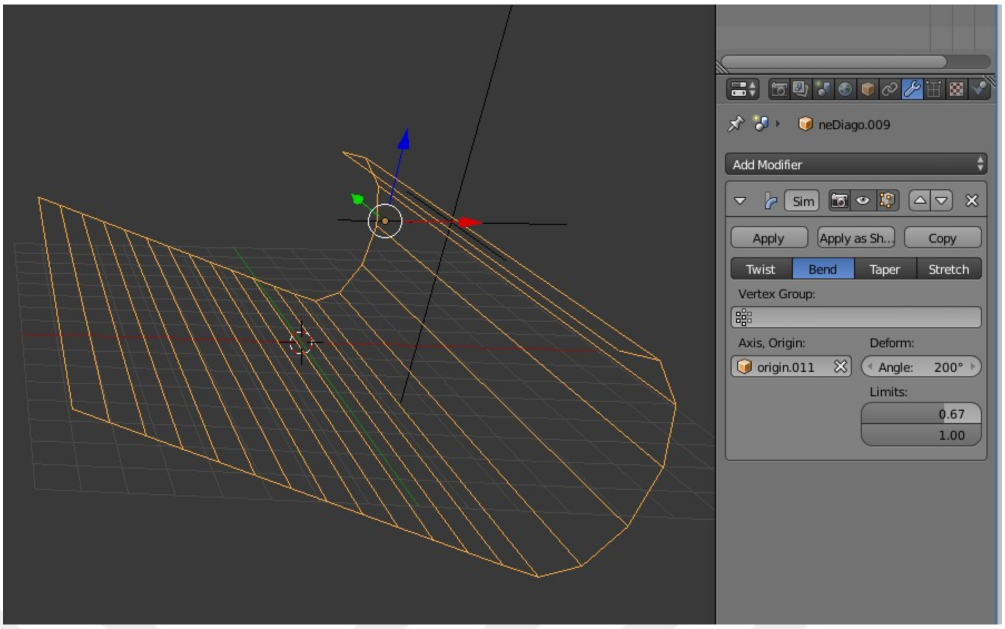

FIGURE 4.6: A Lattice object after applying Simple Deform-Bend Modifier along with its child. The Plain Axes object is used as a paper folder.

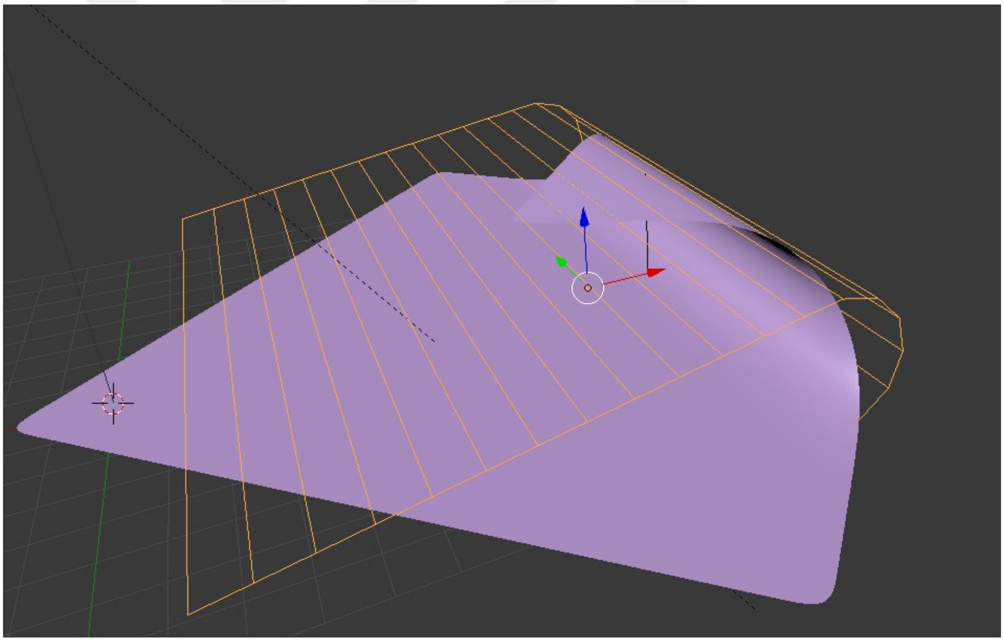

FIGURE 4.7: An outer fold simulated with a Lattice Modifier.

Using armatures and bones requires a delicate design of the plane mesh in terms of edges and vertices, where edges mimic the folds' axes and vertices mimic where the folding force is applied to.

We first make the origami shape in real life and then unfold the shape and observe all the folding axes and folding angles which can be a bit laborious especially when there are multiple folds in the same part of the paper. In Figure 4.8 and Figure 4.9 we demonstrated the folding steps for House and Windmill origamis which are animated by armatures.

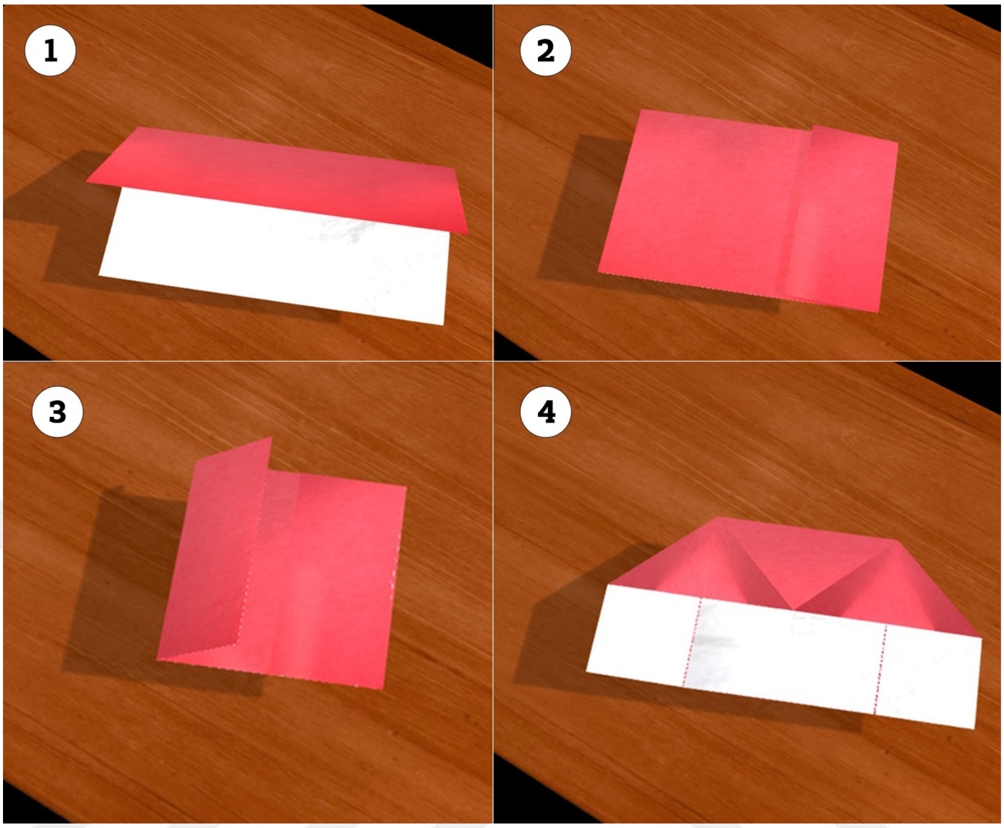

FIGURE 4.8: An example of some folding steps for House origami.

All folding axes are duplicated. In other words, the edges at which there are folds that are doubled with a little space between each edge and its duplicate. That is to simulate the thickness of the fold and prevent overlapping between mesh faces. In other words, paper parts should neither penetrate nor overlap with each other. We then allocate a bone for each and every fold at its corresponding vertex. Each fold affects only a group of the vertices, and not necessarily with the same weight. So each vertex is associated with effect weight to the corresponding group of vertices, see Figure 4.10.

