Haptic Prototype Assembly Tool for Non-Sighted, Visually Impaired and Fully Sighted Design Students, Studying at a Distance.

L. Bowers [1] , N. Braithwaite[1] , R. Hayle[1], F. Amirabdollahian[2] A. Jefferies[2]

[1] The Open University, Milton Keynes, UK
[2] University Hertforshire, Hatfield, UK

Abstract. Designers are known to use a blend of manual and virtual processes to produce design prototype solutions. However often virtual processes can limit the designers feeling of being 'hands-on' with materials and processes. The rise of virtual haptic tools have afforded great potential for designers to feel more 'hands-on' with the virtual modelling processes. This paper presents an investigation of an inclusive educational haptic tool and interface. The Geomagic Touch™ device was selected to operate a haptic rendered interface. The interface was designed to facilitate a prototype design process for non-sighted - visually impaired (NS-VI) and fully sighted (FS) distance learners from The Open University. The parameters examined were 'time' taken to assemble a four block prototype, and collisions (error) caused by participant between block shapes during the prototype assembly. Both time and collision results by NS-VI/FS in two haptic modes, showed insignificant difference in data for either group. Furthermore the time taken to complete the task was never over the accepted industry standard, of 5 minutes, to assemble a prototype within the germinal stages of the design process. This means that haptics have aided both participant groups to achieve the industry 'norm', with no known difficulty.

Keywords: Designers, Haptics, Non-Sighted.

1 Haptics by design

1.1 Introduction

The haptic prototype assembly project was funded by eSTEeM project award board at the Open University, Milton Keynes. The eSTEeM project award board focuses on funding for research to develop STEM teaching and learning for distance learning programs. This project was motivated by the need to diversify the interaction with design interface for non-sighted (NS), visually impaired(VI) and fully sighted (FS) students' registered on design practice modules within The Open University.

The project was designed around three different haptically rendered environments, providing haptic feedback via the Geomagic Touch™. There were three test environments, one focusing on qualitative testing by asking users to use the Think-Aloud technique to narrate their cognitive processes whilst working with MP and VP haptic modes. The next two tests were shown as a pilot test and a core shape assembly test which requested that users assemble a specific prototype shape in two haptic modes.

To guide users on the prototype object an exemplar chair design was used. The prototype chair style was inspired by a similar chair by Walter Gropius *(Circa 1934)* shown as image Fig 1. the inspired prototype chair shown in image Fig.2.

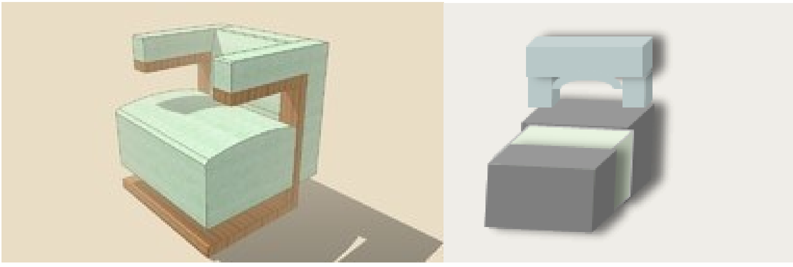


Fig. 1. An Example of Walter Gropius block chair
Figure 2A sketch model of Bauhaus inspired block chair.

The Gropius chair was chosen for its simplicity and brevity of assembly. The aim of this study was to demonstrate the benefits of a novel haptics interface for NS-VI and FS groups.

2 Background

The growth of haptic technology has shown a rise, in recent years, revealing new industries joining the haptic technological field. Design practice has been one such industry, which has readily adapted traditional touch-led prototyping into virtual touch-led prototyping. It could be said that the use of virtual haptics, has afforded designers the opportunity to begin to regain a more hands-on approach to prototype modelling.

Since the beginning of the Bauhaus school (circa 1919-1933) students have been trained on how to craft model prototypes by hand. However through the use of CAD, designers have a reduced amount of opportunities to get fully hands-on with modelling prototypes. Cheshire, Evans and Dean [1] state that there is a strong groundswell of opinion that tactile product development is beneficial to the final products form and so a way should be found to combine the craft based techniques with digital product development.

Scali, Shillito and Wright [2] state that the effective utilization of digital tools from the very early phase could better respond to industries' needs and be beneficial to the designer's cognitive demands. The early phase of design prototyping is the phase where the focus is specifically on 'ideation', and as such designers require the freedom to rapidly respond to a design brief in an intuitive and efficient manner. As it is easier and quicker to alter a parameter of a virtual prototype than it is to alter a manual prototype, designers will naturally turn to the tools which enable speedier more

natural processes. Thereby the introduction of haptics at the early stages and latter stages of the prototyping process would be well received by the design community.
To facilitate a fully hands-on studio practice for online design students is difficult to manage. This is partly due to the nature of distance learning modules being mostly screen-based. Examining Spector's [3]definition of distant learning it is clear to see the difficulty –distance learning is learning that occurs in a context in which students are typically separated from their instructors on computer-based instructional agents, and typically from each other, for more than 75% of a course or instructional program. Most 'face to face' tutorials within distance learning engineering and design courses do offer students hands-on materials and process. However the making space is usually a classroom, which only allows for low fidelity making and modelling. The access to a studio workshop space, for distance students is still incomparable to that of a conventional design student.

