Aalborg University Copenhagen

Thesis for the Degree of

Master of Science in Interaction Medialogy

Gestural Interactive Learning Interface

AN EXPLORATION INTO LEARNING

THROUGH EMBODIED INTERACTION

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1 Declaration of Authorship

I hereby certify that the thesis I am submitting is entirely my own original work except where otherwise indicated.

Copenhagen, Denmark. 29th of May 2014

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2 Abstract

Technology-enhanced learning and innovative content representation can allow users to contextualize and improve science learning. A computer-aided system was developed to enable learners to interact with the educational content using their body. This system, namely GILI; short for Gestural Interactive Learning Interface, attempts to encourage users to interact virtually and engage in hands-on experiential learning.

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4 Glossary

ELM	Experiential Learning Model
ELT	Experiential Learning Theory by David A. Kolb
GILI	Gestural Interactive Learning Interface
ICT	Information and Communication Technologies
LLL	Life Long Learning
NUI	Natural User Interfaces
POLE	Project Oriented Learning Environment. A learning platform for students of international universities with the goal of networking students' discipline's together across cultural boundaries. This effort is a partnership of universities with industry leaders.
SDL	Self-Directed Learning

5 Introduction

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

T. S. Eliot

In this section the author aims to communicate how this exploration started and the context for its beginnings. The all-encompassing topic for this work; education, was first selected due to a parallel international project called POLE. Although this thesis was not developed within this POLE platform, both projects shared a timeframe, an overarching theme and inspiration.

In this chapter POLE will be briefly defined. POLE's current project with the industry will be also described as it happened while this research effort was underway. The point of view of the author as a participant will also be shared. After this, motivations to work on the selected field of study for the entire thesis are given. Finally it completes with the thesis definition of the problem statement.

5.1 POLE

POLE (Project Oriented Learning Environment) is an international study platform between partnered universities and companies to develop real life solutions to industry problems. On this platform, students have the opportunity to network their own fields of expertise with that of other participants, to work together in a common project. One of the main goals for POLE is to improve communication and cooperation within multicultural environments through projects. The participating universities are University of Applied Sciences and Arts Northwestern Switzerland, Tecnologico de Monterrey (Mexico), Aalborg University, Copenhagen (Denmark); Merz Akademie, Stuttgart, BTK, Berlin (both Germany) Windesheim University, Zwolle and Technical University Delft (both Netherlands); University of Lund (Sweden) and Minnesota State University, Mankato (USA).

5.1.1 Motivation

There were a few motivators towards working within POLE. Working in a multicultural and multidisciplinary team was one of them. Most companies highly value the ability to work in and collaborate with different cultures and multidisciplinary groups. Therefore, the skills gained by being part of such teams are important for integrating into many industries. Consequently, they are a sought-after expertise. Additionally, the participation of the researcher for both project collaborations (2013 and 2014) was in part due to the companies involved. Continental and Audi presented a very attractive educational possibility. One that could merge with the interaction profile and professional background of the researcher.

5.1.2 POLE 2013 - ConSenses

During 2013, POLE partnered with the German company Continental to form a collaboration called ConSenses. At the time, the company had the ambition to expand its human-machine interface solutions by working with POLE. This is the first experience the author had with this learning platform. The multidisciplinary and multicultural approach of POLE's method is still evolving and in constant development, and it is highly educational. Part of what makes it very attractive is how close it works with the industry. As this thesis covers; we learn through experiencing, and acquiring this knowledge through contact with companies is one of the strengths of POLE.

As mentioned, Continental; which is mainly a tires and electronic components manufacturer born in Germany, was an industry partner of POLE in 2013. It is a big company with operations in over forty countries and 170,000 employees. For the 2013 project collaboration, research and development regarding the use of mobile technology while driving was the topic. The collaboration between Continental and POLE had the goal of researching about the use of the senses to facilitate the communication with smart mobile devices while in the car. All this considering safety issues. Therefore, students were asked to develop as solution for keeping users connected to their digital lives (phone, texting, etc.) while driving without compromising safety. This research effort led to the development of two reports; one directly as a result of the collaboration with an international team of six within POLE, the other as an individual project. The latest under the title: "Digital Notifications Impact on Attention in Driving Contexts".

The process began with a kick-off week in Guadalajara, Mexico where continental has a big electronic component manufacturing site (figure6-1). This city is also where one of the POLE partner universities hold one of its main campus. This university is called Tec de Monterrey and in it, most of the activities during the kick-off week such as team forming, took place.

Figure 5-1 Electronic Component Manufacturing Site, Guadalajara, Mexico

Several and varied solutions where developed during a four month stretch. The prototypes were developed in different countries and put together during the final week in Windisch, Switzerland. After this all teams presented their solutions and prototypes in Regensburg, Germany, where Continental holds a development site.

The relevance of the aforementioned projects to the development of this thesis is based in the skillset developed as a result of them, a network of coaching which started with POLE and also that it led to the next project under this platform. The described skillset is in connection with collaborating with students from different nationalities and cultures but even more importantly; different educational profiles. Most likely because of the forte of the specific universities partnered, there was a particular mix of backgrounds, mentioned further on. Regarding the coaching network, this might have been an emerging property of the platform; since that first contact onwards, it went on in some form. There was a very rich idea exchange not only between students, coaches and all types of permutations. This contact allowed for a strong network that persisted long after POLE was over, one that continued through email and social networks. The over-all learning experience was a very fruitful one. It motivated the researcher to participate once more.

5.1.3 POLE 2014 – Think 2025

Audi, with a workforce of almost 69,000 employees, is one of the biggest automobile manufacturers in Germany and one of the three best-selling automakers in the world (Contributors 2014). Its headquarters are in Ingolstadt, Bavaria and it is part of the Volkswagen group. It is a highly innovative company; its slogan is Vorsprung durch Technik, meaning "Advancement through Technology". One such innovations can be represented in Audi's *Urban Future Initiative* a competitive award that endeavours to provide solutions to the challenges in transportation and mobility in the world of tomorrow.

For this new collaboration, the teams were asked to conduct a research about future scenarios for the year 2025. The solutions to be presented were asked to be proven for feasibility, producibility and sustainability. The future scenarios were each located in five different environments: Home, Work Place, Shopping, Transit, and Education. They were to be divided among seven teams. The author has always felt a deep curiosity towards uncovering how the learning process works and to find ways of tweaking this process to make it more efficient. Therefore the topic of education was originally selected and ultimately assigned to the researcher's team.

The development process began with a kick-off week in Windisch, Switzerland (figure 6-2), in which the teams were formed and students started working together. The teams were asked to deliver their written statement and team objectives, and to present visually how they were to manage the project.

Figure 5-2 Participants during Kick-off Week, Switzerland

Being familiar with both the requirements of the POLE platform and those of Aalborg University, it was clear from the beginning, the POLE project and the master thesis project were two separate research efforts. They both had some coincidences, but the requirements were very divergent. POLE design process focuses on presenting a fit-to-be-seen prototype, there was a stand where posters, movie and other material are to be shown. In contrast, for AAU and the Medialogy Technology department, as a science based formal education, other guidelines are more relevant. The scientific method; a strong focus on testing a very specific hypothesis and to support one's theoretical background with hard science is crucial.

For the two periods when the researcher participated within the POLE platform, there was a common and very specific mix of backgrounds or study fields within the participants. This mix was composed of industrial designers, psychologist, mechanical engineers, process managers, computer scientists and medialogists. Roughly they are named according to the proportional number of students from each field. In both collaborations, half of the members were industrial designers, and probably because of this, solutions were for the most part good looking, but somewhat lacking in the aspects of usability and interactivity. Also, among most fields of study, there was no notion of scientifically testing the concepts.

POLE's collaboration with Audi was a big motivation for students to join, but even when the company did not share any of its knowledge with the participants, these were required to sign a binding confidentiality agreement, over the ideas exchanged within the platform's setting. This also contributed to distancing both projects.

This master's thesis is then, a separate research effort from that of POLE's but shares a common overarching theme, coaching and time frame.

5.2 Problem Statement and Delimitation

During the kick-off week in Windisch, Switzerland, the team which the researcher was part of came up with the following educational problem statement:

> *"Provide personalized, self-paced, portable, engaging, accessible, educational solutions for life-long learning."*

This statement is too ambitious and also vague; it does not state what the problem is and it tries to solve it in many fronts. Even though the topics mentioned in the above problem statement are of interest to the researcher, due to its vagueness and lack of scope, a more focused approach was sought. After some deliberation and research into the education field the thesis problem statement was shaped into:

> *"How could the experience of embodied interactive educational tools affect the user's learning process. "*

This problem statement separated both the POLE project and the thesis in additional fundamental ways. The consideration of the latter tried to provide a more specific objective to the thesis research work, while also; tries including a Medialogy core into the educational context. The support for writing this problem statement is provided in the analysis section.

6 Analysis

> He who learns but does not think, is lost! He who thinks but does not learn is in great danger.
>
> Confucius

This chapter consists of a thorough research on the subjects considered in the problem statement. These cover a wide range of topics, including relatively new trends in education and learning, experiential learning theory and embodied interaction technologies. For a thesis work on any field, it is virtually impossible to encompass all the range of relevant topics. This is particularly hard when researching about education and learning. Therefore in order to avoid missing on key educational issues, fundamental theories such as the long-standing learning paradigms, are considered. It is important nonetheless, to correctly identify and synthetize the fundamental educational theory that would be the most useful later in the project. Therefore a brief education paradigm summary is followed by a focus on a particular learning theory. Subsequently, relevant trending topics in education such as life-long learning, motivation, and engagement while learning are covered. Afterwards, explorations into natural user interfaces, learning environments and other technologies are presented, in order to discover the best approach to design and implement the concepts into a prototype. Finally, in the last part of the chapter, a research into how the users are changing in regards to how they learn is highlighted.

6.1 Learning

The concept of learning refers to the experience, process or act of gaining skills, knowledge and attitudes (Inc. 2004). It is inherent to a variety of life-forms including human beings. Learning takes place all the time, everywhere, while performing almost any kind of activity. It is such a broad concept that it is hard to identify what its main influencing factors are and thus, recognizing ways to optimize it.

Instructional theories relate learning processes with learning outcomes. In this section a few of these are explained.

Bloom and Gagne are two researchers who came up with taxonomy theories based on learning outcomes; these taxonomies are still used. Bloom, (1956) differentiates between comprehension, knowledge, application, analysis, evaluation and synthesis and he proposes suitable methodologies for instructing these outcomes. Gagne (1968) differentiates between five realms; attitudes, verbal information, perceptual-motor, cognitive strategies and intellectual skills. Just as bloom did, he also proposes methodologies suitable for helping users on each outcome.

Although the relationship between different instructional methods and learning outcomes and/or processes is addressed by instructional theories, there are a number of aspects that affect these relationships. These aspects include the nature of the learning task, the context where the learning takes place and the characteristics of the user. About the learner, factors like age, prior knowledge, general talent/ability, learning style and limitations, etc. they all play a role.

6.2 Educational Paradigms

Research into any field is usually conducted within a particular paradigm. It is the investigator's responsibility to be conscious of how looking through any of those paradigms can heavily influence the research methods and findings. In education, (van Merriënboer and de Bruin 2014) there is traditionally eight prevailing perspectives which can answer questions about human learning in varied ways. The following table attempts to describe the aforementioned views:

Paradigm	**Learning Influenced by**
Gestalt Psychology	Insight and Understanding
Behaviourism	Reinforcement
Developmental Psychology	Learner's stage of cognitive development
Cultural-History theory / Medialogy	Interaction to the world
Information Processing theory	Active and deep processing of new information
Cognitive symbolic theory	What the learner already knows
Cognitive resource models	Limited processing capacity of the mind
Social constructivism	Social construction of meaning

Having mentioned those views, this thesis attempts to consider a wide range of perspectives and keep the research open to alternative and emerging theories, as new ones arise frequently in this field.

A special consideration will be given to one pedagogical/learning style. This methodology is called *experiential learning theory (ELT).* This theory lead by Kolb (1984), emphasizes the important role experience plays in the learning process as opposed to acquisition, manipulation and recall which are stressed by other cognitive theories of learning. These other theories often miss or deny the role of subjective experience and consciousness in the learning process. A more detailed look into ELT will be provided in the next section.

6.3 Experiential Learning

Learning is defined by Experiential Learning Theory (ELT) as "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience" (Kolb 1984 p.38). Experiential Learning Theory is a dynamic view of learning based on a learning cycle (Figure 6-1). ELT integrates the works of several prominent scholars to develop a holistic model of the learning process. The works that it integrates have six propositions in common (Kolb and Kolb 2012):

- Learning is best conceived as a process, not in terms of outcomes.
- All learning is re-learning. Knowledge constructions based on experience.
- Learning requires the resolution of conflicts between dialectically opposed modes of adaptation to the world.
- Learning is a holistic process of adaptation.
- Learning results from synergetic transactions between the person and the environment.
- Learning is the process of creating knowledge.

The ELT argues the abilities required for learning are sometimes opposites of each other, and that the learner must continually adjust which set of learning abilities he/she will use in any given situation. Some learners perceive new information by *experiencing the concrete*, felt, tangible characteristics of the environment through their senses. Others tend to understand information by *abstract conceptualization*, which is by its symbolic representation, analysing and planning rather than using their senses as guides. In a similar way, in transforming or processing an experience, some users tend to observe others who are experiencing, and then reflecting on those observations, while others prefer to jump right in to the experimentations right away themselves.

These two principles are called *reflective observation* and *active experimentation* respectively. (Kolb, Boyatzis et al. 2001)

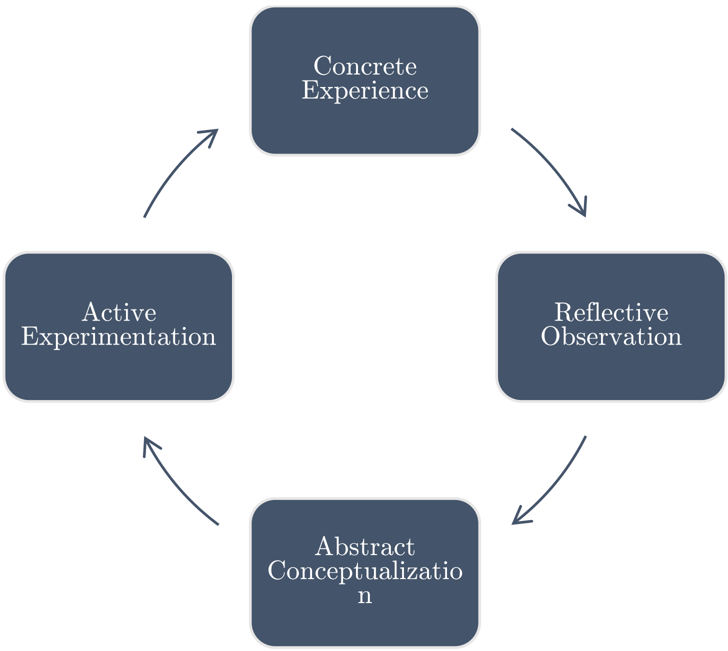

Figure 6-1 Kolb's Cycle of Experiential Learning

These four dimensions (Figure 6-1) are a choice for the learner. It would be implausible to combine them at the same time (e.g. taking a picture vs reading the camera manual). According to this model; because of our brains' physiology, plus our past life experiences and the situation at hand, each learner have an specific way of solving the conflict between abstract and concrete, and between reflective and active. This pattern of selection is called "learning style".