A model with perfect mesh design, armature positioning and weight allocation should not require more than rotating the bones with the corresponding degrees of the fold to have a perfect simulation. Even though it is very difficult to have such flawless model, a fairly realistic simulation can be obtained by, not just rotating, but also moving and scaling the bones.

Misallocation of weights can lead to distortions of the fold. That can be solved by assigning supportive bones to those distortive vertices and synchronizing an anti-distortion

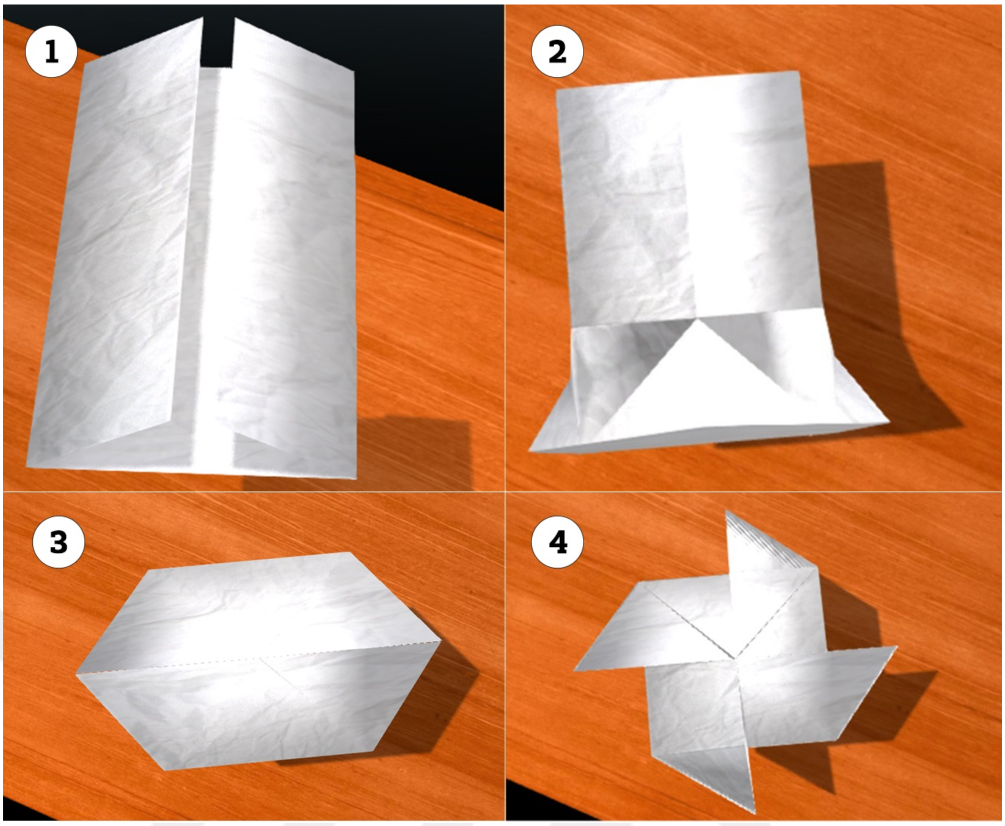

FIGURE 4.9: An example of some folding steps for Windmill origami.

animation between the bones sharing the same vertices. We cannot use shape keys here although it would be a typical solution for this scenario since Blend4Web doesn't allow exporting Vertex Animation and Shape Keys animation together, revisit Section 4.2.1.1.

4.2.2.4 Animation

Lattice Modifiers. Scaling the Z axis of the lattice object corresponds to the angle between the two fingers folding that piece of the paper. Moving the lattice object towards the paper and away from it corresponds to the scale of the fold, that is, the extent of the fold applied on the side of the paper the lattice object is coming towards along X and Y axes. Rotating the lattice object mimics changing the angle of the fold. Changing a lattice object's scale, position or rotation makes up a complete folding step.

Armatures. Rotating a bone mimics bringing the region of the paper on one side of the folding axis to the other side of the folding axis. As mentioned in the previous section, due to difficulties in determining the exact weight to be given for each bone over

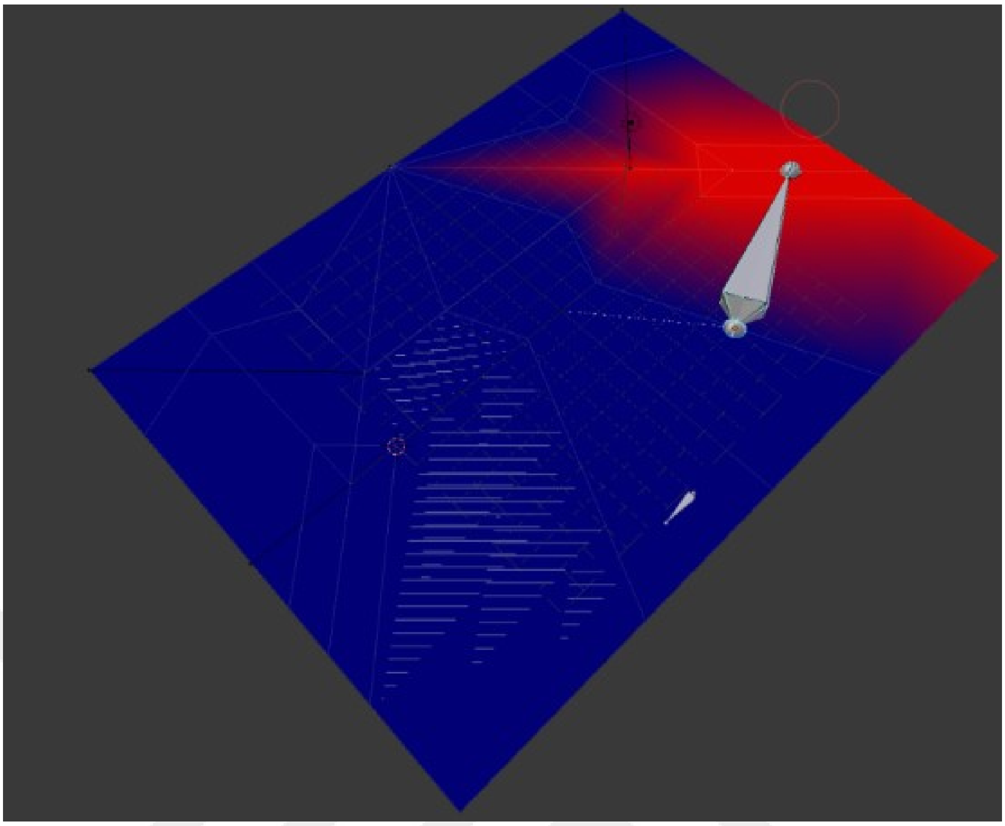

FIGURE 4.10: Each bone affects a certain group of vertices with the corresponding weight.

every associated vertices, a bone's scale and position can be tweaked to alleviate or even eliminate any distortion in the folding animation. Changing a rotation of armatures' bones and, if needed, scale and position makes up the folding step.

By recording a key frame after each folding step, we end up having a complete Origami shape simulation with full control over any frame in the animation timeline. Before exporting the scene to the web player, each plane object should have "Export Vertex Animation" checked in "Export Options" in the "Object" tab and then having the animations baked by adding a new vertex animation, specifying the start and the end of the animation timeline and clicking on "Bake" from "Blend4Web" side tab.

4.2.2.5 Material & Lighting

We used paper textures for the plane objects as main material. Cycles Render mode in Blender allowed us to draw on the main textures. We used that to draw lines indicating a fold's axis. An environment lightning can be added from "World" tab. To have shadows there should be light rays, a Sun object is typical to cast those rays, see Figure 4.11. Each paper object should have both "Cast Shadows" and "Receive Shadows" in the shadows section in "Object" tab.

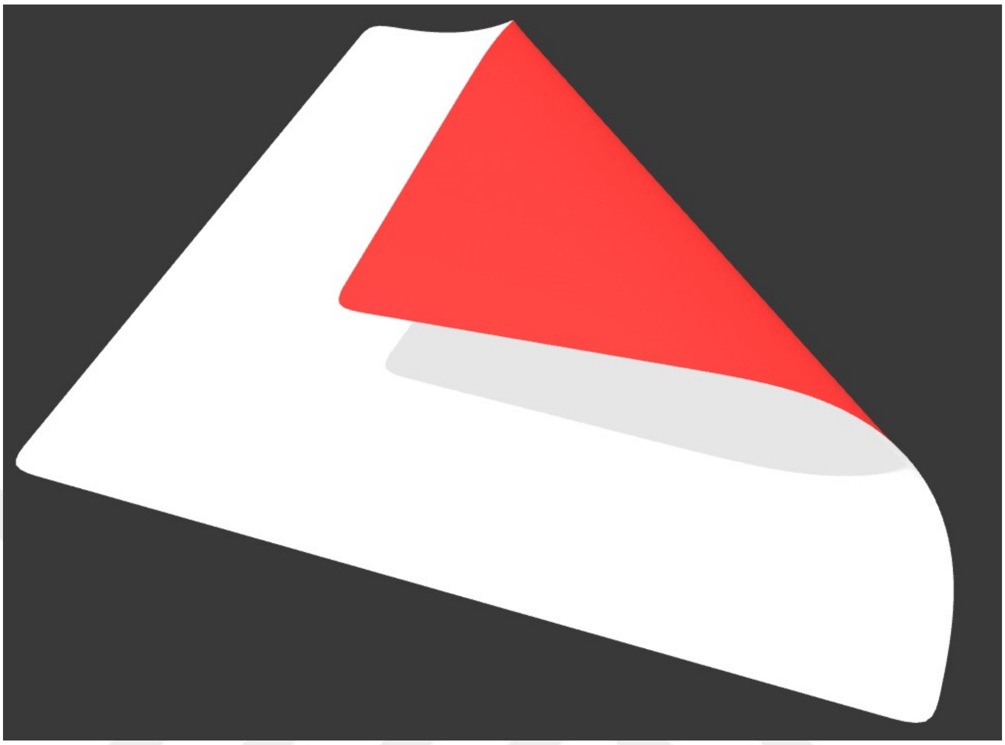

FIGURE 4.11: Casting shadows using Sun object and Environment Lightning.

4.2.2.6 Logic Editor

Along with the plane, lattice and armature objects we have added four other objects as controlling buttons. Two cone-shaped meshes for Next and Previous buttons and two planes, one for Play button and the other for Reset Camera button, see Figure 4.12.

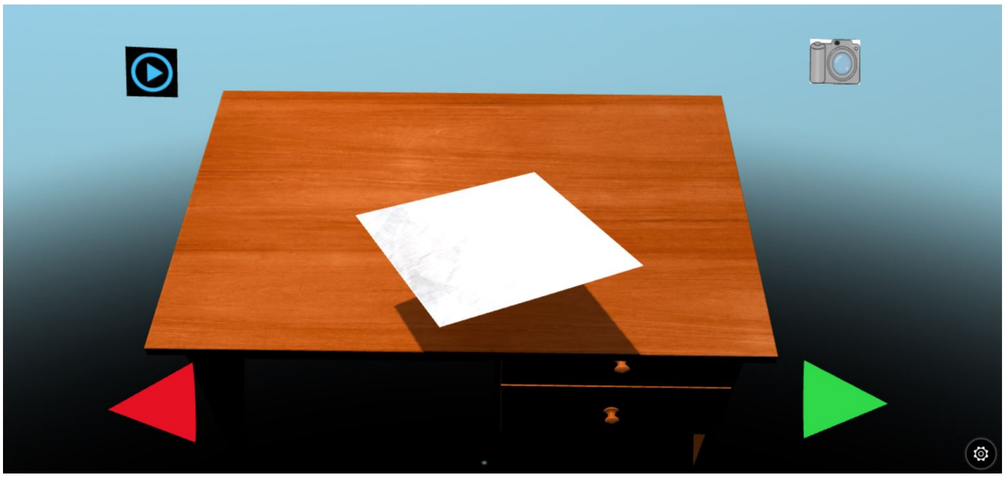

FIGURE 4.12: Game scene showing Next, Back, Play and Reset Camera Buttons.

B4WLogicNodeTree has a variety of powerful tools which we used for giving the player a full control over the scene. We defined two variables, *crnt* and *pre*, to indicate the current and the previous state of the animation, see Figure 4.13. By starting the game, the logic editor expects the player to click on one of the four buttons.

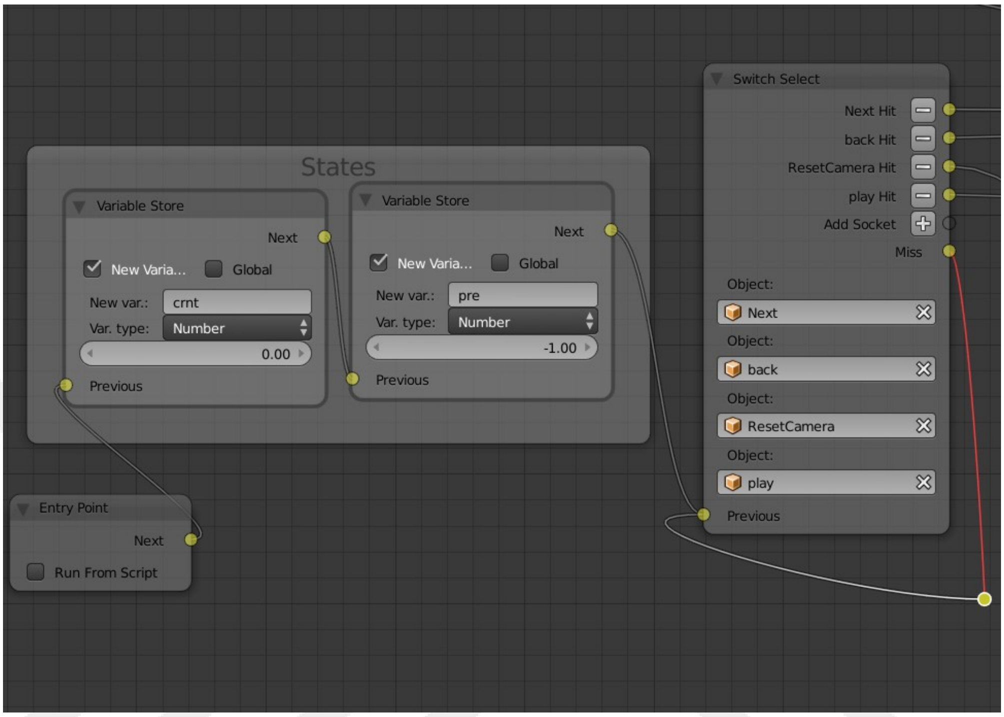

FIGURE 4.13: Game scene showing the current and the previous state of the animation.

"Next" and "Back" buttons play the time corresponding to the current state of the animation, that is, which step in the origami is to be taken next. We could use only one variable, i.e. crnt, to indicate which step is the next one and which is the previous one. However, we wanted the first click on the back button to repeat the last step and not jumping to the one before directly.