Based on where a learner is positioned regarding these four dimensions, David Kolb (2001), developed an instrument to identify individual learning styles. Research on it has helped identify four statistically prevalent learning styles. These are called *diverging*, *assimilating*, *converging*, and *accommodating*. (Figure 6-2)

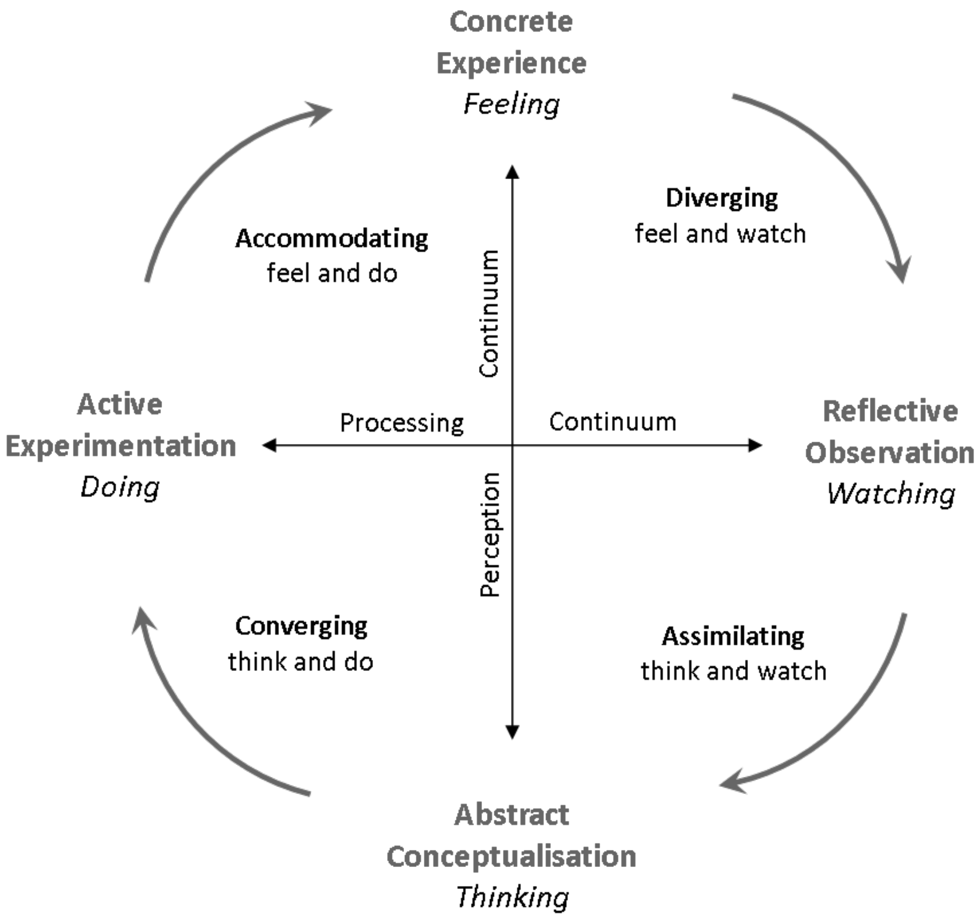

Figure 6-2 Kolb's complete experiential learning cycle

The following is a summary of these four basic learning styles based on Kolb's theory (1984).

Diverging. Learners with this style are best at viewing situations from different angles. They are good for idea generation and brainstorming. These users have broad cultural interests and like gathering information. They tend to specialize in art. For learning they prefer working in groups, listen with an open mind and receive personal feedback.

Assimilating. These learners are best at understanding a wide range of information and putting it into logical, concise form. They are less people focused and more idea and abstract concepts focused. For assimilators, logic of a theory is more important than its practical value. These individuals are good for information and science careers. For learning they prefer reading, lectures, exploring analytical models and having time to think.

Converging. These users are good at finding practical uses for ideas and theories. They are problem solvers and decision makers. They prefer dealing with technical problems and tasks rather than social and interpersonal issues. These individuals are effective specialists and technologists. For learning they prefer experimenting with new ideas, simulations, laboratory assignments and practical applications.

Accommodating. People with this style learn primarily from "hands-on" experience. They tend to act on intuitions rather than logical analysis. For solving problems they rely more in information from people rather than their own analysis. For learning situations they prefer to work with others to get work done, set goals and do field work.

Having covered the learning styles, it has been argued that learning is approached in different ways, and some new theorists propose the use of different intelligences and learning styles as context, learning aim and subject dependent. This might seem like a more plausible scenario. According to Kirschner and company (2013) there is at least three issues when classifying learners into clusters: Many users don't fit into one particular style, the criteria used to assign a style is not always adequate and the number of styles can be so large for particular models that it can be impractical to link particular users to a particular style.

According to ELT a learner can experiment and discover knowledge first-hand, instead of hearing or reading about somebody else's. In order to gain genuine knowledge, David A. Kolb (2012) argues that certain abilities are required:

- The learner must be willing to be actively involved in the experience;
- The learner must be able to reflect on the experience;
- The learner must possess and use analytical skills to conceptualize the experience; and
- The learner must possess decision making and problem solving skills in order to use the new ideas gained from the experience.

It can be argued that the more engaging of a learning experience it is, the easier it is for a user to be willing to be actively involved in the experience.

6.3.1 Educational Software

Combining learning and fun gives birth to what some have called "edutainment"; relying heavily on visuals, narratives and on less formal didactic styles (Buckingham and Scanlon 2000). The original idea of combining education with entertainment might have first appeared back in the 1970's with the first video games. According to Okan (2012) this interest, first inspired by behaviourism and then cognitivist and constructivism, brought educators into incorporating game-like elements into their curriculums with the purpose of creating a "fun and engaging learning environment for students".

The potential to incorporate information and communication technologies to improve the learning process is vast. According to some theorists, (Okan 2012) in the last few years there's been a transition in the educational philosophy, from a traditional instruction to a more engaging, interactive, experiential learning method. These theorists among which John Dewey is, pointed out the importance of excitement and initiative on the learner, and emphasized learning as a lifelong activity fundamental to being human.

The pedagogical methodology of experiential learning, developed by Kolb puts emphasis on an active process of construction of knowledge which involves information exchanges between the environment and the user (Kolb and Kolb 2012).

Educational software, which can relate and balance education and playful engagement; according to Okan (2012), has come to be more frequently found in both the home and at schools. This author also recognizes that this educational software can support new ways of engaging learning such as "learning by doing".

One of the best points favouring the use of educational engaging software technology is that it motivates users to explore subjects in greater depth. This is supported by Malone's theory (1981) of intrinsic motivation. This theory relates how curiosity, challenge and control can be balanced to achieve this intrinsic drive. It stipulates that the user's understanding of the subject is enhanced because he/she is motivated by the use of interesting, rich and engaging learning experiences. Consequently, learners pay more attention as content is provided in a memorable, dynamic way. In addition, it is mentioned that users are motivated to continue for longer periods of time or to undertake the learning activity more often when they are having fun.

6.3.2 Engagement in Learning

It is not very clear what engagement in learning is. It would be easy to think it involves how much time and effort a student devotes to learning. Chickering and Gamson (1987) provide a comprehensive definition which identifies seven guidelines. These are : Increase student–faculty interactions both inside and outside the classroom, give prompt feedback on students' work, set high expectations for students by challenging them to put forth their best effort, provide collaborative learning opportunities with other students, provide experiential learning opportunities, maximize students' time on task in curricular pursuits, appreciate diversity in students' talents and learning styles.

They argue providing opportunities for experiential learning is one of their guidelines for learning engagement. Closely connected, they make appreciating the diversity of learning styles another guiding principle.

Robert Carini in *Engagement in Learning* (2012) discusses that learners should be exposed to challenging, interesting and –more importantly to this study- experiential learning opportunities in a safe and supportive environment. He explains how engagement is a recipe for reversing user's boredom and apathy and goes on arguing that as it taps directly into students experiences, "it may more directly assess learning opportunities than traditional measures of school quality" (Carini 2012 p1153).

6.4 Meaningful Multimodal Learning

When learners use their bodies to experience learning, they receive information through various senses. Therefore it is important to take a closer look at how learning while receiving information from more than one modality occurs. Isolated memories does not account for much, would they be considered knowledge by themselves? According to Shell and colleagues (2010), short term memory does not work by creating these isolated pieces, and it does not "select" information for storage into the long term memory. Every time a memory is "recognized" (a neural pattern in the cortex was the same as the input) rather than creating a new one, the old pattern is strengthened. The term used for this process of identification and matching is *retrieval*.

When the input for a memory is multi-sensorial, both sensory channels will be part of the stored pattern. And when any of this sensory inputs is paid attention to, both original inputs that were stored originally, will be retrieved. This occurs because as neurons are chained together, the activation of one will fire on all others connected to it (Shell, Brooks et al. 2010). The input of one modality could activate and strengthen the retrieval of a whole pattern involving a multi-modal memory.

In the case of already stored multi-sensory patterns, additional modalities can be added. By attending to any of the original sensory stimulus combined with a new one, the original pattern is retrieved and the new input modality is associated with it. The resulting neural pattern would contain all sensory patterns and it could be retrieved by the presence of any of them.

6.5 Motivation

According to Shell, Brooks et al. (2010) learning is built upon three components: knowledge, working memory, and motivation. There are a lot of definitions of motivation in the literature but when it involves specifically learning and education, it could be considered as the push or impetus for directing the working memory (focused attention) to a task.

One of these "ingredients" for learning, the working memory receives a significant input from brain regions associated with emotions (Shell, Brooks et al. 2010). These emotional inputs do affect attention and alter the capacity of the working memory and how it resources are allocated.

Focused, sustained attention requires effort and motivation is the psychological term most used to denote the factors that keep learners engaged in putting forth and sustaining effort. Stored knowledge from previous notions of goals, performance and rewards as well as the emotional inputs constitute the elements of motivation in working memory or the effort level that is put into learning.

Moriarty and company (2012) argue that the majority of undergraduate science, technology, engineering, and math (STEM) undergraduate courses involve oral lectures usually with PowerPoint presentations by the professors to the students, a learning method which according to the authors, the students find boring and thus, impacts their understanding and retention rate. Furthermore they identify this lack of interest and difficulty in learning as contributing factors for low rates in STEM degree completion.

6.6 Life Long Learning

The concept of life-long learning (LLL) is not new, it has been explored at least for a few decades. A research on learning environments (Attwell 2007); points out the recent focus on LLL was driven by a shorter product life cycle, the increasing speed of adoption and implementation of new technologies in the workplace and the increasing instability of employment with the computer driven industrial revolution.

It used to be the case that the state and much later employers were responsible to provide some level of training for workers, as it was consider they would need to continue learning and acquiring new skills to become more competent. Today, the burden of looking for further education and training usually rest on the individuals, and it's often seeker out for self-betterment and employability.

6.7 Informal Learning

It is almost self-evident that the learning process is continuous throughout our lives, it happens not only in classrooms and libraries but in all kinds of context and settings.

Paul J. Hager (2012) defines the concept of informal learning by the features it lacks from formal learning. These features are:

- A specific curriculum
- Instructed by a designated teacher, or a group of them.
- Assessment and certification.

Informal learning can include a much broader category, that of learning by experiencing life (Hager 2012), including the experience of it through our digital devices.

One of the issues with informal learning arises when trying to recognize it or certify it. There is a big effort to recognize informal learning, specially so after the appearances of online courses backed up from universities and renowned institutions (coursera, harvardx Stanford). (Koller 2012)

6.8 Learning Assessment and Recognition

There has been an important shift over the last decades in regards to assessment of qualification. The shift has occurred by translating qualifications into competences and outcomes. A user does not necessarily need to be locked into a program at a university or learning center to get qualified but he or she learns in a multitude of ways and is allowed to present her knowledge to prove competence. (Attwell 2007)

The industry is increasingly asking for proof of the ability to apply knowledge.

6.9 State of the Art

In this section there is first a literature review of a scientific paper relevant to this effort. Right after there is a short discussion on how to possibly integrate touchless technologies into the learning process.

6.9.1 Natural User Interfaces – A Literature Review

This section is a review of the paper *On the Naturalness of Touch less: Putting the "Interaction" Back into NUI* (O'hara, Harper et al. 2013).

Natural Users Interfaces (NUI) is a term that comprises a variety of emerging technologies and their applications to communicate in a more intuitive way with computers. These technologies include devices with pen-based inputs, multi-touch screens, cameras and infrared sensors. In this paper, O'Hara and colleagues (2013) summarize the essential principles about NUI from various sources, which is; that by identifying gestures and other movements used to manipulate the world, new interaction paradigms could be designed. This would empower people to communicate in ways they feel more naturally inclined to and might eliminate the need of users to learn the particulars of a specific technology.

O'Hara and colleagues point out the lack of homogeneity in the meaning of *naturalness,* in gestural interactions as these may relate to very different types of activities. The term natural in this context can mean easy to use, easy to learn, intuitive, and others; it is loosely defined by various sources.

A main perspective for of the NUI narrative (Jacob, Girouard et al. 2008) is that its objective is to leverage from pre-existing actions used in every day, to communicate and manipulate the world. The principal idea behind this approach is to "filter" human-computer interactions through them, to make it as if interacting with the non-digital world. This viewpoint assumes a universality of actions and communicative gestures, and that these interaction have an ideal form by which the naturalness of the interactions can be measured. This perspective has led to important innovation in ergonomics and interface design, but O'Hara and colleagues argue, that developing in this direction can sacrifice understanding of what HCI could entail particularly in embodied interaction interfaces.

The authors of this paper contrast this idea, with a view that distinguishes between the *objective* and the *lived* body. The objective body can be simplified as how bodily actions are described by an observer, the lived; as the experience and perception of the world by the embodied actor. This latter view is also stressed by Merleau-Ponty (1962).

From the perspective that naturalness is not something to be represented, but rather something to be actively produced by people, in particular places and occasions; an important property is that actions, are not only linked to space, but also to the people occupying it. This brings one of the most important points argued by the authors: "naturalness of how a technology might be interacted with lies not in the physical form of that technology, nor in any predefined interface but in how that form and the interface in question meld with the practices of the community that uses them."

The authors of this paper make a technological comparison, five characteristics are considered: proxemics (distance of the body from the sensor), transfer of matter, momentum and pressure, constrains of movement and haptic feedback.

This comparison might be inherently flawed since it considers the *dichotomy* of touch vs touch less when in reality, technological advancement has filled the gaps between the two. This technological emergence has made touch and touch less part of *continuum*. An example of this is touch screens on smartphones which require the finger or a pen-like input device to merely hover a few centimetres above the screens. On this example, there is no transfer of matter, and no momentum and pressure, but the constrains of movement are virtually the same as with old touch screens; rendering a grey area.

The authors make very relevant argumentation about the *communities of practice*; different properties of technologies and their potential for action are meaningful in different ways by different groups. Embodied touchless interaction is particularly beneficial for certain groups of users. Communities of practice also helped the author of the thesis understand how people from different educational backgrounds may be used to experiencing the world through the use of specific gestures

Another factor that plays a role in embodied interaction is the *setting* which O'hara and colleagues define as the physical environment, the architectural arrangement, the ecology of artefacts within which a piece of interactive technology might be placed and the social actors.

Taking into account these three aspects of embodied interaction – properties of touchlessness, communities of practice and the setting-, the researchers conclude about what makes an embodied interaction natural; "it arises from the potential for action enabled by various properties of touch less interaction and how this properties come to be made meaningful in practice of specific communities in particular social settings."(O'hara, Harper et al. 2013 p.09)

This scientific paper conveys a valuable perspective for evaluation in regards as to how to judge the naturalness of embodied interaction. For this thesis work it should not exclusively be judged based on how close it approximate to human-human communication or body movements, rather; the interaction design should consider how to allow beneficial reconfiguration of practices and how the user experience the world because of it.

Arvanitis and colleagues (2009) argue it has been demonstrated there is a need to transition to technology-enhanced classrooms in which a real environment can coexist with virtual objects allowing learners to visualize abstract concepts and complex spatial relationships.

According to Terrence and associates (2000), advances in natural gesture human interfaces and depth sensor cameras provide a more lifelike alternative to outdated object-based control systems for exploring virtual reality environments. Since the early 2000's there has been numerous improvements in 3D virtual reality environments but also, depth sensors appeared around that time. At the beginning there was not a lot of developments in relationship to gesture recognition. According to some authors (Moriarty, Lennon et al. 2012), Microsoft with its red, blue, green and depth sensor camera in its Kinect, has been leading the field. This had been the case for a few years but, competitors have quickly caught up. One such technology competitor is the Panasonic D-Imager, which provide greater depth detail than Kinect without using an RGB sensor. It uses a specialized charge-coupled device (CCD) sensor.

The latest iteration of Kinect's software development kit has incorporated some general gesture recognition (Microsoft 2013).

A real game changer for depth sensing cameras made its debut in the second half of 2012; the Leap Motion. This device, although it has a more limited range than other competitors, it provides the possibility for near field gesture controls and about its accuracy claims it "tracks all 10 fingers up to 1/100th of a millimetre. It's dramatically more sensitive than existing motion control technology and can track your movements at a rate of over 200 frames per second" regarding its responsiveness. (LeapMotion 2013).

6.9.2 Personal Learning Environments

This concepts according to Attwell (2007), identifies the responsibility of the user to organize and lead his own learning. It is based on the concept of mobility or that learning can take place in different situations and contexts. It supposes learning is not provided by a single learning figure or teacher and it recognizes that the process is continuous.

Personal learning environments are an effort to extend educational technology access to everyone who wishes to organize their own learning and to bring all learning together, including informal learning, workplace learning, learning from home, learning driven by problem, learning motivated by personal interest and formal learning from educational programs (Attwell 2007).

The concept of managing one's own learning is one that could be considered in the design of the system to be developed, or future iterations.

6.9.3 User 2.0

Learners which have been exposed to a wide range of new digital technologies, mobile devices, games and gadgets have arguably evolved into a new kind of user, the "natives", the "immigrants" (Cobcroft, Towers et al. 2006), the "digitally literate", "NetGen" or "millennial student" (Oblinger, Oblinger et al. 2005). These students process information in a different way than prior generation learners. Some authors have pointed out the easiness with which these users adopt and adapt to new technologies, and have even provided the year of 1982, as the one after which people born, are more focused on social interaction and "connectedness". These users have a highly developed ability in multitasking and a mind-set based on information technology (McMahon and Pospisil 2005)

According to Oblinger and company (2005) this "Net Geners" possess a combination of attributes, some of them listed next:

They have a desire for *experiential learning*. Authors argue that students learn more when they interact and actively construct their own knowledge; they point to a positive correlation between interaction and student retention.