For resetting the view when the player lose his/her way in the game scene, we created an empty object at the default camera position. By clicking on the Reset Camera button, the main camera gets transitioned back to its original position and rotated to look on the paper object again. In Figure 4.14, animation process is demonstrated.

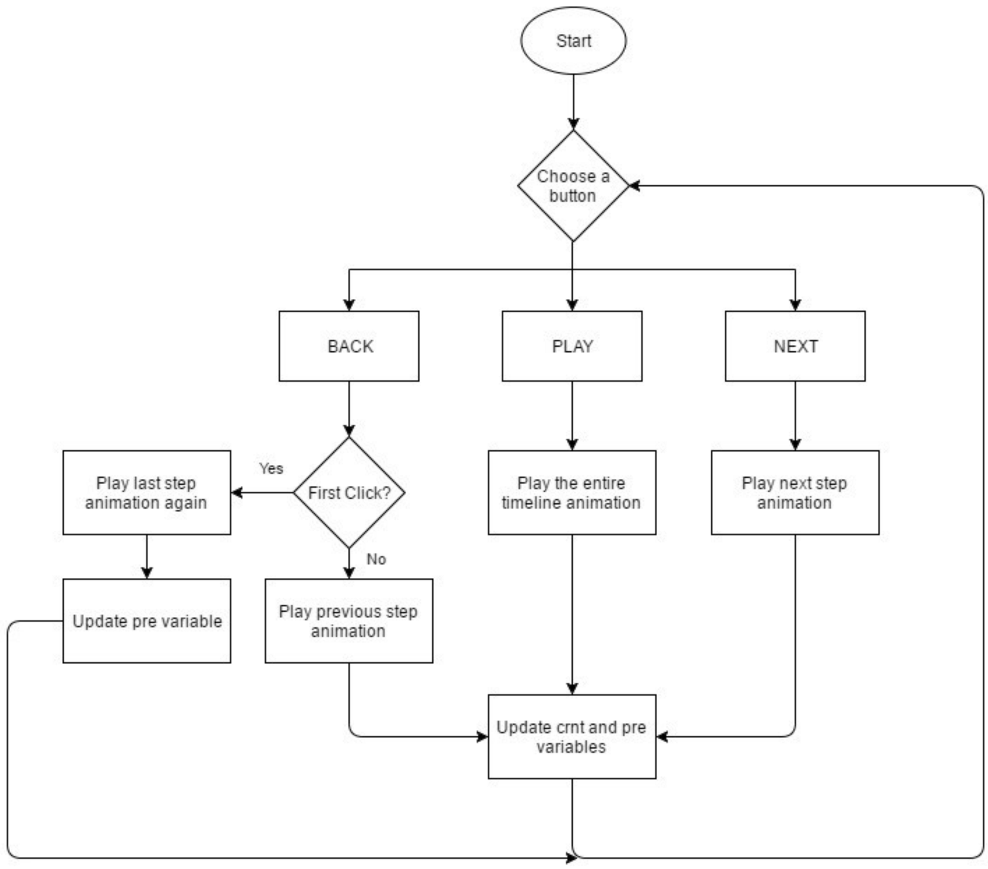

FIGURE 4.14: Animation logic flow chart.

Chapter 5

Performance Evaluation

5.1 Preliminary Test

We carried out experiments to test various subjects and see

- if our tool can diagnose any of them with VSMD,
- if the game when used as therapy can improve the performance of the subjects,
- if the instruction medium better is in Paper or PC,
- if the game design needs improvement.

For testing, Memori was set to present animations of various origami shapes such as T-shirt, Basic House, Sailboat, Duck, Heart, Windmill and Plane. The participants were recruited from Istanbul Sehir University. Our experiment was conducted for 4 weeks. Details are explained in the following sections.

5.1.1 The Test Game

During the Tutorial, the player gets used to the game environment, game progression and folding activity. Then for each origami shape, the whole animation of folding from the first step till the last one is played. Player is allowed to watch the animation as many times as needed. However, once player starts folding, animation cannot be watched again but the final shape of the origami will be visable. For the purpose of our game, it is obligatory to remember the sequence of steps and fold the origami figure correctly.

5.1.2 Participants

24 adults (ages range between 18 and 27) have participated in this study. No subject had ADHD or any physical disabilities and none of them were under medication during the game play that have affected their attention.

5.1.3 Procedures

Participants were provided a room with no distractions. ASUS brand laptop with Core i5 is placed on a table. The game is displayed via Google Chrome. Subjects were asked to play. In total 6 origami shapes (including the tutorial) were folded in 2 sessions (1 session per week).

Before starting the game, participants answered a questionnaire about demographic information, visual memory, and physical abilities (regarding fine motor skills). Each of them were given a *participant ID* to preserve their privacy. 4 participants were randomly selected to be assigned to one group that received the demonstration by instructor. Everyone received instructions and presentment about how to play the game.

For the non-computer game, the instructor showed the folds and the participants repeated them from their memory. For the computer-based game, the same procedure was applied except origami animation was played on the web browser.

After playing the game, participants reflected their observations and suggestions to improve the game.

5.1.4 Experimentation Stage

As explained earlier, the game consists of Tutorial, Diagnosis and Therapy parts.

1. *Tutorial:* This level aims at familiarizing the user with the game environment and folding process. On average, it takes 128 seconds to finish the tutorial. Only for this level, time duration for each fold is saved.

2. *Diagnosis:* In this part, there are 3 origamis; Basic House, Sailboat, and Duck. The difficulty, i.e. number and complexity of folding steps, increases in the corresponding order. Along the diagnosis protocol, users must play the whole origami folding animation and then try to construct the shape.

3. *Therapy:* In this level, players sees the whole animation and do the folding. If they are unable to finish all the steps then by using Next and Back buttons, they can navigate through the animation and complete the folding activity.

5.1.5 Data Processing

Number of successive correct folds and time spent for one origami are used to diagnose for VSM. Therefore these parameters are noted down for analysis.

We defined an equation, as shown below in Eqn (5.1).

$$Performance = \frac{\frac{s}{r}}{t * n} * 100 \tag{5.1}$$

where s is the correct number of folds for the participant, r is the total number of folds for one origami, t is the time that the participant takes to finish the folding activity and lastly n is the number of times the participant watched the animation.

This equation gives participants a score to determine the *performance* for each participant. Similar to the experiment in [22], we used the number of correct folds and the times animation is watched as features. Distinctly we decided to add another variable to the equation: *time.* Since time is an important feature for performance [34] and additionally it is seen as a crucial tool for visual objects like animation [35], we inserted *time* as a supplementary variable for our equation. Later, we tested the performance equation on the dataset in [22], and specified the threshold for diagnosing VSMD.

To compare the performance in two different mediums, we selected 8 people who showed the resembling characteristics based on the pre-survey we conducted before playing our game. Then among these people, 4 of them were randomly assigned to one group which received the instructions by the instructor and the rest were assigned to the other group.

At the end of the forth week, participants were kindly asked to share their suggestions about the game.

5.1.6 Measurements

Our main interest was the performance of each participant. However we needed few more variables to answer the research questions stated in Section 5.1:

- *Performance.* As defined in Eqn 5.1.
- *Memory.* Number of correct steps the participant folded.
- *Attentiveness.* A variable defined by how many times the origami animation watched.
- *Medium.* Performances of each medium; Paper and PC.

5.1.7 Experimental Results & Discussion

In order to diagnose people with VSMD, we defined a *performance* score and test it with the data set given in [22]. After testing, we were able to determine a threshold which if the participant is below that, it indicates that the player is suffering from VSMD. In Table 5.1, we can see the corresponding performances for participants. Based on the testing dataset, the threshold is calculated as 0.2. Any participant with performance score of 0.2 or less is diagnosed with VSMD. In our experiment, participant 7301, 7338 and 7868 are detected.

Some participants, i.e. 5835 and 5507, took more time to fold not because they didn't remember the sequence, but because they wanted the folds to be perfect and geometrically equal. Therefore for future work, we believe that we should define another variable indicating correctness of the final shape for the performance equation. One important limitation of the experiment was that there was no time limit. Hence some participants used trial-and-error method for figuring out the correct fold. Next step in our research, we inted to settle a max time for each origami to avoid such practices.

During our research we diagnosed 3 participants with VSMD. Nonetheless, participants 7590, 2414, 7452 and 8542 have scores which are very close to the threshold value, see

TABLE 5.1: Performance score for each participant

Participant ID	**Performance**	**Medium**
5473	0.96	PC
1061	0.39	PC
7301*	0.14	PC
3996	0.31	PC
3682	0.88	PC
7338*	0.11	PC
8249	0.31	PC
3225	0.32	PC
7590	0.22	PC
2414	0.21	PC
5507	1.03	PC
7452	0.21	PC
5835	0.47	PC
2502	0.41	PC
6385	0.80	Paper
9828	1.04	Paper
1164	0.78	Paper
4947	0.33	PC
3464	0.73	PC
2430	0.59	PC
7868*	0.20	PC
2772	0.68	Paper
8542	0.23	PC
5697	0.47	PC

* indicates diagnosed participants

Table 5.1. Since we conducted our experiment only for 2 sessions, we think that it is a significant limitation to our results. Having more sessions will provide additional data which will result in more accurate diagnosis.

Table 5.2 contains the comparison of *attentiveness*, *memory*, and *performance* for two sessions. *Attentiveness* refers to the quick respond defined by the times origami animation is watched. As can be seen, the average time is decreased slightly from 2.33 to 2.02. *Memory* is assigned as the percentages of the average number of correct folds. There is a remarkable increase in memory percentage which indicates successful progress for future sessions as well. Likewise, same trend is observed in *performance*. The increment from 3.16 to 4.16 shows promising effect in improving VSM skills.

Lastly, we wanted to see if the instruction medium is better in paper or PC. We compared

Table 5.2: Preliminary Experiment Results

	Attentiveness	Memory	Performance
Session 1	2.33	%67	3.16
Session 2	2.02	%80	4.16

the variables, see Table 5.3. For the non-computer game, almost all the players preferred to see the instructions only once, but for the computer based game, they watched the animations till they feel confident enough to start folding. Although this helped them to increase the correct number of folds, it affected our results in attentiveness and therefore performance.

Table 5.3: Medium Comparison

	Attentiveness	Memory	Performance
Paper	1.10	%74	0.75
PC	1.70	%83	0.61

During our experiments, we observed improvements in performance. Our preliminary results show promising enhancement in VSM skills.

Although the *performance* results of game medium for Paper was better than PC, our game has many advantages; (i) can be done in the natural environment of the player, (ii) time saving, (iii) financially economical since the game runs on web browser, its accesibility is quite high.

After testing the game, we received feedback from the players as listed below:

- Some origami shapes were missing few steps of leaving marks before the certain folding acts, e.g. T-shirt and Sailboat.
- Sailboat animation step 5-6 are not that clear.
- Sailboat animation is fast.
- Colored paper is needed because all-white paper makes it hard to see the edges and corners.

In line with inducement and collimation obtained, we improved our game. Additional steps were introduced in the game, animation speed was adjusted, sailboat animation was reorganized, and papers were colored.

Finally, we were satisfied with the design and performance results of our game to begin testing with kids.

5.2 Experiments with Children

5.2.1 Participants

We tested our game at Safir International School and Al-Manar International School in Istanbul. Our inclusion and exclusion criteria for testing were age range on 7-12 and no mental defect, no motor skill problems, or any other known social or cognitive disabilities.

8 female and 14 male participants with average age of 9 were gathered at Safir School. At Al-Manar School, we conducted the test on older kids. Their age average was 11. 5 female and 12 male students took place. The mean of origami experience for both of the schools was 2 out of 5. This information is summarized in Table 5.4.

TABLE 5.4: Pre-survey information on Safir & Al-Manar Schools

	Safir	**Al-Manar**
age average	9	11
gender f:m	8:14	5:12
origami experience	2/5	2/5

5.2.2 Experiment Procedure

In this section, we will explain how we performed the experiment. Firstly, we started with pre-survey to select the participants who meet our criteria. The inclusion and exclusion criteria are explained in section 5.2.1. Based on the pre-survey results, the participants were chosen and they attended KCIT. KCIT was conducted to inspect the intelligence level of the participants. Any participant with mental deficiency was excluded. The ones who passed these phases, joined the experiment. Experiments started with CBTT. Via CBTT, we were able to partition the children into sub-groups. And finally, we began playing our game *Memori*. For testing the game and collecting the data, we followed two different methods; Ammar and Rehab. These methods were same for the tutorial shape but varied in the diagnosis and treatment shapes. At Ammar method, for diagnosis and treatment phases, participants watched the animations till they feel they are ready to fold. Then they started folding but once the folding begins, they were not allowed to watch the animation again, only the final origami shape was avaliable for their vision. For each shape, the times the animation watched, the final correct step the participants reached, and the total time taken were noted. Ammar method is practiced at Safir International School whereas Rehab method is used at Al-Manar International School. At this method, participants played the game on "trials". At each trial, they watched the animation and folded the origami. They repeated the cycle till they no longer desired to continue. We collected the data as the number of trials, total correct steps, and total time taken for all trials of each origami.

5.2.3 Measurements & Results

5.2.3.1 Psychology Tests

Knox Cube Imitation Test. Although KCIT can be used for VSMD, we decided to apply it as an intellegence test. Knox probed this test on migrants in USA as a diagnostic tool for mental deficiencies. We, also, tried it out on Egyptian schools located in Istanbul. He characterized the subjects based on their performance. These groups can be presented in decending order as follows: Bright, Normal, Moron, Feebleminded, and High Grade Imbecile. For labelling the participants, we adopted the same terminology as Knox. As shown in the Table 5.5, our participants do not suffer any subnormality.

After observing that the intelligence level of the participants match our criterion, we included all of them in the experiment.

The Corsi Block Tapping Test. CBTT embodies its own data features which are *block span*, *total score*, *total correct trials*, and *memory span*. *Block span* is the correctly done maximum sequence. In each sequence length, subject has two trials. In order to proceed to the next level, i.e. to the upper sequence, only one of the two trials has to be correct. Sequence lenghts range between 2 to 9. *Total correct trials* is defined as the total number of correct sequences till the test was over. *Total score* equals to the multiplication of *block span* and *total correct trials*. It takes into account of both trials in one sequence. For our evaluations we used *block span* and *total score*. Corsi score evaluation is explained in the following Eqns (5.2).

Table 5.5: KCIT Grouping Results

ID	Group	ID	Group
30484	Normal	**45845**	Normal
46098	Moron	**24406**	Normal
13253	Normal	**35010**	Normal
22198	Moron	**24021**	Normal
97670	Normal	**53800**	Normal
86005	Bright	**62498**	Moron
33268	Normal	**35858**	Moron
92712	Normal	**33081**	Normal
30157	Feembleminded	**50677**	Moron
91014	Moron	**96283**	Bright
83157	Normal	**56645**	Normal
22365	Feembleminded	**49767**	Moron
89393	Normal	**80155**	Moron
69950	Bright	**66505**	Normal
77712	Normal	**64344**	Normal
25262	Moron	**46887**	Normal
83377	Moron	**10703**	Normal
19087	Normal	**32636**	Normal
90726	Bright	**34337**	Moron
61879	Moron		

$$\begin{aligned} totalscore \leq ave - 2 * std &\Rightarrow \text{“}Retarded\text{”} \\ totalscore \leq ave - 1.3 * std &\Rightarrow \text{“}Border\text{”} \\ otherwise &\Rightarrow \text{“}OK\text{”} \end{aligned} \tag{5.2}$$

As a clinical criterion, threshold coefficients for *total score* is set at 1.3 and 2 [27]. Borderlines are estimated on the basis of these data. According to Lezak [36], if the *total score* is smaller than 1.3 times the standard deviation, then the participant lies on the border area, and if it is smaller than 2 times the standard deviation, our subject is classified as "retarded". For our calculations, we followed Lezak's metholodogy and just regarded the rest of the participants as "OK".