NetGens are also used to receiving information fast; they can parallel process and multitask better. They expect immediate gratification and this applies to access to services and friends.

Digital natives are mover visually literate than previous generations; they are more comfortable with image-based rather that text only environments.

Further studies suggest additional differentiation within this group. In regard to online learning activities, older students showed a strong preference for video-based lectures while younger users indicated an inclination towards more interactive learning activities. (Simonds and SJ 2014)

6.10 Analysis Conclusions

Theories and technological developments in the educational field which are considered to be relevant in solving the problem statement, were investigated. Many of the concepts in this previous analysis are considered for the design and implementation of the system that will be developed. Unfortunately some, although very desirable for later iterations, are outside the scope of a testable implementation within the time frame of the research. Exploring these areas was fundamental to gain a notion and perspective for the development of a testable learning system.

The education theoretical backbone of learning through experience is merged with the state of the art concepts in natural user interfaces to try to improve specific aspects in the learning process.

7 Design and Implementation

This chapter covers a set of sections; first a discussion's about the author's processes of ideation in regards to natural user interfaces. It then will then justify the selection of a suitable body tracking technology. The chapter will then explain the considerations for the selection of themes. It will then move on to the software development and the gestural control and finish mentioning the parts the system consists of.

7.1 Embodied Natural User Interfaces

This section is a brief discussion on how embodied natural user interfaces could be integrated into a solution that could potentially aid in the learning process.

It is often the case that when one thinks of ways to integrate more technological tools into the learning process, the idea of a mouse and keyboard connected to a computer comes to mind. Even when they go a little bit further to include smartphones, tablets or similar, the thought of interacting with the system in a more natural way -through sensed body movements and touch less gestures- is usually not considered. In this same category of techniques, non-vision tools can also be recognized such as multi-touch gestural and pen-based inputs.

It could be easy to contemplate all these embodied interactions as a more natural or intuitive way of communication with a machine. If this was the case, the requirement for training in their use could be reduced or even eliminated and users could merely be instructed to operate the interface "naturally".

The central principle for natural user interfaces consists on identifying everyday gestures; the way people interact with objects, and apply those to communicate with an interface. Users would not have to adapt their movements to the system□s particular interface technology but their intuitive gestures and their bodies themselves would become the interface itself.

7.2 Body Tracking Technologies

The detection of the learners own body was a requirement for the system's design. Several sensors and technologies were considered before selecting the Leap Motion as a suitable body tracker. As mentioned in the state of the art section, it was the case that Kinect was the main and more robust body tracking device. This is still the case to an extent but for the development of the system to be used in this research, Leap has clear advantages. Kinect can detect a skeleton in a range from 80 to 400 cm which makes it a good choice for whole body tracking but it's not suitable for very close distances or very precise movements. It was the researcher's objective to interact with objects in a virtual space, using one of the most precise and sensible tools in the human body, the hands. This limited the search for technologies and made the Leap Motion an ideal candidate. According to its technical specifications, it can track all ten fingers with a very high precision and responsiveness, as mentioned in the state of the art section (6.9.1).

7.3 Themes

Using the learner's body to manipulate objects that he or she can already interact with in real life would be interesting to try and test but, the idea of allowing the user to get out of its own paradigm was a far more exciting one.

Therefore, the selection of science-related concepts steered around other-than-human scales. Scientific interest can be usually directed towards the study of objects which are much larger or much smaller than human scale. This distinction also involve time. Scientist use very large and small numbers for both description of objects and theoretical purposes. The notion of “common sense” help relate ideas with human experience but there is no common sense intuition for other-than-human scales. Abner Shimony (2000) in his book “The Large, the Small and the Human Mind” talks about this notion of understanding the boundaries between the physics of the small and those of the large. He explains how the laws that govern the large-scale behaviour of the world and those which govern the small are very different. This gaps between where humans have a sense of understanding of the world and the large and small scales seemed to be plausible areas to be benefited by embodied interaction technologies.

7.4 Platform Selection

The implementation with Leap Motion started using Processing as platform and programming language. After the implementation of a solar system navigation prototype, Processing inadequacies became apparent. It was considered limited in terms of its scalability and responsiveness. Scalability was needed to implement better gestural features and the responsiveness was crucial as it had to be fast enough for the interaction to be as natural as possible.

After this first trial with Processing, Unity was selected as a possible platform choice for development as there is some support from Leap Motion for this development environment. Communicating the Leap's software development kit with Unity was relatively straightforward and there is friendly documentation and programming guidelines to follow.

One of the chosen concept themes dealt with the very large planetary scales; a solar system model which represented the sun, planets and other spatial objects in their correct relative-to-each other scales. The possibility of comparing to human scales objects for reference, was a feature. For its development, some assets were gathered and put together in Unity 3D. For some of these models, a material (map) was applied to them to simulate the real appearance of the planet. Shaders and particle system plugins were used to give the objects a more realistic look. These maps are real photographs taken by NASA (2013) under their image policy license. All original mesh spheres are based on the same geometry but scaled to real life proportion. These proportions were obtained from the Wolfram Alpha computational search engine (2014). Then the implementation of navigation controls based on hand movements started. The purpose of this application was to be able to explore the bodies and to compare them to each other. This would be achieved by navigating around them and see them close to each other. A representation of the user's hands was implemented so he/she would know their position in space and possibly get a sense of being present.

Figure 7-1 The Interactive Solar System

The planets were displayed next to each other as the immense amount of space might prevent learners to grasp the size of the objects. The astronomical objects selected for comparison are the Moon, Earth, Jupiter and the Sun.

It was ultimately not the interactive solar system application which was selected as a proof of concept. An understanding of scales in the other direction; the microscopic, was chosen. It is very common to find cell biology as part of the curriculum in early stage education. Most students go through this subject at one point but very few remember any of it later on, as it would be found. The possibility of getting "in direct contact" with a cell and its components (organelles) was a very attractive one. This concept was to drastically depart from the traditional way of teaching the subject, which is by reading from a textbook while possibly having the opportunity to see a diagram.

The idea behind the application is to represent a virtual reality cell body including its main components and the possibility to explore their details. Navigation around the virtual cell is intended to be an immersive experience. Moving through in a world representing a real although microscopic environment.

Implementation for the interactive solar system was not as extensive as the one for the interactive cell. After gathering online assets from repositories and trying them out, a cell biology application meant for smartphones was found. It was developed for educational purposes by a Brazilian university, Universidade Estadual de Campinas. In it, a user could navigate through an animal cell and learn more about its components by selecting them. This educational effort is led by Eduardo Galembeck (2014). It was considered plausible to try to implement the desired functionality and interactivity principles in an application which was developed for a different type of interface (mouse/touch) and which it would later be found, was written in a different programming language than the one previously used by the researcher.

Contact with the project leader Eduardo Galembeck and programmer Rodrigo Dias Takase was made, to consider the possibility of a cooperation. After a few emails exchanged, a research collaboration was agreed upon and a few days later a package containing the code for the smartphone application was received. The controls for it were mainly written in a programming language called JavaScript but so far all the Leap Motion implementation in Unity 3D had been done in another one called C-Sharp. Making both communicate to each other inside the app was not an easy task. Some of the existing functionality of the app had some publicity attached to it, which was removed since it didn't serve any purpose for this investigation.

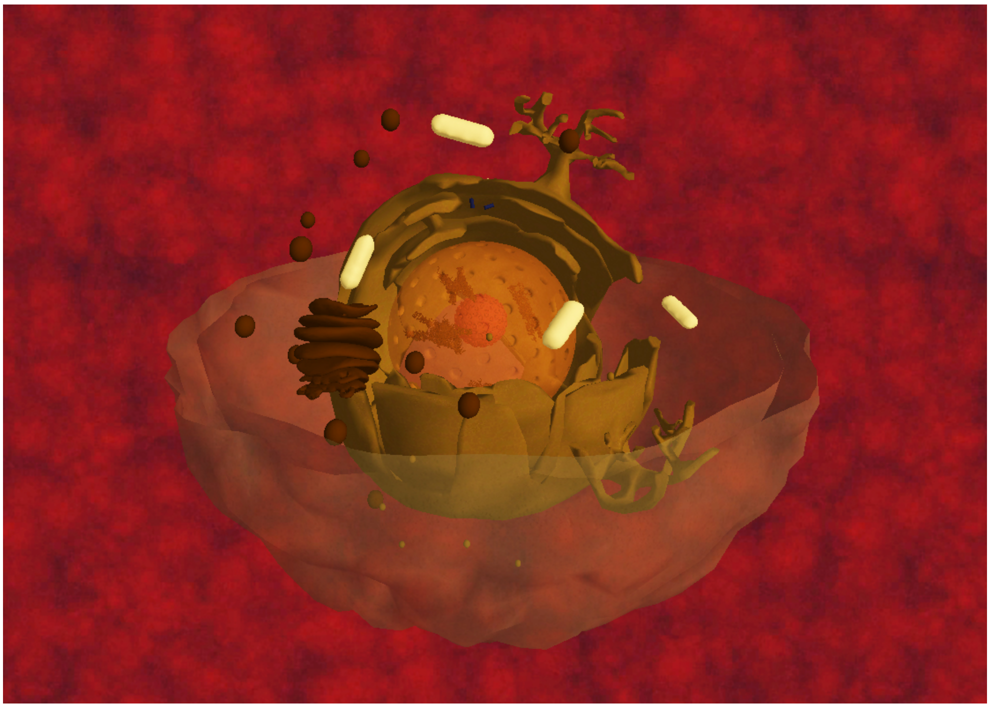

Figure 7-2 First glance at The Cell's interface.

A representation of the user's hands was at first implemented for both applications but was later removed for the latest iterations (tested version) since they reduced the working space and didn't serve any functional purpose (Figure 7-3).

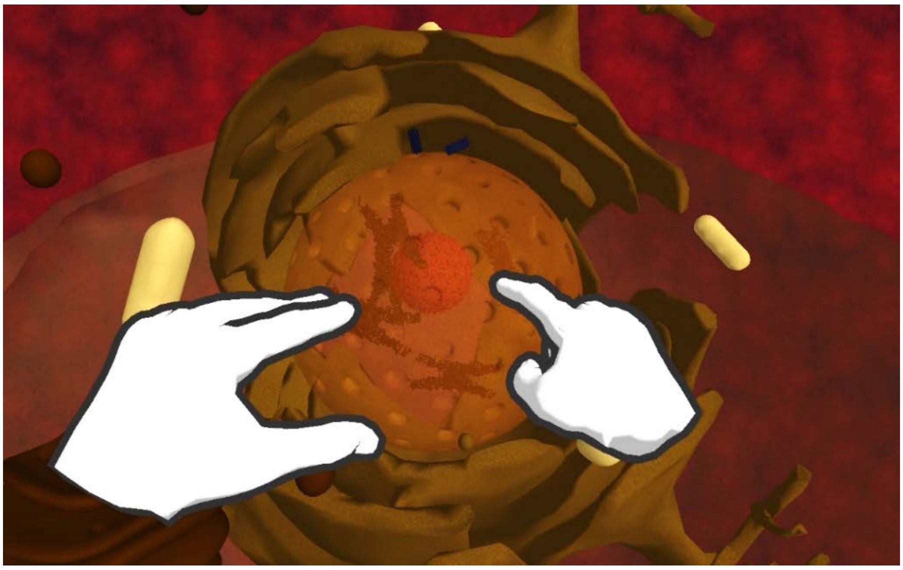

Figure 7-3 the Cell

Twelve cell components were present in the final app: plasma membrane, ribosomes, smooth and rough endoplasmic reticulum, nucleolus, nucleus, mitochondria, Golgi apparatus, peroxisome, chromosomes, centrioles and lysosomes (Figure 7-4).

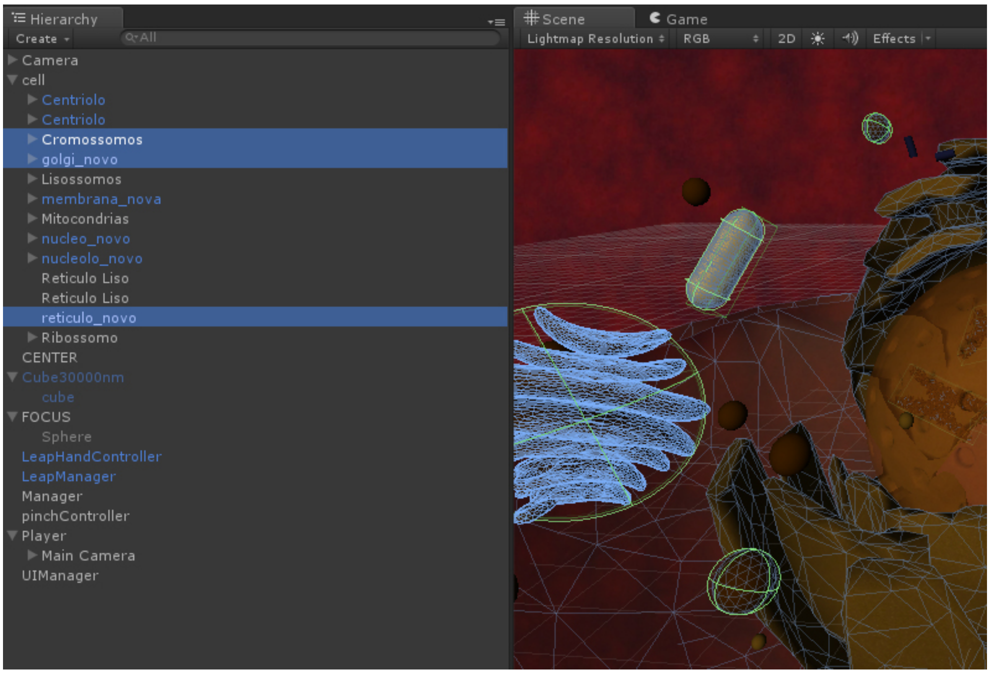

Figure 7-4 Listing of Organelles in Unity's Interface

All of them selectable through the circle gesture embodied interface. When a selection has been made, a floating information panel transitions in. This panel provides additional information for the selected component and can be contracted back. There is additional functionality which the user can take advantage of; a dissection tool, which divides the organelle in half so the insides can be observed, and a ruler tool, which toggles a dimension visualization on and off.

This idea of navigating and interacting with a cell and its organelles was one that could be greatly aided by embodied interactivity. Virtually moving in an out of the cell wall, looking at and navigating through its components, being able to select them and get additional information about them; this interactive functionality might provide different layers of understanding.

Working on concepts for both large and small worlds, addresses that lack of contact with different than human dimensions in the user's daily life. Learners can see the dimension information of the organelles when they activate this functionality (Figure 7-5). The activities in virtual reality of *zooming in and out*, and visualizing objects close to each other could specially help the learner develop a deep understanding in how different components relate to each other to form the whole.

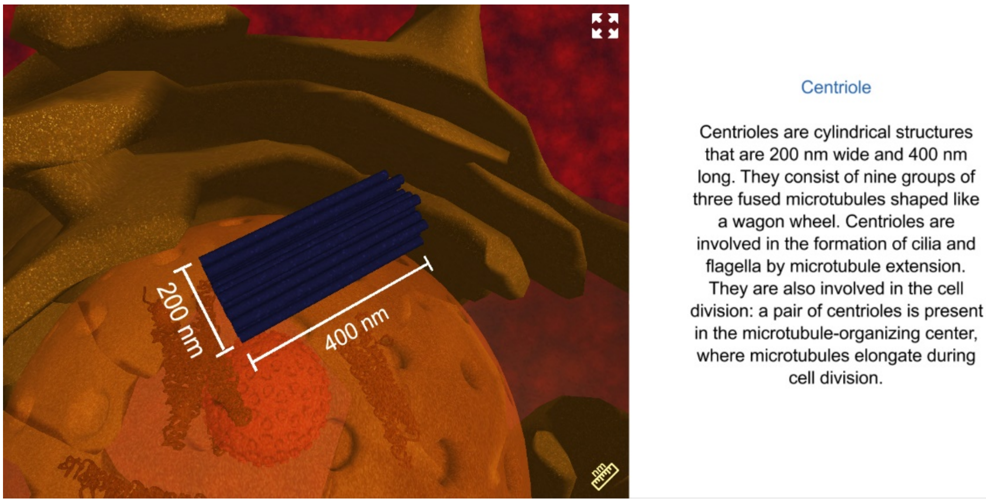

Figure 7-5 Representation of User Interface in the Cell. Users can get textual and graphical information.