We have calculated averages and standard deviations for Ammar and Rehab methods separately and labeled the participants accordingly. In the Ammar method, we have 10 participants in group "OK" and 12 in "Border" as for Rehab method, 13 in "OK" and 4 in "Border", see Table 5.6.

TABLE 5.6: CBTT Results

Ammar Method		**Rehab Method**	
ID	**Group**	**ID**	**Group**
30484	OK	**35010**	Border
46098	OK	**24021**	Border
13253	Border	**53800**	OK
22198	Border	**62498**	Border
97670	Border	**35858**	OK
86005	OK	**33081**	OK
33268	OK	**50677**	OK
92712	Border	**96283**	OK
30157	Border	**56645**	OK
91014	Border	**49767**	OK
83157	OK	**80155**	Border
22365	Border	**66505**	OK
89393	Border	**64344**	OK
69950	OK	**46887**	OK
77712	OK	**10703**	OK
25262	Border	**32636**	OK
83377	OK	**34337**	OK
19087	OK		
90726	Border		
61879	OK		
45845	Border		
24406	Border		

5.2.3.2 Clustering Methods For Data Analysis

We preferred to use R to run clustering algorithms since R is a powerfool tool for statistical analysis and data visualization. Cluster numbers has no significance, they are rather dummy.

K-means Clustering. After seeing CBTT results, we concluded that we should find two clusters in our dataset. We set the function parameter for cluster k=2 and we used the Euclidean distance to calculate the distance between points and centroids. In Figure 5.1 and 5.2, data points are displayed along with the cluster centroids and each of the points is colored according to their clusters.

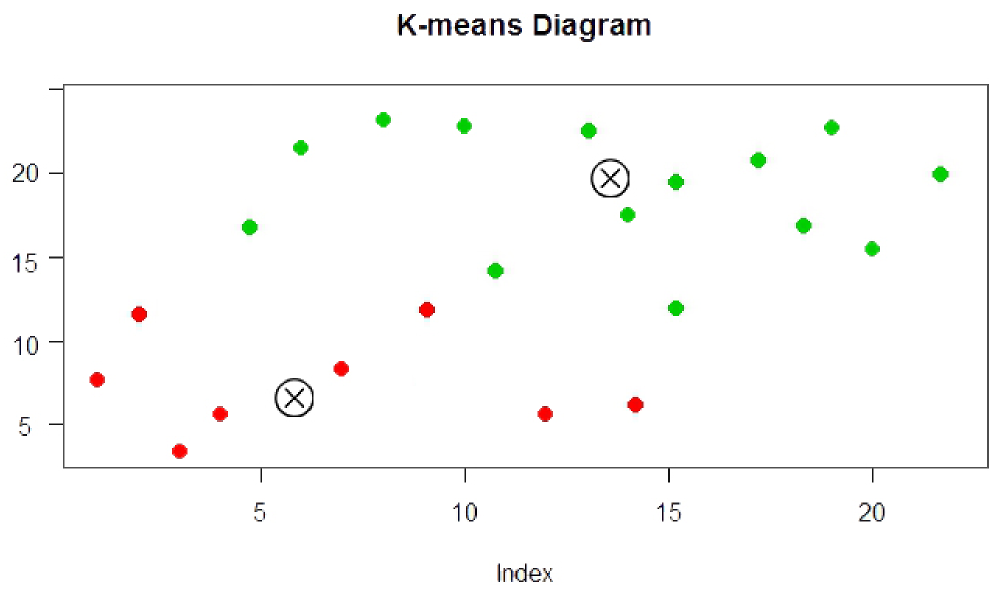

FIGURE 5.1: K-means Clustering for Ammar Method.

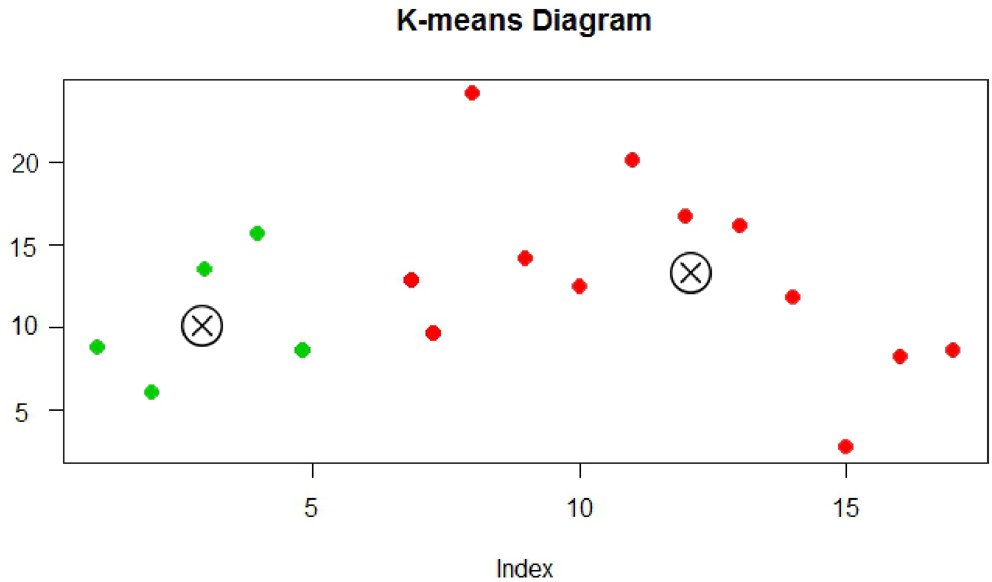

FIGURE 5.2: K-means Clustering for Rehab Method.

In the Table 5.7, the results of k-means clustering are represented. For Ammar method, 8 participants are in cluster 1 and 14 in cluster 2 while for Rehab method 5 in cluster 1 and 12 in cluster 2.

Table 5.7: K-means Results

Ammar Method		**Rehab Method**	
ID	**Cluster**	**ID**	**Cluster**
30484	2	**35010**	1
46098	1	**24021**	1
13253	2	**53800**	1
22198	2	**62498**	1
97670	2	**35858**	2
86005	1	**33081**	2
33268	1	**50677**	1
92712	2	**96283**	2
30157	2	**56645**	2
91014	2	**49767**	2
83157	1	**80155**	2
22365	2	**66505**	2
89393	2	**64344**	2
69950	2	**46887**	2
77712	1	**10703**	2
25262	2	**32636**	2
83377	1	**34337**	2
19087	1		
90726	2		
61879	2		
45845	2		
24406	1		

Hierarchical Clustering. Applying hierarchical clustering produced the following dendograms, see Figures 5.3 and 5.4.

As can be seen, the height difference between the two main clusters are bigger in the Rehab method. And on Ammar method, we have one class including only 1 data point, the rest are subdivided into 2 groups. In the Table 5.8, we presented the subjects with their corresponding cluster (1, 2 or 3). For Ammar method, 15 participants are in cluster 1, 6 in cluster 2, and 1 in cluster 3 whereas for Rehab method 5 in cluster 1 and 12 in cluster 2.

Spectral Clustering. Spectral clustering outcomes are expressed on Table 5.9.

For Ammar method, 15 participants are in cluster 1, and 7 in cluster 2 whereas for Rehab method 11 in cluster 1 and 6 in cluster 2.