7.5 Gestural Interactive Learning Interface (GILI)

In the development of Gestural Interactive Learning Interface (GILI), the Leap Motion sensor camera technology has been integrated with a virtual reality environment to create an interactive and immersive learning experience. By using the gesture recognition in Leap Motion, with the interactivity in virtual reality, and the ability to use the user's hands to navigate, and select objects by hand-picking them in a way approximating real life experience, the learner could have a better understanding as he/she is provided with contextual cues. The goal of the system is to encourage the learner to immerse in the educational experience and to explore the virtual learning space, which is designed for a specific scientific field of study. The user can hand-pick the most interesting elements of the interaction to get further information about them. By providing an environment that is navigable and interactive by the use of the learners hand movements, the learning experience is based on the user's curiosity and desire to learn, not in the more traditional way of using the learner's willpower to pay attention for long periods of time. The learning experience using GILI is non-linear, which allows users to select what material to focus on, based on their individual interests and needs, avoiding redundancy. GILI's user interface allows for the subject to see his/her own hands, represented virtually on the screen, responding in real time to the learner's movements. This visual feedback allows for an easy learning curve, potentially for all age groups. It is precise enough to show the individual finger movements. Additionally, thanks to this visual representation, the learners can get a sense of their virtual position and in a way, experience a connection with the content they are studying.

The reason 3d gesture control is promising avenue for this work is because we are all natural experts at hand interactions from early age. We are trained by life to interact with object in a 3d environment. We are comfortable and confident with using our hands and communicating through gestures.

7.6 Controls

7.6.1 Navigation

The controls had an iterative design process, the end result was not the way they began. They went through changes in occasions due to technological challenges and also due to user preferences and what the author considered, based in previously mentioned literature; a more natural way of interacting.

For the *navigation* controls, the user view can be manipulated with three degrees of freedom. The navigation controls are activated only when the system detects a pinching gesture (more about these gestures in the next section) The user can zoom in and out by pinching and moving the hand on the *z plane*, (Figure 7-7) +z for zooming in, -z for zooming out. The learner has rotation controls as well. They are activated by moving or merely tilting the hand in the direction of the desire rotation while pinching (Figure 7-6). For counterclockwise rotation in the horizontal, system must detect hand movement towards the +x-axis, clockwise –x while pinching.

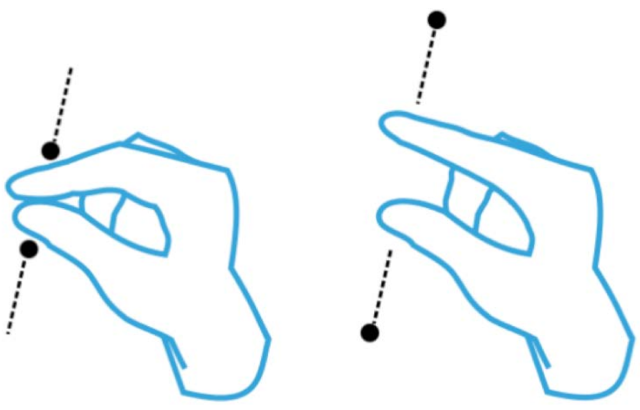

Figure 7-6 Pinching

The principle behind the activation of the navigation control is to simulate what could be considered a natural gesture. That of moving an object by grabbing part of it. This may be better understood if one is to imagine pinching the space to move it around. Following the themes analogy, it would be just like pinching the dark matter for the interactive solar system, or the cytosol or intracellular fluid in the interactive cell application.

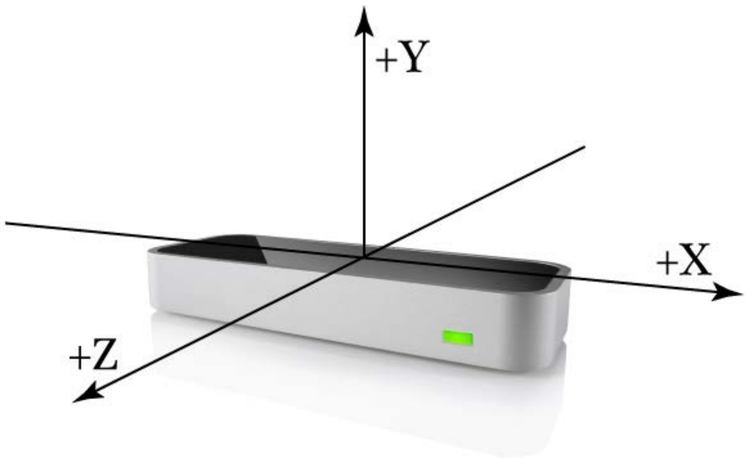

Figure 7-7 GILI Coordinate System

7.6.2 Selection

The controls for navigation were implemented through the use of an additional gesture. This is the circle gesture which is represented by a circular finger movement. This movement is recognized when the tip of the finger draws a circle which is detected by the infrared sensors. The selection happens by a laser-like virtual ray which picks whatever objects is in the center of the circle when the gesture occurs. The circle can be made with any finger or even a tool such as a pen. This gesture is continuous; it will end when the user either stops the locus trajectory or moves the finger too slow.

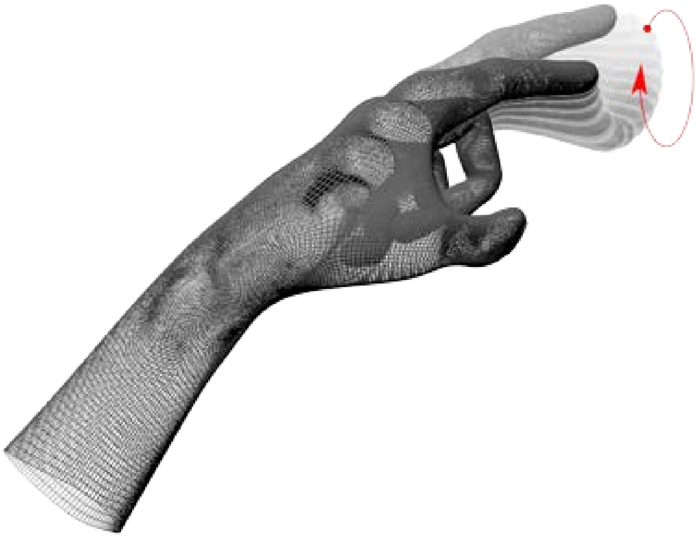

Figure 7-8 Circle Gesture

A cursor on the screen is presented at any point a finger is detected. This way the learner is able to know the exact location where the finger is pointing at on the screen.

Other gestures were tried on the process before the circle selector was chosen. These including a gesture for screen tap and another one for key tap. All of them involved the detection and tracking of the forward-most finger, usually the index to perform a movement pattern. In contrast with the circular, the tapping (Figure 7-9) is a discrete gesture and it is activated when the learner quickly moves an extended finger forward. This pushing forward movement simulates the user pressing a vertical touch screen. As it is a discreet gesture, only a single selection is added per tap gesture. Circle gesture worked the best during the pre-test, so all further implementation efforts were focused on it.

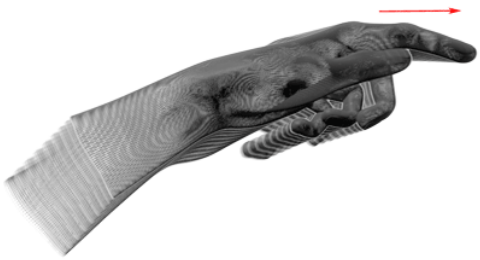

Figure 7-9 Forefinger screen tap gesture.

7.7 Parts

The system is composed of the following parts:

Leap Motion Device connected via USB 3.0 to a laptop running the Leap Motion Developer controller software version 2.0 and Unity 3d Pro alongside.

Software-wise, the Leap Motion drivers carry on the detection and communication of the device with the software through the use of the Unity 3D pro plugins.

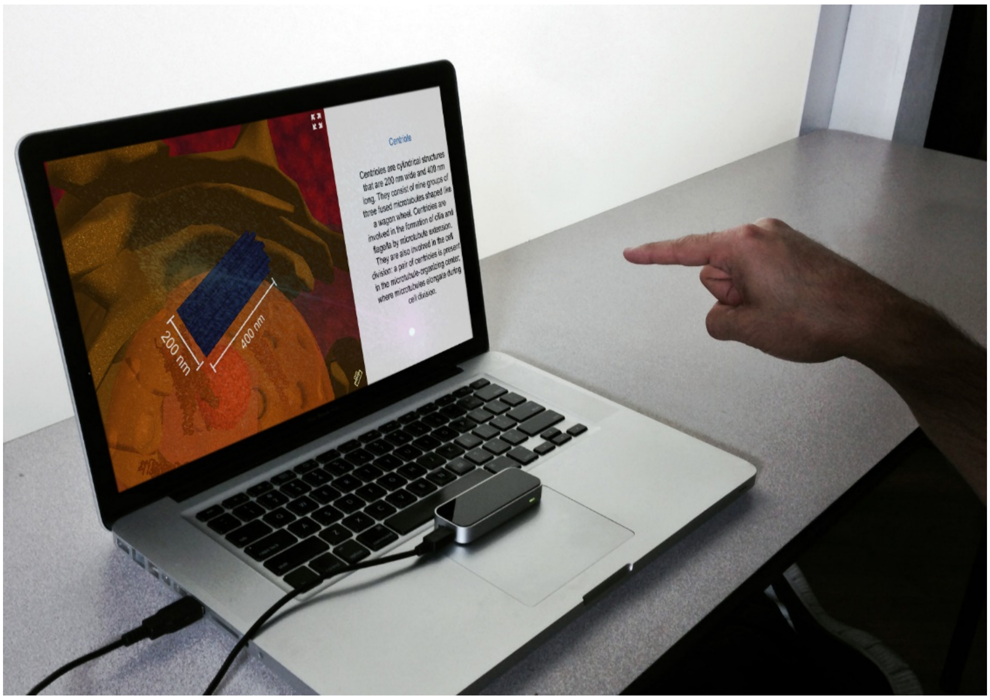

Figure 7-10 System's hardware components.

7.8 Hypothesis

"University students exploring cell biology using GILI will perform different than students reading a textbook with illustrations about the subject."

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8 Evaluation

8.1 Methodology

8.1.1 Test Design

The main goal of this evaluation was to investigate to what extent there is value in the application of embodied interactive learning systems such as the GILI in education, and if this is so, recognize the scope of the benefit to a field of study. The development of GILI was carried on to test this idea. It allows the user to use his/her hands to carry out operations and to control an interface, possibly facilitating understanding on levels which might not be obvious.

In order to evaluate the hypotheses, a *randomized, controlled crossover study* was conducted. According to the SPSS Knowledge center a crossover trial is a study in which each user is observed more than one period and is exposed to a different treatment (learning method) at each period (IBM 2011). Therefore in this study, participants were exposed to a sequence of different exposures or treatments. These treatments in the case of education were the learning methods of the GILI system and another system decided to be called *the traditional system*, which is a name to represent reading information on paper, the way a student typically studies from a textbook, which is usually considered a traditional learning method. In this randomized trial, each learner is randomly assigned a sequence of two exposures of which one was the GILI system the other the traditional system. This crossover design had a "balance", which means all users were exposed to two learning sessions with no repetition or avoidance.

There is advantages to using crossover studies; in them users serve as their own control and also crossover design are mentioned to be statistically efficient and therefore require fewer subjects. (Jones and Kenward 2003)

The information on paper was presented on an A3 size sheet and it contained an animal cell diagram, the way it is usually found in textbooks. A scaled version of it can be seen in the Setup section in Figure 8-2. The same information is presented in both scenarios. It is the medium; the methodology that changes.

8.1.2 Questionnaire Design

A questionnaire was designed to assess knowledge and understanding of the subject. It contained different sections to evaluate separate aspects of what could constitute a deep conceptualization of animal cell anatomy. The main sections of the questionnaire are four; factual knowledge, spatial understanding, attitudes, and preferences. The first three are asked three times at different moments of the test. The preference part of the questionnaire is presented only at the end of the test. This questionnaire can be found in the appendix.

The factual knowledge questions were those concerned with information presented in text for in both systems. This type of questions were all multiple choice, and were answered either correctly or incorrectly. These factual knowledge questions were presented to all users in three occasions; first as part of questionnaire phase 0, at the beginning of the test, then again after finishing with the first learning session (phase 1), and a third time after finishing with the second learning session (phase 2). Please refer to Figure 8-1 for the test procedure diagram. It should be mentioned that all the questions in this area were multiple choice and the option to answer with a question mark "?" to indicate a lack of knowledge, was provided. This option was also considered as a wrong answer but it might have discourage subjects from just guessing. The order in which each user was presented the learning session was as previously mentioned, randomized; and therefore half the subjects started at the first learning session with the traditional methodology and the other half with the GILI system.

In addition, an exit interview was conducted with all 30 subjects. They were asked how they felt during the test and to elaborate on their experience with both methodologies. These interviews were all captured on video, these clips are included in the DVD.

In order to measure the knowledge the subjects already "came with", an assessment had to be applied prior to both learning scenarios. This is, a preliminary testing scenario, to measure the subject's familiarity with the subject.

A total of 30 participants were involved in the testing. All of them were either graduate or undergraduate students enrolled at Aalborg University. The test lasted between 20 min to one hour. This variability was the result of allowing the users to try both learning methods for as long as they felt comfortable and understood the information.

The following diagram illustrates the complete test procedure:

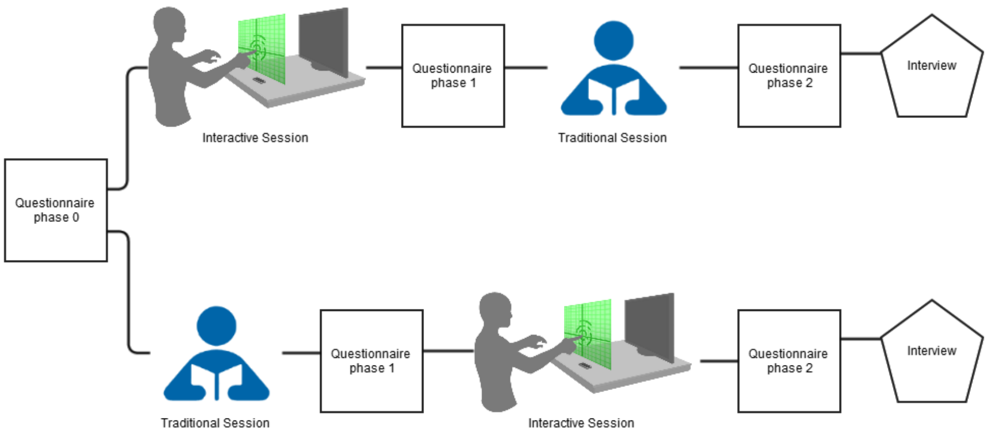

Figure 8-1 Test Procedure Diagram

Likert Scale Questions

Likert-type questions were used both at the beginning of each section for the attitudinal section and at the end of the complete questionnaire for the preference segment. Five options ranging from "strongly agree to strongly disagree" were chosen in a symmetrical structure with a neutral option in the midpoint. The inference that the distance between contiguous categories was made, and for good practice; an equidistant presentation of the options was designed. Some authors argue that while Likert scale is ordinal, if it is symmetric and equidistant it will behave like an interval-level measurement. (Mogey 1999, Contributors 2014, Munshi 2014)

8.2 Setup

For the test, the setup consisted of one Laptop with an external monitor and leap motion attached to it, all placed on a desk with an additional well-lit space for reading during the traditional session. The computer was running Unity 3D Pro and a browser for filling up the questionnaire.

Although reading a textbook with images and/or diagrams cannot be consider the only traditional learning method, for this test purposes, “the traditional learning method” refers to the learning session while reading from a textbook example including a large diagram image.

Both the interactive session using GILI and the traditional method using the textbook contained the same textual information. Also, both methodologies presented the anatomy of the cell graphically; as a diagram in the case of the textbook and as a 3D object in the case of GILI.

At traditional method session, users were presented with an A3 size double column sheet of paper with a large diagram in the center and text information surrounding it. The text was ordered according to the picture, as to have both the graphical information and the text close together. An illustration of this pane is shown below in (Figure 8-2)

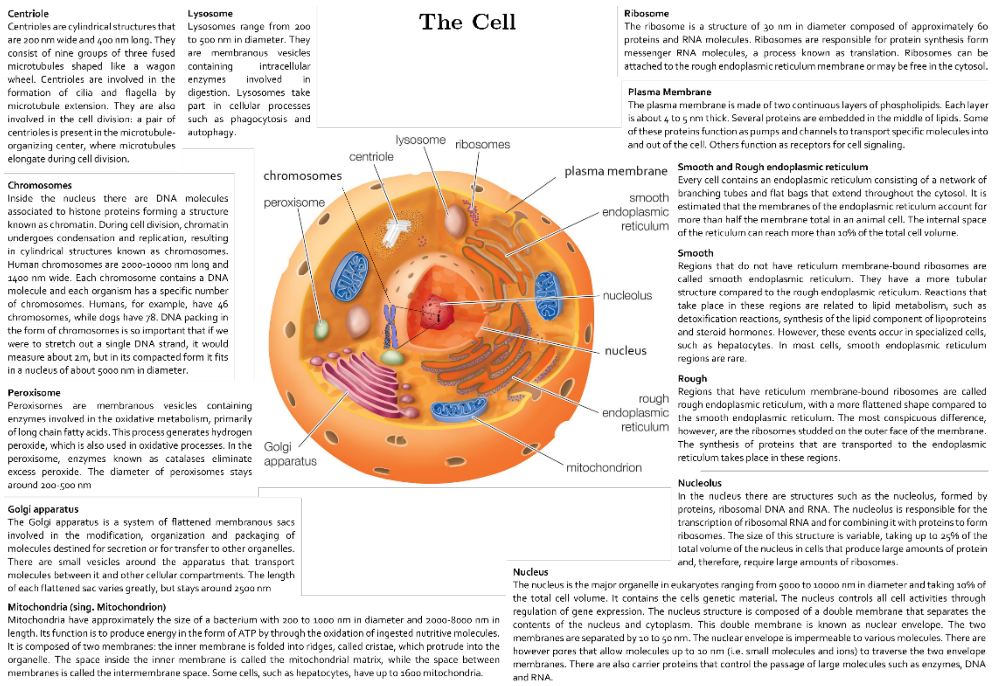

Figure 8-2 Traditional Method Testing Pane

8.3 Participants

There was a total of 30 test participants, 23 males and 7 females. The age of the participants was between 20 and 29 years old. All of the participants were university students from varied educational fields. None of them was currently studying any life-science related program, but all of them had taken a cell biology course as part of their earlier education. Participants had varied nationalities and underwent their complete educations all the way to pre-graduate level in a number of countries. Participants might therefore have been exposed to different educational systems. (Figure 8-3)

Figure 8-3 Locations where test participants took their primary to high-school educations.

The participants were divided into two randomized groups; Group I, in which users were exposed to the interactive learning session with GILI first and the traditional learning session second, and Group T, in which the order was reversed. Refer to Figure 8-1 for the test procedure diagram.

The test duration was between 30 to 45 minutes.

8.4 Procedure

The users were tested separately. Right they arrived to the test room, they were greeted and instructed to take a seat. They were told the approximate duration of the test and its theme: education and learning, and more specifically; learning about cell biology. They seated first in front of the laptop, the external screen would be deactivated at first, this way only the questionnaire would be visible to them. They were instructed to answer to a preliminary questionnaire about their knowledge of biology (phase 0). They were told about the options to select a question mark response in case they did not know the answer. After finishing this phase of the questionnaire, an instruction to stop and wait for instructions appeared on the screen.

Next, depending on the sequence that particular participant had randomly been assigned to, he or she would either take another seat at the table or remain in front of the screen. If they had the traditional method assigned first (group T), they were instructed to change place in front of a desk. Then the textbook-like A3 sheet of paper with information, would be placed in front of them, and they were instructed to begin reading it, for as long as they felt comfortable with the contents.

Figure 8-4 Traditional learning session

If the users were part of the group I, they were instructed to remain seated after finishing with questionnaire phase 0 as the external screen was activated. Just before they started exploring the interactive application, they were provided with the instruction about how to operate GILI. The controls, which are described in the Design section, (7.7) were explained to the learners, and a reference guide with the gestural controls (Figure 8-5) was placed on the desk for them to re-examine, in case they felt a need.

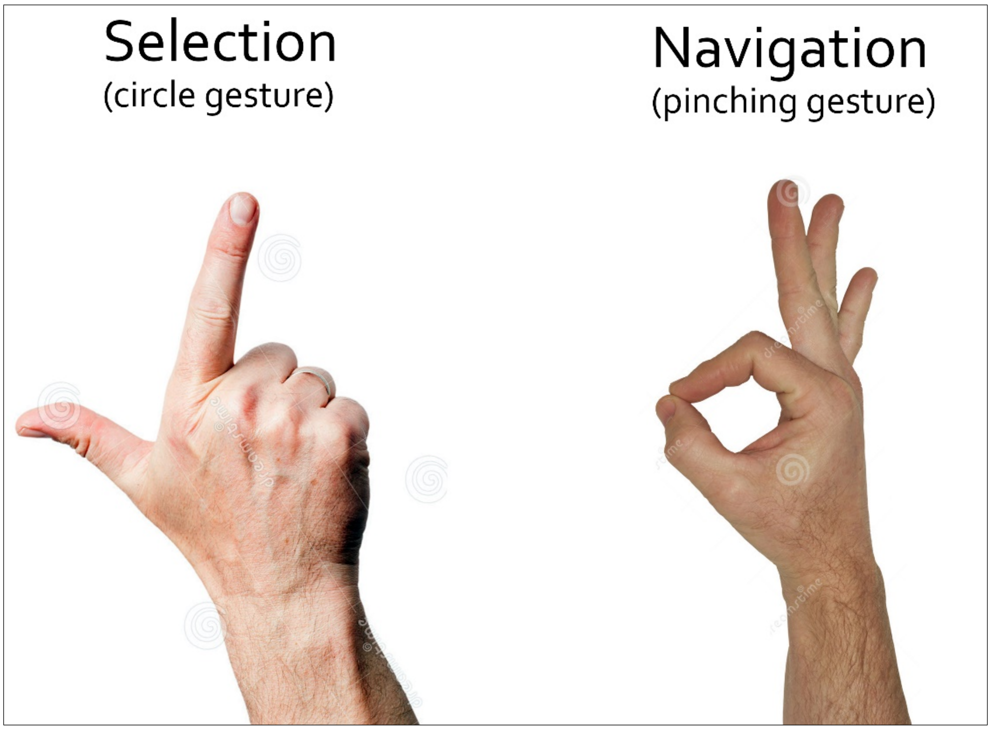

Figure 8-5 Reference guide while operating the GILI system.

On this second display, they would see The Cell's interface for the first time. The test instructor performed a basic operation to briefly demonstrate the controls, and right after the users were instructed to begin experimenting with the system, for as long as they felt comfortable with the contents. Usually they began by navigating around the virtual cell and after a minute they started selecting components to get information from them (Figure 8-6).

The first learning session, for both systems typically lasted between ten to twenty five minutes, depending on the user. When the users indicated they were ready to continue with the test, the instructor would then provide the questionnaire phase 1, on the laptop screen. As mentioned before, the questionnaire contained on the same inquiries throughout the phases, with only an additional attitudinal section at the end.

Figure 8-6 Learner interacting with the GILI system.

After users from both groups had indicated they were finished with the learning session 1, the electronic questionnaire phase 0 was provided so they could answer based on what they had just learned. Once the learners had reached the end of phase 1 in the form, an indication to stop and wait for instructions was provided once more. They would be instructed in the next learning session they had not yet taken. All the instructions would be the same and presented in the same way. Usually the time spent in the second learning session was shorter than when the same system was tried as a first learning session. When the users were done with the second learning session, they were allowed to begin with the last part of the questionnaire, the phase 2. In this section they would find an additional Likert-type scaled question area at the end. When they were finished with these attitudinal questions they indicated so, and the instructor then, proceeded to conduct a final video recorded interview.

Figure 8-7 User being interviewed at the end of the test procedure.

In this interview they were asked to elaborate on how they felt with both systems and to mention the main differences they perceived between them. They had also the opportunity to comment on the test procedure.

9 Results

The entire set of data gathered during testing can be divided in mainly three areas of interest:

- Factual Knowledge
- Spatial Understanding
- Likert-type Data

These main divisions were created because of the different nature of the data (scaled, nominal, ordinal), if it was related to knowledge or attitudes, and the skills required (spatial memory, etc.). Dividing the data this way allowed for an easier understanding of it and to make it more relevant, as answers are clustered together by type. This way the results will be further subdivided and analysed in the following sections. The complete questionnaire is available in the appendix.

As mentioned in the evaluation section, the participant sample size was 30. This was possibly not big enough to have any desirable statistical significance. Unfortunately, volunteer availability and time constrains, were a limiting factor.

9.1 Factual Knowledge

The first analysis of the data include a set of questions regarding specific knowledge of the subject. The answers to these questions can be clearly differentiated as right or wrong. After presenting a histogram with the percentage of correct answers, a t test statistical analysis is also shown. The t tests in this section were realized to compare the data in both groups and find if there is a statistically significant difference, therefore they were independent sample t tests. The complete output from the statistical analysis is included in the appendix.

The questions for this section of the form are represented by letters in the graphs according to the following table:

What kind of molecule does a chromosome contain?	A
Does the nucleolus hold the chromosomes?	B
How large is the nucleus compared to other organelles?	C
What does the nucleus contain?	D
Are the peroxisomes inside the nucleus?	E
Does the plasma membrane contain the nucleus?	F
How many membranes are there in a mitochondrion	G
Are mitochondria smaller than the cell nucleus?	H
What is the mitochondria's main function?	I
What is the shape of a centriole?	J

Figure 9-1 List of Questions in the Factual Knowledge Section

9.1.1 Phase 0

Users from both groups started with slight variations on their subject knowledge prior to either learning session. The users from group T answer on average 25.3% of the questions correctly in phase 0 compared to 20.0% in group I.

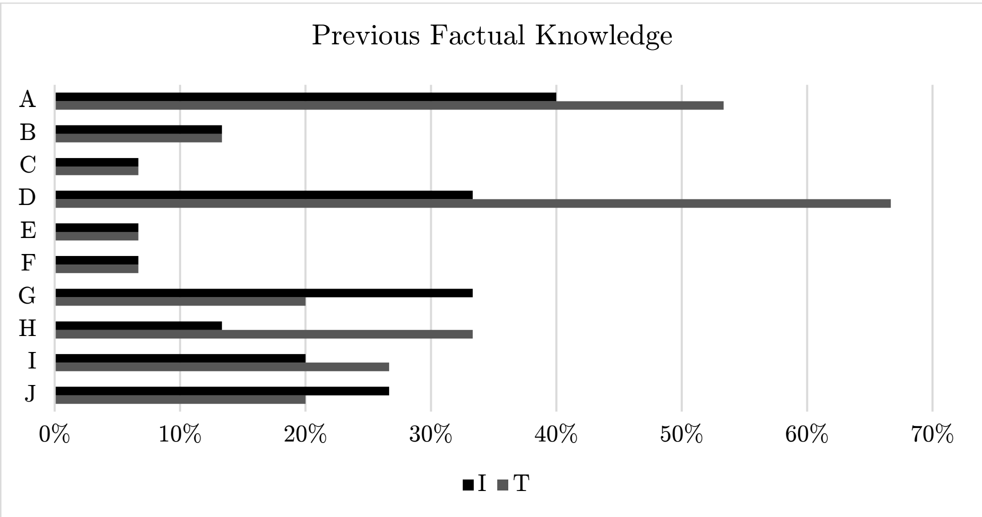

Figure 9-2 Percentage of correct answers to each question before exposure to either method for both groups.

An independent-sample t-test was conducted to compare factual knowledge questions in groups I and T. When averaging the means between the groups, the 5.3% initial factual knowledge difference favouring group T at the start is confirmed.

The statistical analysis showed there was not a significant difference in the scores for group I (average M=0.253 average SD=0.390) and group T (average M=0.200 average SD=0.383) for all questions in phase 0 under the conditions shown on table Figure 13-1 and Figure 13-2 on the appendix.

9.1.2 Phase 1

After the learners were exposed to the first learning session, there was a very high increase in their knowledge for all questions. This growth in knowledge was roughly equally as large for both group I and T (43.3% and 44.7% respectively)

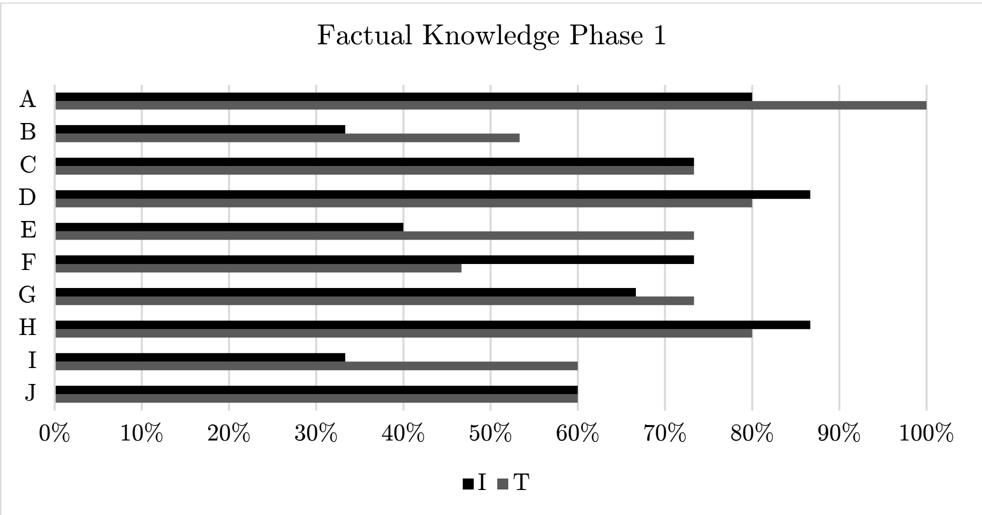

Figure 9-3 Percentage of correct answers to each question after exposure to first learning session for both groups.

An independent-sample t-test was conducted to compare factual knowledge questions in groups I and T for phase 1.

The statistical analysis showed there was not a significant difference in the scores for group I (average M=0.633 average SD=0.4512) and group T (average M=0.200 average SD=0.4248) for all questions in phase 1 under the conditions shown on table Figure 13-3 and Figure 13-4 on the appendix.

9.1.3 Phase 2

For the second learning session the increase in knowledge was not as prominent for both groups. The increase of correct answers was of 8% for the group I and 2% for the group T. The difference in the increase was then of 6% for this phase and type of questions, in favour of the traditional method.

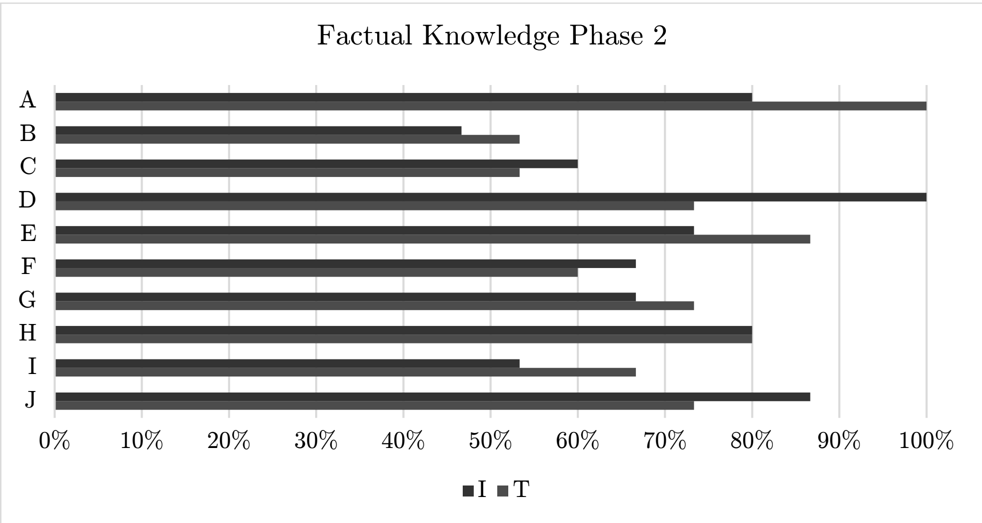

Figure 9-4 Percentage of correct answers to each question after exposure to second learning session for both groups.

An independent-sample t-test was conducted to compare factual knowledge questions in groups I and T for phase 2. The statistical analysis showed there was not a significant difference in the scores for group I (average M=0.633 average SD=0.4512) and group T(average M=0.200 average SD=0.4248) for most questions in phase 2 but one under the conditions shown on table Figure 13-5 and Figure 13-6 on the appendix. There was significant difference for question D "What does the nucleus contain?" for group I (M=1.00, SD=0.000) and group T (M=0.73, SD=0.458) conditions; t(14)=2.256, p=0.041.

The overall learning for the entire test regarding factual knowledge questions was of 51% and 47% for groups I and T respectively.

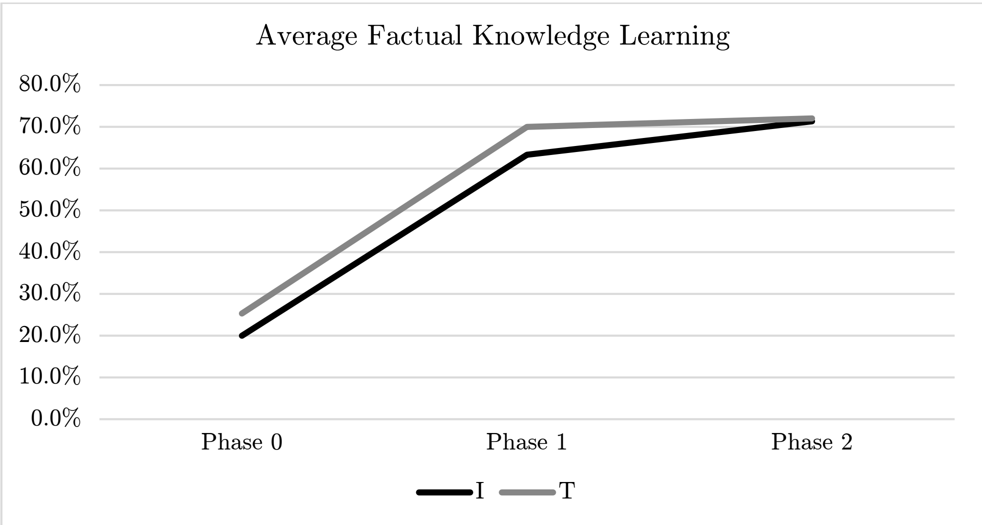

Figure 9-5 Average for all factual knowledge questions within a phase for each group.