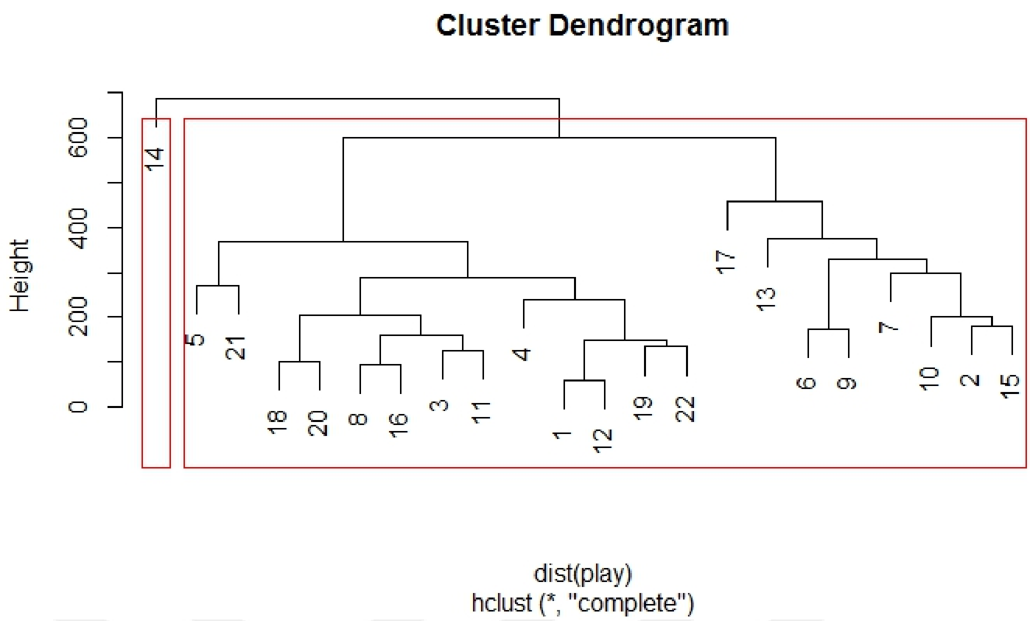

FIGURE 5.3: Hierarchical Clustering for Ammar Method.

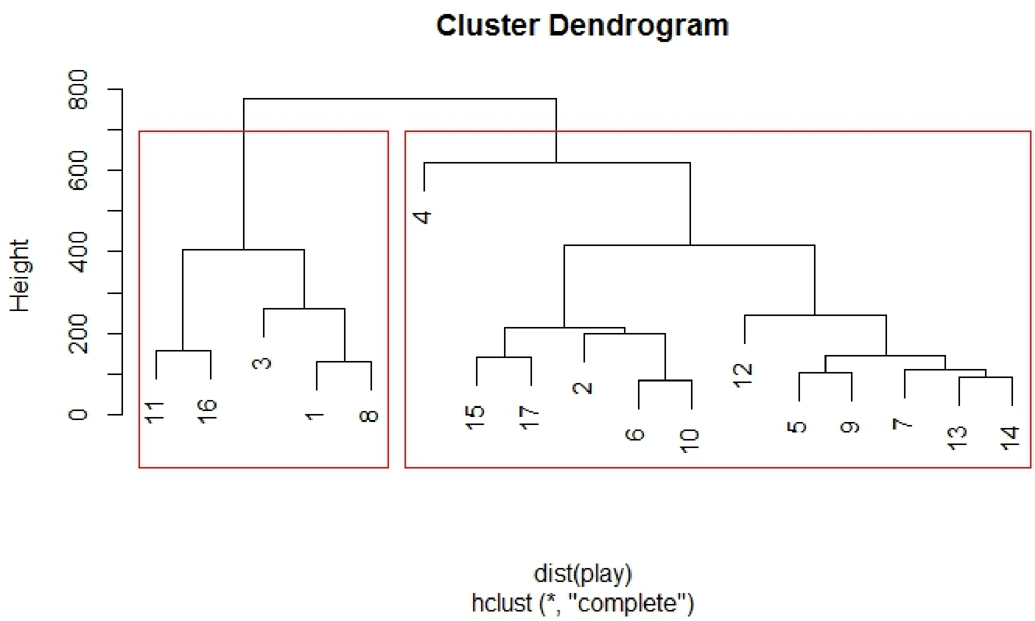

FIGURE 5.4: Hierarchical Clustering for Rehab Method.

5.3 Results Comparison

The bar graphs in Figure 5.5 provide information about the total number of participants for each folding step. A prominent observation is that a significantly high number of childen finished the Heart origami while most children could not fold more than half of the rest of the origamis. For House origami, there is a rapid fall after the first step.

Table 5.8: Hierarchical Clustering Results

Ammar Method		**Rehab Method**	
ID	**Cluster**	**ID**	**Cluster**
30484	1	**35010**	1
46098	2	**24021**	2
13253	1	**53800**	1
22198	1	**62498**	2
97670	1	**35858**	2
86005	2	**33081**	2
33268	2	**50677**	2
92712	1	**96283**	1
30157	2	**56645**	2
91014	1	**49767**	2
83157	1	**80155**	1
22365	1	**66505**	2
89393	1	**64344**	2
69950	3	**46887**	2
77712	2	**10703**	2
25262	1	**32636**	1
83377	2	**34337**	2
19087	1		
90726	1		
61879	1		
45845	1		
24406	1		

Although this is the simplest origami among all shapes, this might be due to the lack of adaptation to the game environment. To decrease the dramatic effect of adaptation, participants played the Tutorial, however, its influence still can be seen. A similar but more apparent trend can be observed for Duck, Sailboat, Windmill and Plane. After the 4th, 5th, 5th, and 6th step, respectively, many participants discontinued the game. This trend is more visible especially on Sailboat and Windmill. After the 5th step, for Sailboat, only 1 participants continued folding and for Windmill this number reaches to 3. Additionally, the performance on Plane origami is really low. Noone finished the folds. The reason for this is that the participants already knew another way to fold a plane. Even though they were instructed to replicate the folds as shown in the animation, they tend to do what they had in their mind.

Table 5.10 gives more detailed information about *time* spent for playing one origami, the max *step* which the participant reached, and *animation played* for origami shapes.

TABLE 5.9: Spectral Clustering Results

Ammar Method		**Rehab Method**	
ID	**Cluster**	**ID**	**Cluster**
30484	1	**35010**	2
46098	2	**24021**	2
13253	1	**53800**	2
22198	1	**62498**	1
97670	1	**35858**	1
86005	2	**33081**	1
33268	2	**50677**	1
92712	2	**96283**	1
30157	1	**56645**	1
91014	1	**49767**	1
83157	1	**80155**	2
22365	1	**66505**	1
89393	1	**64344**	1
69950	2	**46887**	1
77712	1	**10703**	1
25262	1	**32636**	2
83377	2	**34337**	2
19087	2		
90726	1		
61879	1		
45845	1		
24406	1		

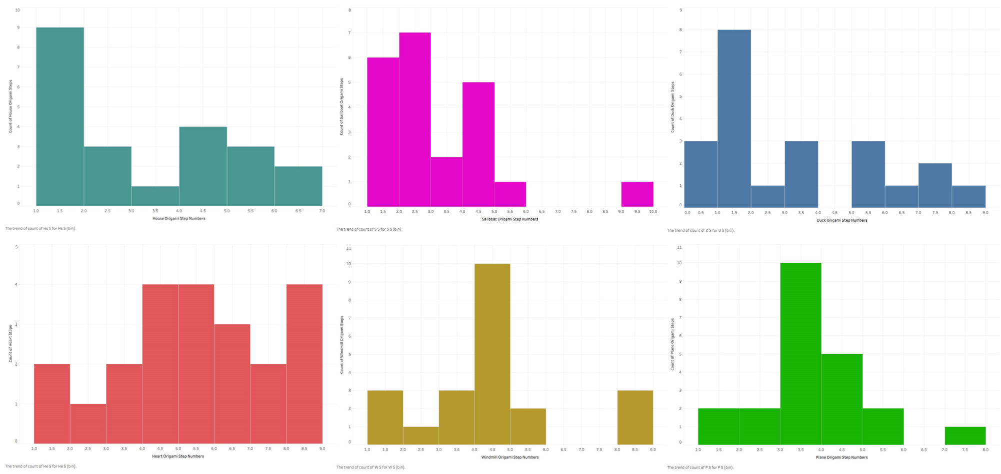

FIGURE 5.5: Origami Shapes Histogram for Ammar Method.