Even though both groups started out with a difference in knowledge, as measured in questionnaire phase 0, group I managed to reach the same factual knowledge level as group T.

9.2 Spatial Understanding

This section of the questionnaire was composed of a series of questions regarding ordering the cell organelles by size. Users had to order eight organelles by adjusting a dropdown menu, as illustrated in Figure 9-6.

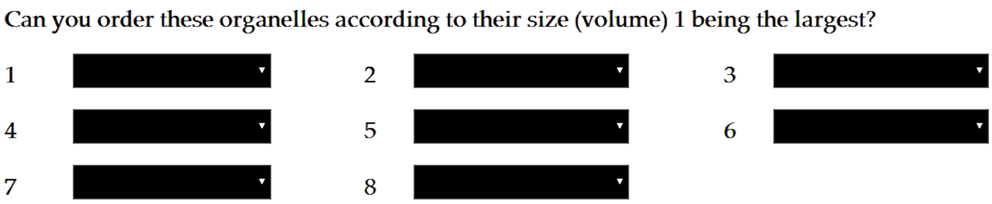

Figure 9-6 Representation of the organelle order-by-size dropdown-type questions.

It was a set of eight questions regarding the relative sizes of the cell organelles a category denominated *spatial* was set. In this set of questions the user was to order each of the eighth organelles covered by both methodologies by size. Each of the answers were selected from a drop down menu containing all eight possible options.

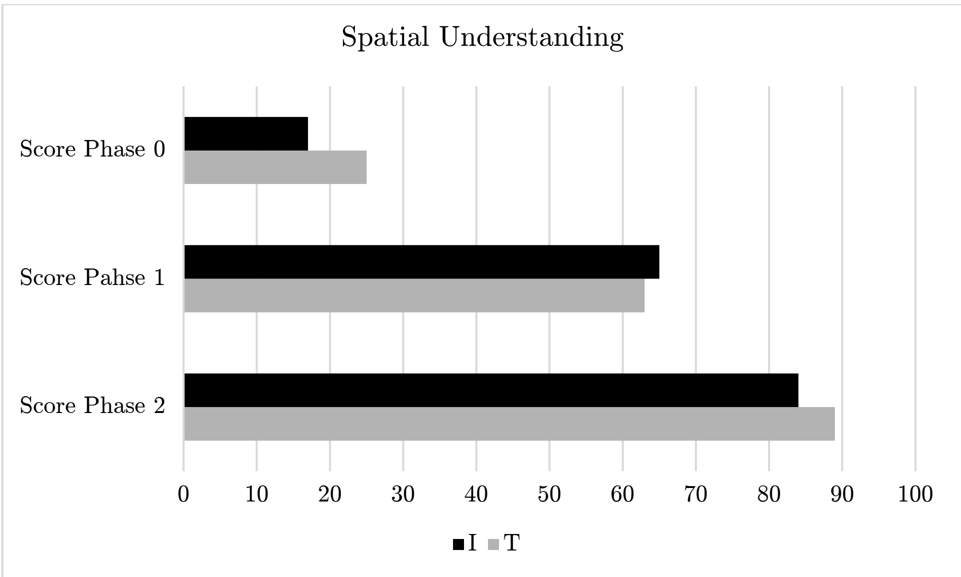

Figure 9-7 Number of Correct Answers for Spatial Understanding for both Groups

It can be seen in the table that the increase from the two learning sessions were influenced to a much larger extend by the GILI system. This is more shown more clearly in the next chart.

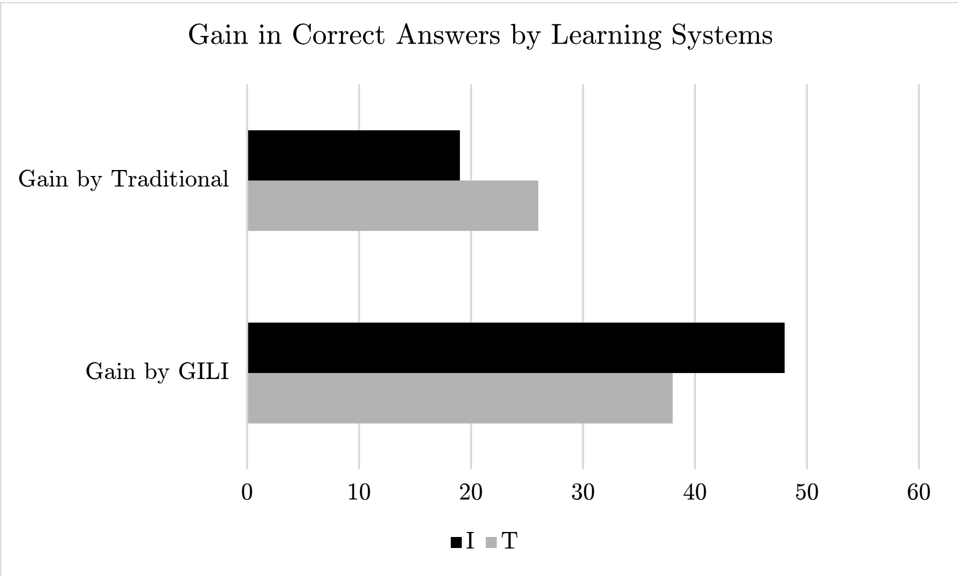

Figure 9-8 Increment in number of correct answers due to each learning system for both groups.

The increase in the number of correct answer was larger for users in both groups after being exposed to the GILI learning system. This was the case even when the Traditional session was applied first. Learners improved by 48 correct answers by GILI in phase 1 against 38 by the traditional system in the same phase. For phase 2, participants improved by 26 right answers against 19 by the traditional system.

There was no statistically significant difference in the increment of correct answers as determined by a pair sample t test (p=0.157)

9.3 Likert-type Sections.

After users finished with the phase 2 questionnaire, users were presented with an additional section containing a Likert-type scale group of questions. These were answered out of five possible choices ranging from *strongly disagree* to *strongly agree*. When using Likert scales some authors such as Mogey (1999) suggest not assigning codes to the answers (1,2,3,4,5) or (0%,25%,50%,75%,100%), as the distance from one option to the next might be user's specific, so for this study it was kept with its original tags.

As both groups had already been exposed to both methodologies, for the final section of the questionnaire, containing only Likert-type scales, data from both groups is combined.

One possible distortion in Likert-type scales is the central tendency bias in which participants may avoid using extreme responses (Ola 2011). Also according to this author, in Likert scales, all agree and disagree responses are sometimes combined into the categories of "accept" and "reject". Therefore from the 5 option scale, 3 response categories were considered. Consequently for this section, data is presented using clustered bar charts, which were consider more effective at comparing values given categories were reduced to three.

9.3.1 Preference

Users were asked two questions regarding their preference towards interactive and traditional methodologies. They gave a rating to the sentence: "I like -learning method- better". For the question regarding preference towards textbook learning methods, the results showed a strong neutrality (43%) and relatively lower but still strong acceptance towards the statement (40%).

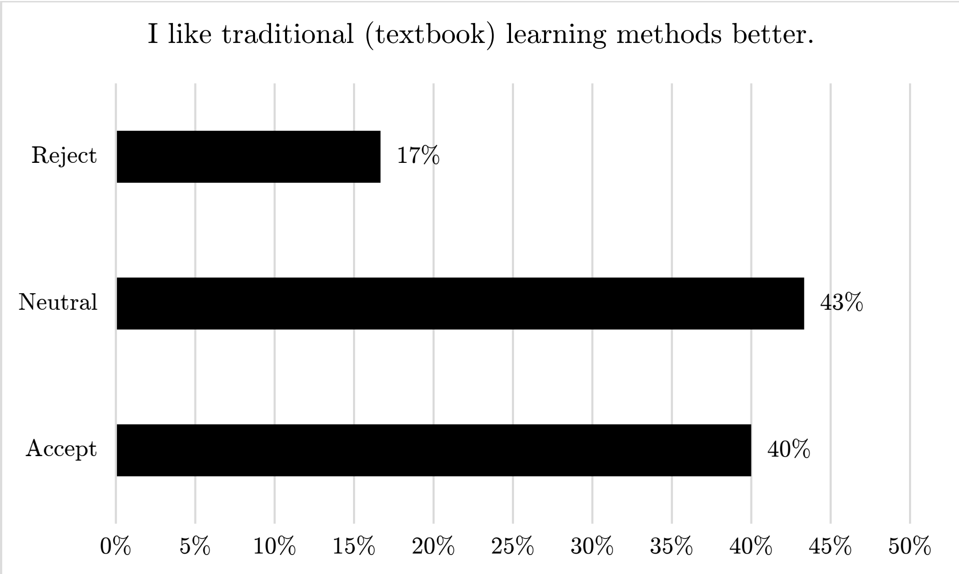

Figure 9-9 Preference towards traditional methods in percentage.

When asked to respond to the statement “I like interactive methods better”, half the number of participants accepted the statement and only one of five rejected it.

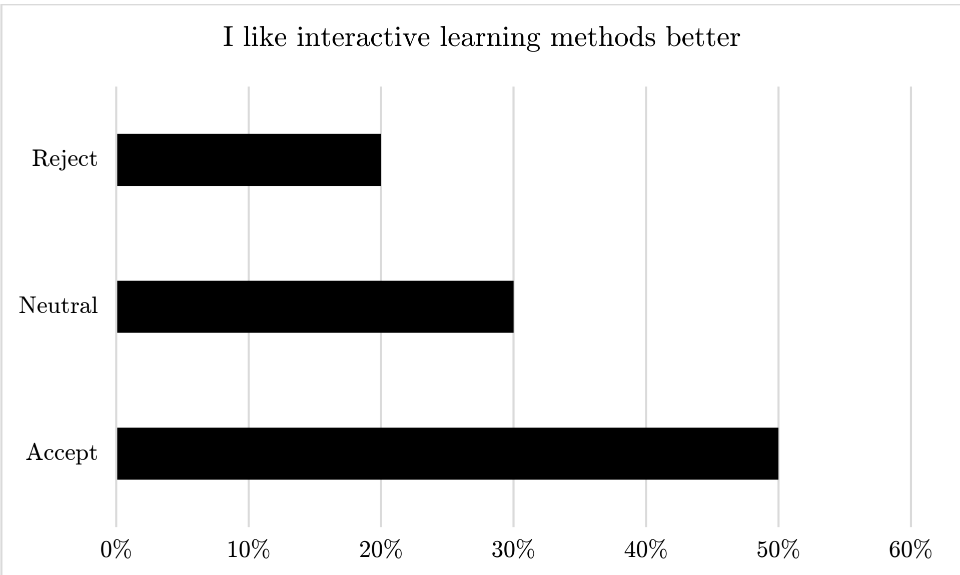

Figure 9-10 Preference towards interactive methods in percentage.

9.3.2 Pleasure Level

In addition to preference level, during the final part of the questionnaire learners were asked to rate their pleasure level for each methodology. This was done by asking them to answer in a five rate Likert-type scale the answer to "*I had fun while learning using the TEXT ON PAPER*" and "*I had fun while learning using the INTERACTIVE system*". This five rate scale was again clustered into the three positions "accept", "neutral" and "reject."

In the case of reading text on paper, there was a very strong negativity towards the statement, with every 3 out of 5 users rejecting it and only 1 of 10 supporting it.

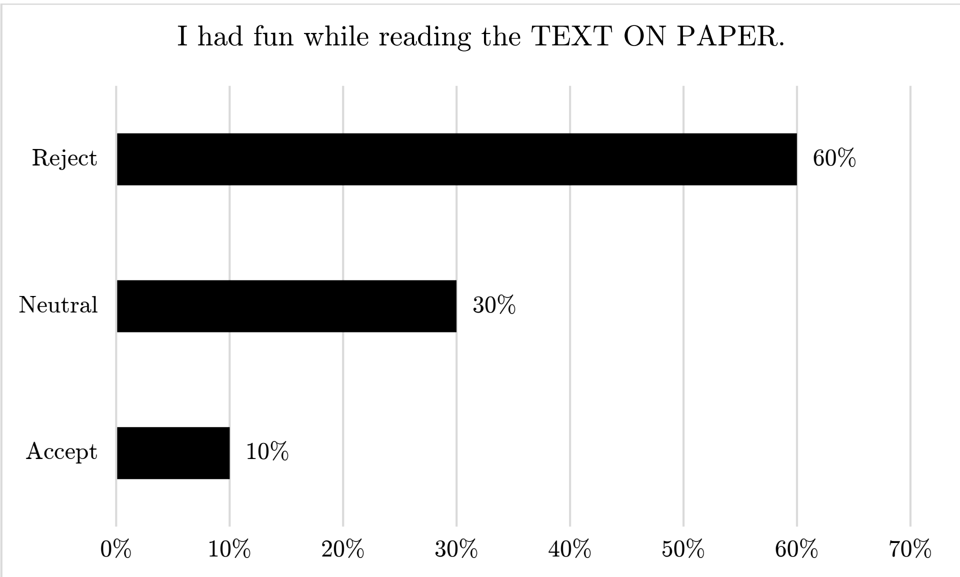

Figure 9-11 Pleasure level for the traditional method in percentage.

Users expressed remarkably high levels of pleasure while using the GILI system with over 7 users out of every 10 experiencing fun when using it.

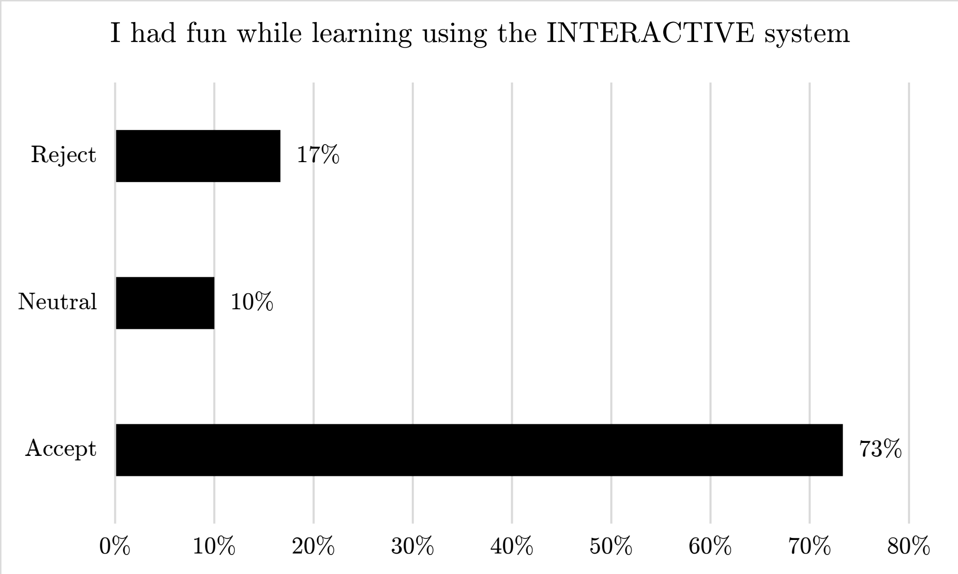

Figure 9-12 Pleasure level for GILI in percentage

9.3.3 Educational Perception

The users were asked to rate how educational the learning sessions they had completed were. The statement they were asked to rate were: "*The INTERACTIVE session was highly educational*" and "*The TEXT ON PAPER session was highly educational*". The majority of users (two thirds) considered the traditional session to be highly educational.

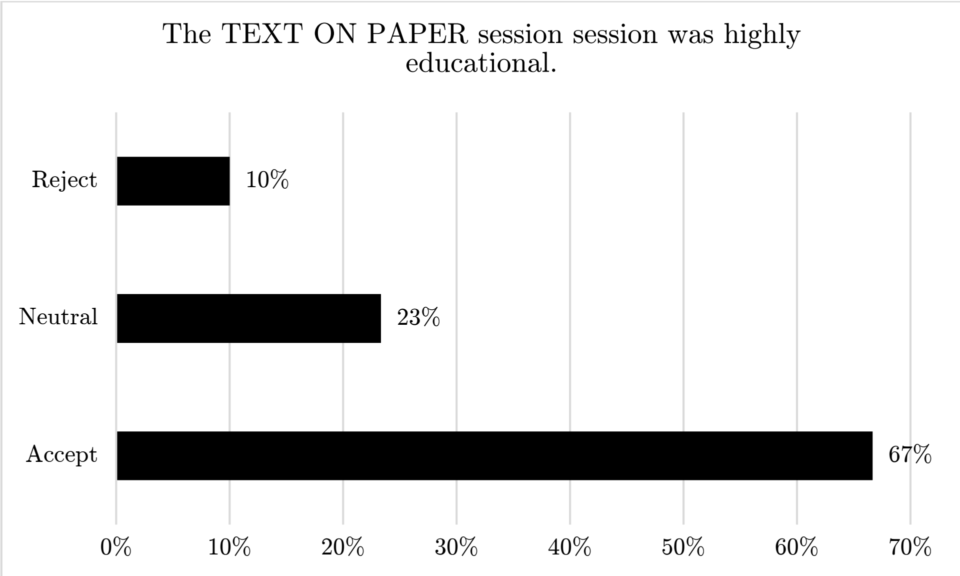

Figure 9-13 Traditional methodology educational perception in percentage.

Regarding the interactive learning session, the percentages are very similar with 60% agreeing with the statement.

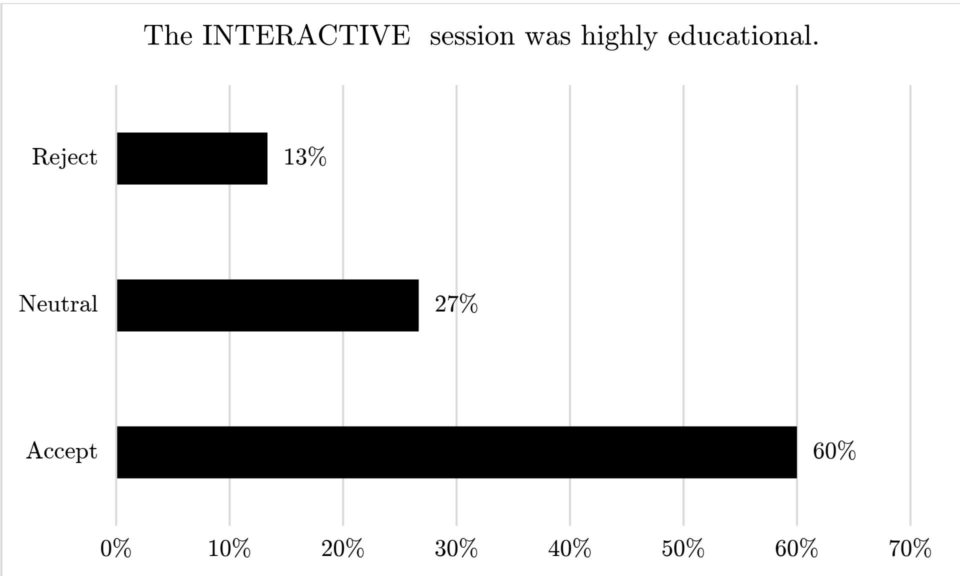

Figure 9-14 Interactive Methodology Educational Perception in percentage

9.4 Attitudes

Also in the form of Likert-type questions, a section was present in all the questionnaire phases, in a page of its own, before answering the subject's specific questions.

9.4.1 Knowledge Confidence

Users' perception of their understanding. Test participants were asked before each phase a question on their perceived knowledge of the subject. More specifically they had to choose an answer from strongly agree to strongly disagree in regards to the question "I have a good understanding of cell anatomy". The question was rated using a similar Likert-type scale as the one presented in the last section. The results for their initial understanding of the subject (before any learning session) are shown in the next chart. There was an additional Likert-type question along the same section regarding the statement "I like learning about science", but its percentages were not impacted by the test.

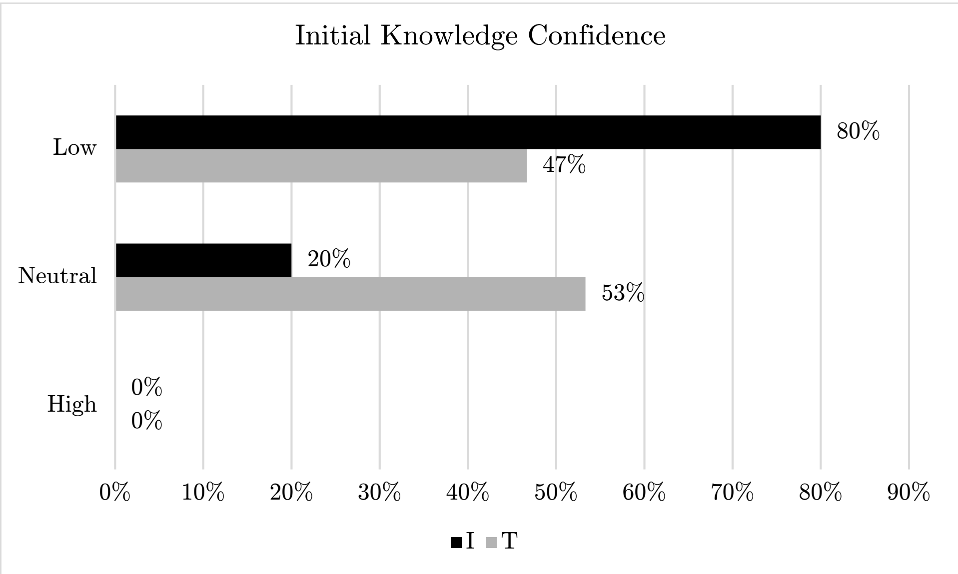

Figure 9-15 Perception of understanding of the subject prior to learning sessions in percentage.

It can be observed that none of the participants agreed with having a good understanding of the subject. Group T had a more positive opinion of their understanding in the original measurement with more than half of the participants being neutral to the statement while in group I, 4 of every 5 users disagreed with it.

After learning session phase 1, there was a big shift in the participants' perception. The previous differences between groups were completely eliminated after the scales were clustered into the high, neutral, and low categories. For both groups, 1 out of 5 agreed to have a good understanding of the subject. The number of users having a low impression of their understanding in group T remained but as shown in the Figure 9-3, the number of users with a negative perception was reduced by almost half for group I.

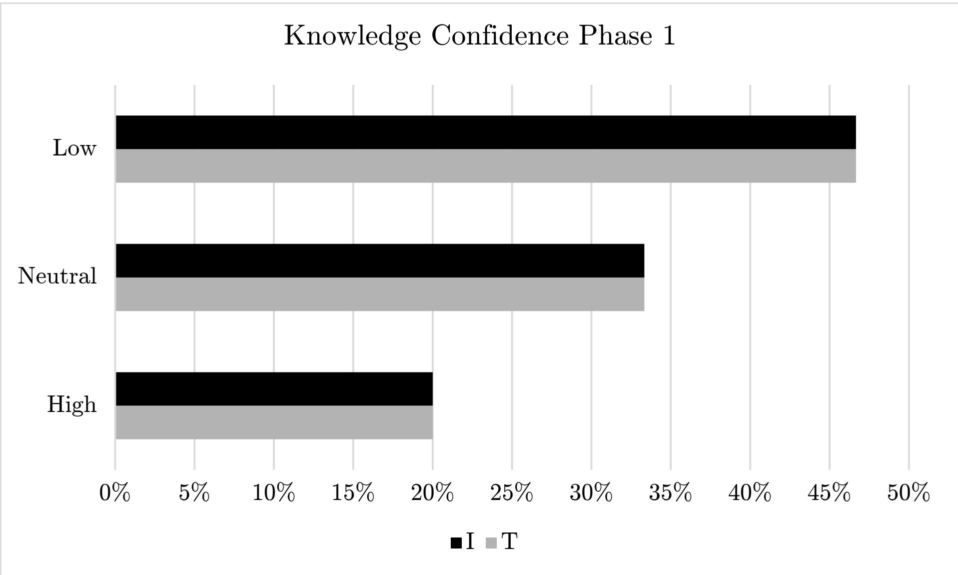

Figure 9-16 Understanding Perception after the first learning session in percentage.

The difference in understanding confidence in the percentage of total users per group between phase 0 and phase 1 is shown in Figure 9-17. In this chart it is easy to appreciate a very strong decrease in low opinion of understanding in group I after being exposed to the GILI system. The number of users with low opinion of their understanding remained the same for group T after being presented with the traditional method.

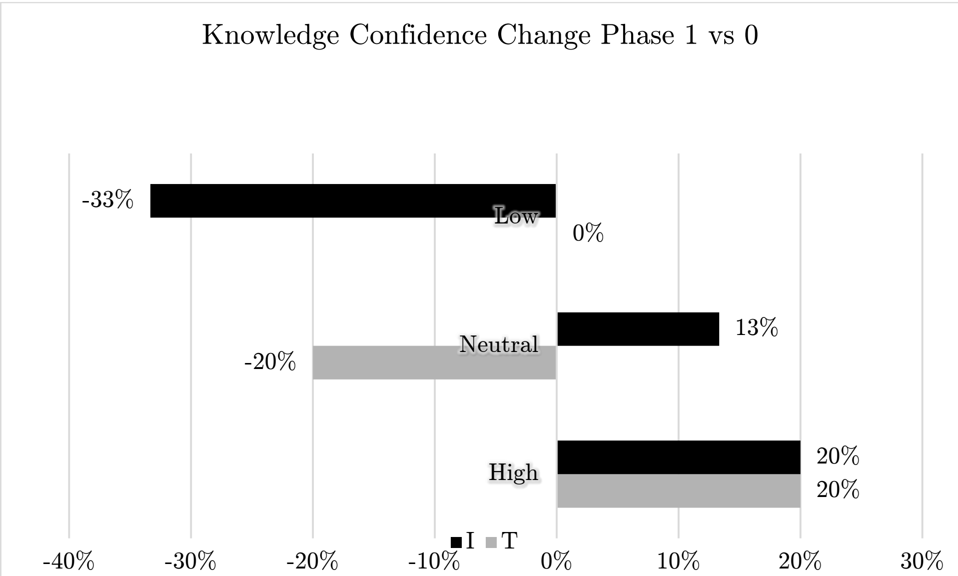

Figure 9-17 Percentage of change in understanding confidence between phase 1 and phase 0 for both groups in percentage.

The initial difference in understanding perception is then completely balanced after learning session 1.

The users' understanding perception after being presented with the learning session 2 are shown next for each group, (Figure 9-18). One can see that 1 in every 3 learners have a high knowledge confidence by now, which is an additional increase from phase 1 questionnaire, when for both groups only 1 in 5 had that positive perception.

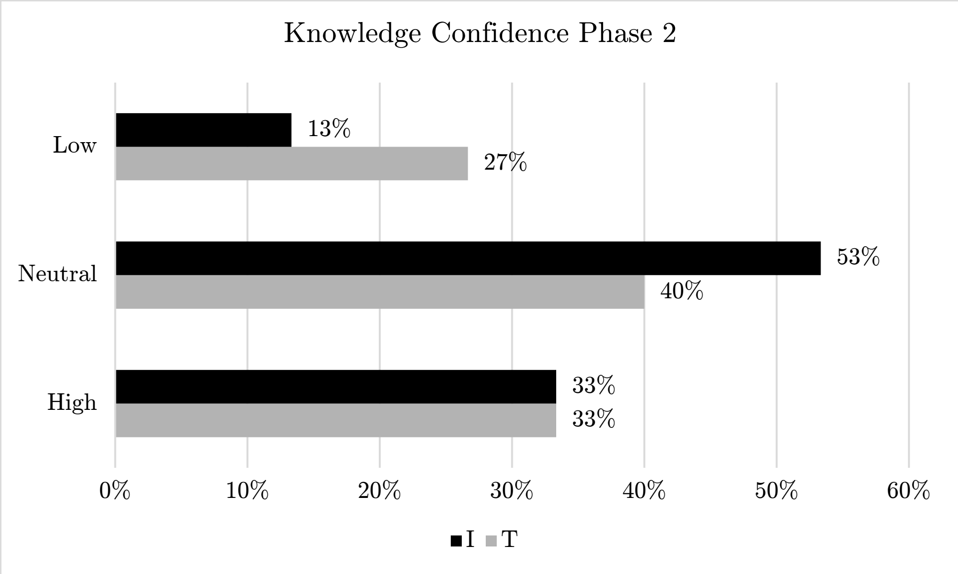

Figure 9-18 Understanding Perception after the second learning session in percentage.

There are differences in the understanding perception for both groups between phase 2 and phase 1. Both groups had an additional increment in agreeing with the statement previously mentioned. Also there was an important reduction in low perception for both groups, with a more favourable change for group I.

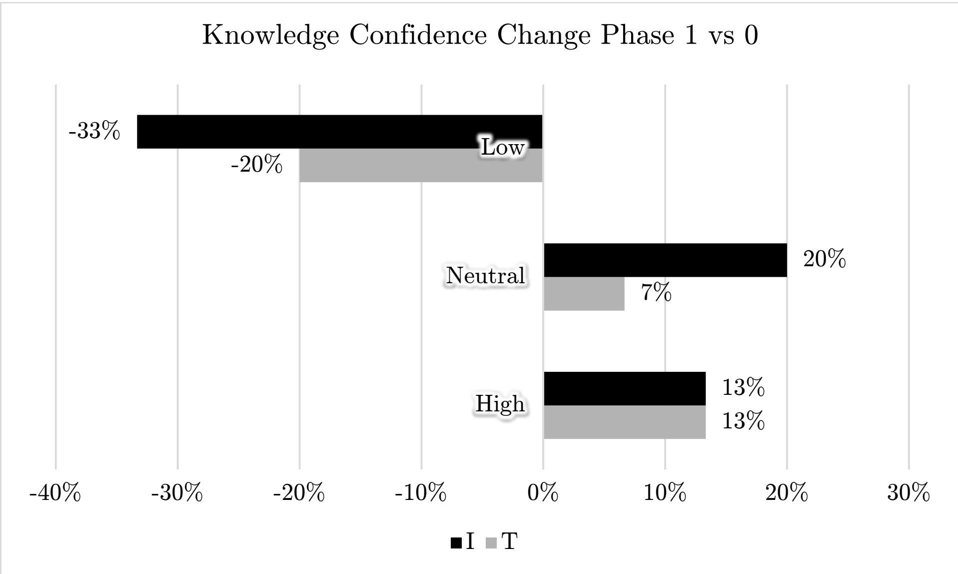

Figure 9-19 Understanding perception change between phase 1 and phase 0 in percentage.

All of the above charts included in this attitudinal chapter, have led us to one graphic representing the sum of the changes in understanding perception due to each of the systems separately. In other words, this graph represents the addition of the perceptual changes for each system. For the GILI system, it is the changes after the first learning session for group I plus second learning session for group T. For the traditional method, the changes after second learning session for group I, plus the changes after the first learning session for group T.

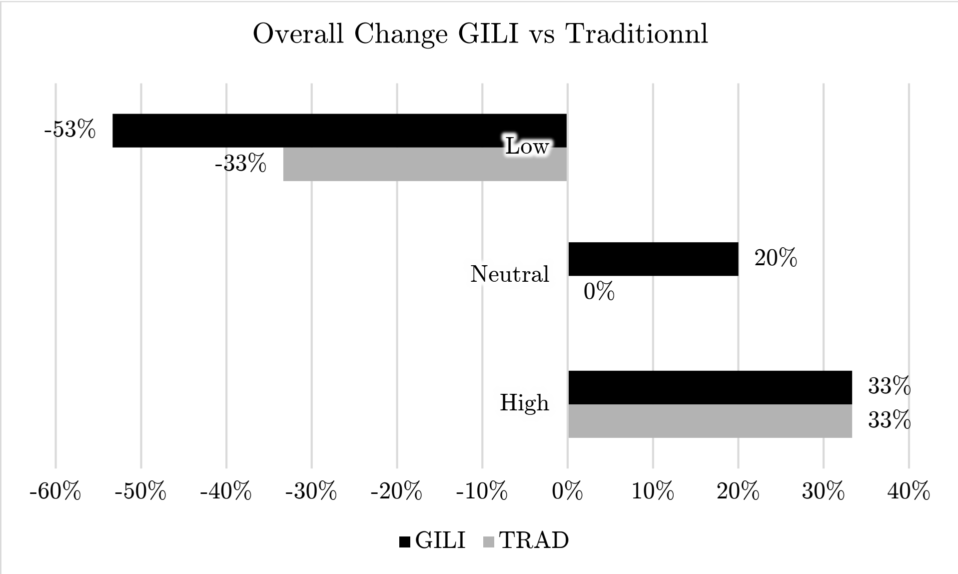

Figure 9-20 Understanding Perception overall change due to GILI vs Traditional Methodology in percentage

It can be seen that both systems contribute the same towards changing the understanding perception for the High category; increasing the number of learners with high confidence in their knowledge to a third of the total population. There was a strong difference in the way the systems impacted the understanding perception for learners who were in the low subject understanding category. The GILI system was responsible for the positive change of perception of more people in this low category, "moving" more than half the total amount of people to both neutral (1 out of every 5), and high (1 out of every 3) categories.

In contrast, the traditional system changed the perception of 1 out of every 3 learners.

9.4.2 Additional Findings

The question "*I think learning by doing is a good approach*" was asked to all users at the end of the questionnaire. This question, to the researcher's opinion, may not be directly related to either of the methodologies, but it was considered relevant as it has a direct connection with the backbone methodology of experiential learning. It is very clear that all users included in the study have an overall very positive acceptance of the statement.