Minimum, maximum, average, and standard deviation values are calculated and shown in the table. Each origami has the following step numbers: House 6, Sailboat 9, Duck 8,

TABLE 5.10: Statistics For All Origamis

Statistics		time (sec)				step #				animation #			
		min	max	ave	std	min	max	ave	std	min	max	ave	std
Ammar	tutorial	66	183	115	30	-	-	-	-	-	-	-	-
	house	10	388	111	80	1	6	3	2	1	8	3	2
	sailboat	37	450	157	107	1	9	3	2	2	9	4	2
	duck	46	671	181	142	0	8	3	2	2	11	5	3
	heart	64	376	131	70	1	8	5	2	1	10	4	2
	windmill	62	386	157	74	1	8	4	2	2	9	4	2
	plane	46	352	140	90	1	7	3	1	2	10	4	2
Rehab	house	44	217	95	49	2	12	6	2	1	6	3	1
	sailboat	42	557	254	132	3	18	11	5	1	9	5	2
	duck	49	568	248	173	0	18	10	5	1	9	5	3
	heart	115	547	211	93	3	30	12	5	1	14	4	3
	windmill	123	483	235	98	9	35	15	6	2	16	5	4
	plane	65	260	168	42	9	40	14	7	2	20	5	4

Heart 8, Windmill 8, and Plane 9.

According to the table, participants for Ammar Method remembered the folds for Heart shape till 5th step on average which is very high considering it has 8 steps max. While this score is 3 for House, Sailboat, Duck, and Plane. The Duck origami was the most challenging shape with the highest *time*, *animation* and the lowest *step* values on average. The difference between Duck and the other origami shapes is even more marked in *time*. The max time that the participant took to fold is 671 seconds which is 450 seconds for Sailboat. The minimum success of Ammar method belongs to the first three origami shapes. It can be noticed that on the last three shapes, Heart, Windmill, and Plane, the average step number increses which indicates that our game help them to master their VSM skill.

The data for Rehab method is not very obvious to read since the way it was tested hides some patterns. But overall, it is clear that there is a steep increase in between the minimum time of first three origamis and the last three while the maximum time slightly decreases. In addition to that, same inclination is noted in step. This could be interpreted as participants spent more trials on origamis' folds, therefore more time is spent and eventually the total number of steps rapidly increased.

5.3.1 Clustering Analysis

In this section, we will demonstrate and compare the clustering methods. The goal is to specify an analysis method for our testing modalities.

The Table 5.11 illustrates the results of clustering methods and corsi grouping. The results are compared with corsi grouping. Based on this evaluation, accuracies are calculated and written on the bottom of the table. Moreover, the Table 5.11 contain data for misclassified participants.

On average, clustering methods achieved to congregate the data by 76% efficiency. It is noticeable that k-means clustering is strikingly higher than hierarchical clustering by 11%. While hierarchical clustering performed 72% and 70% precision for Ammar method and Rehab method, spectral clustering was 77% and 76% accurate, respectively. In general, it can be asserted that k-means, hierarchical or spectral clustering functions well but overall, it is clear that k-means is the best algorithm with the highest percentage in accuracy by 82% on both methods.

What is remarkable about our analysis is that the three clustering methods are reliable for detecting the subjects at "Border" area and rather poor for "OK" group. This also proves that they can be used for diagnosis.

Additionally, on participants 30484, 61879, and 53800 all three clustering methods failed. This can refer to a high probability of that the collected data is wrong and the algorithms see them as a noise.

Table 5.11: Corsi Grouping Results Vs Clustering Methods

	ID	Corsi	K-means	Hierarchical	Spectral
Ammar Method	30484	OK	2*	1*	1*
	46098	OK	1	2	2
	13253	Border	2	1	1
	22198	Border	2	1	1
	97670	Border	2	1	1
	86005	OK	1	2	2
	33268	OK	1	2	2
	92712	Border	2	1	2*
	30157	Border	2	2*	1
	91014	Border	2	1	1
	83157	OK	1	1*	1*
	22365	Border	2	1	1
	89393	Border	2	1	1
	69950	OK	2*	3	2
	77712	OK	1	2	1*
	25262	Border	2	1	1
	83377	OK	1	2	2
	19087	OK	1	1*	2
	90726	Border	2	1	1
	61879	OK	2*	1*	1*
	45845	Border	2	1	1
	24406	Border	1*	1	1
Rehab Method	35010	Border	1	1	2
	24021	Border	1	2*	2
	53800	OK	1*	1*	2*
	62498	Border	1	2*	1*
	35858	OK	2	2	1
	33081	OK	2	2	1
	50677	OK	1*	2	1
	96283	OK	2	1*	1
	56645	OK	2	2	1
	49767	OK	2	2	1
	80155	Border	2*	1	2
	66505	OK	2	2	1
	64344	OK	2	2	1
	46887	OK	2	2	1
	10703	OK	2	2	1
	32636	OK	2	1*	2*
	34337	OK	2	2	2*
Accuracy	-	-	82%	71%	76%

* indicates misclassification.

Chapter 6

Conclusion and Future Work

In this thesis, we created a game system to gather and analyze data for diagnosing and treating children with VSMD. Participants are gathered from 2 Egyptian schools located in Istanbul. At first, they have answered a pre-survey. After that they attended KCIT and then proceeded to CBTT. Lastly, they played with our game. They were exposed to two different experiment methods. The data features are chosen distinctively based on the experiment methods; Ammar and Rehab. Finally, we analysed the data and determined how well the clustering methods performed.

Our experiences during game design process suggests that Blend4Web is an easy-to-use tool especially for creating animation scenes although it lacks of exporting various animation types. Blender is very powerful since it includes multiple options for generating objects, deforming shapes, simulators, and modifiers.

Analysis of game results show that for the both methods the participants were very good at Heart origami. Several reasons could effect this success, such as; its animation type and the origami order. The Heart animation has better features in terms of visualization. Its animation is the only one whose folds are created by Lattice Modifier which gave a curly effect on the fold acts. The Heart origami was the first shape for the second session which is held on the second day of the experiment. It can be deduced that on the first day, the participants trained their VSM skill on the first session and achieved better on the second.

Based on the insights we got after evaluations of the game results, we came to a concluson that k-means is an optimal solution. Although k-means is sensitive to outliers and noise, it gave better classification, namely 82%, among the methods practiced. This attainment could be rooted in its simplicity for implementing and running. In addition to that, its cluster results are easy to interpret.

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6.1 Areas in Future Research

While the proposed game accomplishes determining children with VSMD, few further improvements can be implemented for better precision in diagnosis. For this purpose, we intend to observe hand movements and capture if the player folds back and folds again using Kinect [37] or similar technologies. This will also help in avoiding trial-and-error effect.

Adding variables such as correctness of the final shape and time limit for data analysis is another possible way to increase efficiency in diagnosis.

We also plan to add more shapes of animation type with Lattice Modifier to further prove that the animation style effects performance.

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