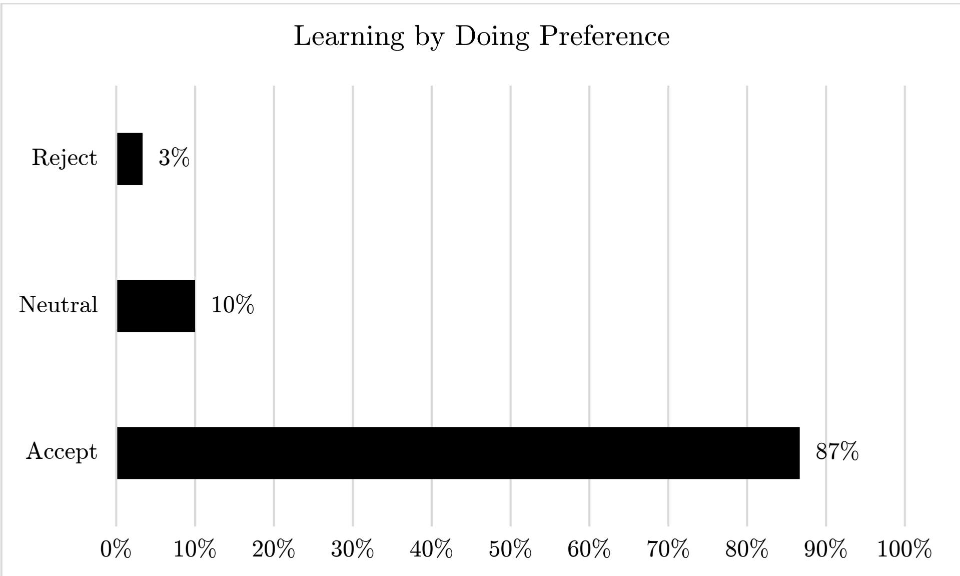

Figure 9-21 User Preference of the Learning by Doing Approach in percentage

10 Discussion

The objective of the testing procedure was to investigate if using the GILI system was beneficial to a user's learning, and if so, try to identify to what area of learning and to what extent was it a positive influence. It was then important to test the experiential theory using embodied interaction within a topic that users could relate to.

Based on the data obtained during these test sessions some observations can me noted:

- Learners considered GILI as a more fun way of learning, and according to the intrinsic motivation theory (Malone 1981) users pay more attention as content is provided in a memorable, dynamic way. In addition, it is mentioned in the same source that users are motivated to continue for longer periods of time or to undertake the learning activity more often when they are having fun. Because of this, in retrospect it would have been highly desirable to keep a record of the duration of each learning session to compare both methodologies this ways as well.
- When the learners were tested for all knowledge types, there were slight but considerable differences in the preliminary knowledge between groups. These average differences between groups, were maintained after learning session 1 but they were completely balanced after learning session 2. Both groups at the end achieved the same average factual learning level.
- Most users struggled to an extent with the selection gesture, and had trouble switching the information displayed on the side panel for different organelles. This might explain why learners did not do remarkably better in the factual knowledge section with GILI, as selecting through this gesture was required to display the text in the application.

- The test and analysing the results from it were done in order to get an understanding on how users could benefit. The system was comfortable and well designed by the large majority of users, 28 out of 30 experienced no discomfort and were successful in operating the interface. Having said that, two users experience some level of discomfort while using the interface. These users apparently lacked the fine motor skills required to perform many tasks, including using the proposed system. There should be much more testing if it was to be implemented in larger contexts as issues concerning motor skill may present a challenge for a number of learners. Most users felt the gestures intuitive as there were a few iterations of them tried out. But as not all users share the same learning style certainly not all users loved learning using the GILI system.
- Crossover studies are very common when doing trials for new drugs. In these studies, there is a "cool down" time between the application of treatments, as drugs have to be metabolized before a new one can be applied and tested. This cool down was not used in this test. It was not considered practical to apply the test within different time frames for subject availability, the differences in memory for subjects and because of the "noise" that brings any unrelated learning between sessions/treatments. This might have provided a difficulty while doing the statistical analysis as it is fairly obvious that users would learn much more on the first learning session for both systems than in the second one. Then comparing the gain in knowledge within a subject did not produce a good statistical significance possibly because subjects were to gain much more knowledge in their first treatment, than in the second one.
- The total number of test participants might have not been large enough to improve the potential to get better statistical significance. The researcher considers 30 to have been an adequate number of participants since it was a crossover study

and users were their own controls but recognizes the value of numbers for more conclusive statistics. Having said that there was no statistical significant differences between both systems except for one isolated factual knowledge question.

According to the data and its visualizations, the GILI system had improved substantially more the users' spatial understanding than the traditional system. Learners might have been able to remember the organelle's relative size better, because they were able to move their hands to navigate through the spaces between these objects, and by doing so, have a more intuitive comprehension. The GILI system did 26.3% better than the traditional system after the first learning session and this increased to 37% better than its counterpart after learning session 2. One can speculate than reading text from screen might not be a very different experience than reading text from a textbook but, it might make a much larger impact to be able to navigate real time using one's body through the objects of study, than to look at a static diagram.

The researcher identified what might have been a linguistically problematic area with the object identification of the organelles. There are some object pairs with close-to-each-other names. Most notably, the pair Nucleus-Nucleolus might have presented a challenge due to their names. To a lesser extent, the pair Lysosome and Ribosome. This challenge was present for both methods.

Some of the most important findings were gathered from the scaled attitudinal Likert-type questions.

It can be observed that both systems had a similar generally positive impact with regards to "liking the system better". Having said that the response the GILI system had was substantially more positive, (50% vs 40% accepting the phrase) but also slightly more negative (20% vs

17%). It is difficult to say much with such small percentage difference but it would seems the opinions are more divided with regards to preferring the GILI system.

In regards to the pleasure level, the data indicates using GILI was more fun for users in both groups, which according to Robert Carini (2012) is the aim of engagement. Therefore as users consider using GILI more fun, it could be assumed than several outcomes related to engagement could improve; namely, learners putting more quality effort and enthusiasm into the learning opportunity. According to the data using GILI was clearly a more pleasurable experience for all test subjects, potentially engaging learners. GILI in this way could be considered that practical lever mentioned by Carini (2012), to improve many of the students' outcomes.

The difference between the two systems was overwhelming, only 1 of every 10 found learning using the traditional system to be fun, while over 7 out of every ten found the same for the GILI system.

In regards to how the student rated the educational value, both learning systems rated too similar to make a significant distinction. Both methodologies rated high with well over half the participants accepting the statement. The text on paper did slightly better with 66.7%, and 60% for the GILI system.

The users started with very different confident levels with regards to their cell anatomy knowledge. Even though none of the participants started with high confidence in their understanding, group T had more than half of its participants in a neutral position while 80% of the participants in group I rejected the statement. This changed surprisingly rapidly as all subjects in both groups would have the exact same confidence level after the first learning session. This balanced level was achieved as a result of a positive impact of the GILI system in the users' perception. Users exposed to the traditional learning method practically did not switch any of the users in the low confidence category. After learning session 2 there was gains in confidence levels for users in both groups, achieving a 33% of the user-base with a high knowledge confidence. The overall positive knowledge confidence change in all learners was due to both systems but GILI achieved a higher positive impact, converting 53% of low confidence users vs only 33% due to the traditional system. This results might prove the GILI system have a positive impact in learners optimism and their overall image as themselves as good learners.

11 Synthesis

The GILI system was developed in order to integrate embodied interaction virtual reality technologies deeper into the educational process, and by doing so; try to provide a solution to those users whose learning style might be disregarded.

The aim of this research effort, stated in the problem statement is:

> *"How could the experience of embodied interactive educational tools affect the user's learning process. "*

In order to achieve that objective a few fields of study were analysed. Relevant educational methods and learning theories were gathered. It was an immensely interesting and rewarding exploration.

By researching on existing technologies a software implementation was developed. This system, GILI was evaluated. The chosen crossover study approach is likely to have been a correct way of testing the premise.

This research and discussions suggest that employing and integrating technologies which enable embodied type of interactions might have potential in supporting certain types of learning. In that objective it achieves its purpose with some caveats: the gather data is not statistically significant and therefore not supportive of strong conclusions. This is in part due to the number of participants. However, important observations can and were made with the aid of visual representations of the data. It can be said at the end the GILI system can be helpful for spatial learning and understanding scales, while being fun and even engaging but it is not for everybody.

More work about the possibility of finding more intuitive gestures and certainly further testing with larger groups, would be necessary to provide more conclusive answers to the problem statement. There is also without a doubt the possibility that other statistical tools, suitable for this crossover study which the researcher was not aware of, might have improved the conclusiveness of the research.

The use of additional nonintrusive technology such as ultrasonic haptic feedback would be highly desirable for further explorations of the system.

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13 Appendix

13.1 Statistical Analysis Complete Output

Group Statistics for Factual Knowledge

	Group	N	Mean	Std. Deviation	Std. Error Mean
A	I	15	.40	.507	.131
	T	15	.53	.516	.133
B	I	15	.13	.352	.091
	T	15	.13	.352	.091
C	I	15	.07	.258	.067
	T	15	.07	.258	.067
D	I	15	.33	.488	.126
	T	15	.67	.488	.126
E	I	15	.07	.258	.067
	T	15	.07	.258	.067
F	I	15	.07	.258	.067
	T	15	.07	.258	.067
G	I	15	.33	.488	.126
	T	15	.20	.414	.107
H	I	15	.13	.352	.091
	T	15	.33	.488	.126
I	I	15	.20	.414	.107
	T	15	.27	.458	.118
J	I	15	.27	.458	.118
	T	15	.20	.414	.107

Figure 13-1 Group Statistics for Factual Knowledge Questions Phase 0

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
A	.413	.526	-.714	28	**.481**	-.133	.187	-.516	.249
			-.714	27.991	.481	-.133	.187	-.516	.249
B	.000	1.000	.000	28	**1.000**	.000	.128	-.263	.263
			.000	28.000	1.000	.000	.128	-.263	.263
C	.000	1.000	.000	28	**1.000**	.000	.094	-.193	.193
			.000	28.000	1.000	.000	.094	-.193	.193
D	.000	1.000	-1.871	28	**.072**	-.333	.178	-.698	.032
			-1.871	28.000	.072	-.333	.178	-.698	.032
E	.000	1.000	.000	28	**1.000**	.000	.094	-.193	.193
			.000	28.000	1.000	.000	.094	-.193	.193
F	.000	1.000	.000	28	**1.000**	.000	.094	-.193	.193
			.000	28.000	1.000	.000	.094	-.193	.193
G	2.635	.116	.807	28	**.426**	.133	.165	-.205	.472
			.807	27.277	.427	.133	.165	-.206	.472
H	7.338	.011	-1.288	28	.208	-.200	.155	-.518	.118
			-1.288	25.461	**.209**	-.200	.155	-.520	.120
I	.707	.408	-.418	28	**.679**	-.067	.159	-.393	.260
			-.418	27.723	.679	-.067	.159	-.393	.260
J	.707	.408	.418	28	**.679**	.067	.159	-.260	.393
			.418	27.723	.679	.067	.159	-.260	.393

Figure 13-2 t-test for Equality of Means for Factual Knowledge Questions Phase 0

Group Statistics for Factual Knowledge

	Group	N	Mean	Std. Deviation	Std. Error Mean
A	I	15	.80	.414	.107
	T	15	1.00	.000	.000
B	I	15	.33	.488	.126
	T	15	.53	.516	.133
C	I	15	.73	.458	.118
	T	15	.73	.458	.118
D	I	15	.87	.352	.091
	T	15	.80	.414	.107
E	I	15	.40	.507	.131
	T	15	.73	.458	.118
F	I	15	.73	.458	.118
	T	15	.47	.516	.133
G	I	15	.67	.488	.126
	T	15	.73	.458	.118
H	I	15	.87	.352	.091
	T	15	.80	.414	.107
I	I	15	.33	.488	.126
	T	15	.60	.507	.131
J	I	15	.60	.507	.131
	T	15	.60	.507	.131

Figure 13-3 Group Statistics for Factual Knowledge Questions Phase 1

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
A	24.889	.000	-1.871	28	.072	-.200	.107	-.419	.019
			-1.871	14.000	**.082**	-.200	.107	-.429	.029
B	1.544	.224	-1.090	28	**.285**	-.200	.183	-.576	.176
			-1.090	27.911	.285	-.200	.183	-.576	.176
C	.000	1.000	.000	28	**1.000**	.000	.167	-.342	.342
			.000	28.000	1.000	.000	.167	-.342	.342
D	.924	.345	.475	28	**.638**	.067	.140	-.221	.354
			.475	27.290	.638	.067	.140	-.221	.354
E	2.120	.157	-1.890	28	**.069**	-.333	.176	-.695	.028
			-1.890	27.711	.069	-.333	.176	-.695	.028
F	3.646	.067	1.497	28	**.146**	.267	.178	-.098	.632
			1.497	27.603	.146	.267	.178	-.099	.632
G	.592	.448	-.386	28	**.702**	-.067	.173	-.421	.287
			-.386	27.886	.702	-.067	.173	-.421	.287
H	.924	.345	.475	28	**.638**	.067	.140	-.221	.354
			.475	27.290	.638	.067	.140	-.221	.354
I	.516	.478	-1.468	28	**.153**	-.267	.182	-.639	.106
			-1.468	27.959	.153	-.267	.182	-.639	.106
J	.000	1.000	.000	28	**1.000**	.000	.185	-.379	.379
			.000	28.000	1.000	.000	.185	-.379	.379

Figure 13-4 t-test for Equality of Means for Factual Knowledge Questions Phase 1

Group Statistics for Factual Knowledge

	Group	N	Mean	Std. Deviation	Std. Error Mean
A	I	15	.80	.414	.107
	T	15	1.00	.000	.000
B	I	15	.47	.516	.133
	T	15	.53	.516	.133
C	I	15	.60	.507	.131
	T	15	.53	.516	.133
D	I	15	1.00	.000	.000
	T	15	.73	.458	.118
E	I	15	.73	.458	.118
	T	15	.87	.352	.091
F	I	15	.67	.488	.126
	T	15	.60	.507	.131
G	I	15	.67	.488	.126
	T	15	.73	.458	.118
H	I	15	.80	.414	.107
	T	15	.80	.414	.107
I	I	15	.53	.516	.133
	T	15	.67	.488	.126
J	I	15	.87	.352	.091
	T	15	.73	.458	.118

Figure 13-5 Group Statistics for Factual Knowledge Questions Phase 2

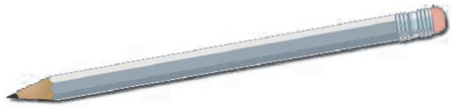
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
A	24.889	.000	-1.871	28	.072	-.200	.107	-.419	.019
			-1.871	14.000	**.082**	-.200	.107	-.429	.029
B	.000	1.000	-.354	28	**.726**	-.067	.189	-.453	.320
			-.354	28.000	.726	-.067	.189	-.453	.320
C	.413	.526	.357	28	**.724**	.067	.187	-.316	.449
			.357	27.991	.724	.067	.187	-.316	.449
D	50.286	.000	2.256	28	.032	.267	.118	.025	.509
			2.256	14.000	**.041**	.267	.118	.013	.520
E	3.422	.075	-.894	28	**.379**	-.133	.149	-.439	.172
			-.894	26.263	.379	-.133	.149	-.440	.173
F	.516	.478	.367	28	**.716**	.067	.182	-.306	.439
			.367	27.959	.716	.067	.182	-.306	.439
G	.592	.448	-.386	28	**.702**	-.067	.173	-.421	.287
			-.386	27.886	.702	-.067	.173	-.421	.287
H	.000	1.000	.000	28	**1.000**	.000	.151	-.310	.310
			.000	28.000	1.000	.000	.151	-.310	.310
I	1.544	.224	-.727	28	**.473**	-.133	.183	-.509	.242
			-.727	27.911	.473	-.133	.183	-.509	.242
J	3.422	.075	.894	28	**.379**	.133	.149	-.172	.439
			.894	26.263	.379	.133	.149	-.173	.440

Figure 13-6t-test for Equality of Means for Factual Knowledge Questions Phase 2

13.2 Test Questionnaire

The following is a representation of the original questionnaire, which was filled up online. The content is completely the same but the design was modified to improve readability in this document. Pages are divided by a dashed border.

Cell Anatomy



Please answer the following questions about cell organelles

Learner Number ☐

Learning Experience Code ☐

How much do you feel you know about Cell Anatomy?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have a good understanding of cell anatomy.	○	○	○	○	○
I like learning about science.	○	○	○	○	○

How much do you feel you know about Cell Anatomy?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have a good understanding of cell anatomy.	○	○	○	○	○
I like learning about science.	○	○	○	○	○

Learning session.

Please STOP. You will be provided some learning material and instructions. Please use the material/system for as long as you feel comfortable.

How much do you feel you know about Cell Anatomy?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have a good understanding of cell anatomy.	O	O	O	O	O
I like learning about science.	O	O	O	O	O