It has been shown that hands-on learning enhances students understanding of prototype construction and extends fine motor skills [4] [5] NS-VI distance learning students studying as a design novice, could be said to specifically require additional support to overcome the lack of hands-on teaching and learning within the design modules. Due to the visual nature of virtual learning environments NS-VI design students are facilitated with alternative resources. The alternative resources are typically in the form of either audio or Braille transcriptions. Both of these transcriptions types do offer a level of assistance, but they are limited to a singular sensory mode touch or sound. Therefore the lack of multi modal feedback can create problems for NS-VI students to understand new learning material. These alternative resources are typically in the form of either audio or Braille transcriptions. Both of these transcriptions types do offer a level of assistance, but they are limited to a singular sensory mode: touch or sound.

The paper reports on an inclusive investigation of the use of haptics as a novel application for use by NS-VI and FS distance learning design students. The haptic application was designed to aid users to assemble a prototype at the early stages of design using multi modal feedback. The experiments are presented as a two layered approach, to include 1) a quality test used by design academics at The Open University Engineering and Innovation school, 2) a VP usability test to assess assembly of prototype. This study hypotheses that *haptics is able to enable a set assembly task within an acceptable time and with limited difficulty to the users.* This study aims to 'level the playing field' via the facilitation of 'hands-on' interaction for design students working within the virtual realm. A full report from both phases and all groups tested are presented below.

3 Formative Pilot

A preliminary quality test was set up to understand whether a haptic tool would be of value to design students studying at a distance. A group of three design academics,

volunteered from a recruitment drive via The Open University. All three participants were fully sighted (FS) and the age M = 53yrs ±7.63sd. None of the participants had previous knowledge of the test, nor did they have any prior experience of haptic tools. The study was approved by The Open University ethical board and each individual gave due consent (HREC/2016/2276).
As design academics are able to activate agency within the design process, it was considered to be important to include them in the early stages of design and implementation. Thereby a design academic user group, was perceived as offering insightful input to the first iteration of the haptic VP interface. It should also be noted that all three design academics had taught, or were teaching, NS-VI students and had specific experience of students with these ability needs. The academic volunteers were requested to work through the testing within a computer lab, on site at the Open University campus. Throughout all the tests volunteers were asked to use the Think-Aloud technique and post trail they were asked to complete a Lickert questionnaire.

3.1 Preliminary Results from the pilot study

From a thematic review undertaken in NVIVO (v10) the 3x design academics qualitative response, the most common word response was **useful** and **interesting**. The think-aloud feedback recordings showed that the participants were initially tentative about moving around the virtual bounded space using the probe. It took a few minutes to orientate themselves within the space and to gather their immersive sensibilities. Once accustomed to the space and using the probe, participants were keen to explore all the walls and ceilings of the space using the probe, once the walls were touched they were surprised by the ping sound which accompanied the contact and they were also surprised at the way the virtual environment responded by offering the user the same touch feedback as would be expected in a real world context, "Can I feel [sic] the walls and floor as a resistance?" "I am going to try and pick this up now…oh it's moving…" [6]

Once participants had probed the environment fully, they were then more confident to interact with the 3D shaped blocks, centered on the floor of the space. Two of the participants felt that they needed to draw on the facilitator to remind them of what to press and felt that they had to pause to collect their thoughts before acting on the instructions. The volunteers seemed to be tentative about over forceful use of the probe and the virtual environment, however this behavior disappeared once the volunteers had been using the tool for 10 mins or more. After this time volunteers were observed to relax back in their seat and not ask as many questions.

From the formative results two significant modifications were actioned as a result of the pilot test 1) technical issue of shape jitter, each of the 3D shapes when picked up and held in virtual space for longer than a few secs' began to jitter and shake. This was distracting for the user and was due to a technical fault in the software communication with the haptic device. The developer reviewed the shape technicality and smoothed the links between haptic device and haptic environment. 2) Assistances for disability, participants reported that it would be more beneficial to users if more sounds could be added to the environment. To that end, three further sounds were added to the environment, 1)a foundation block dull sound, 2)a block connecting sound – a ping, and 3)a completion sound a higher pitch blend of sounds.

4 Experiment Design : Material and Methods

The haptic interface was set up with a single 21″ display screen, the haptic device was aligned directly in front of the display screen, in line with the yellow foundation block on-screen. In a training session, all participants were guided on how to hold the stylus and how to press the buttons on the stylus. NS-VI participants were permitted to touch and explore the actual Geomagic Touch™ device prior to using it, to gain a better mental picture of the device and to aid understanding of the use of the device.

Table 1. Participant Demographics

Participants	No.	Dominant hand (L/R)	Age (Years) Mean ± SD
Males (NS/VI)	5	2/3	42 ±22.8
Females (NS-VI)	5	1/4	47 ±14.9
Males (FS)	7	0/7	33 ± 13.1
Females (FS)	3	1/2	29.6 ± 5.5
Total	20	20	37.9± 8

All participants were requested to complete a pre-trial task prior to the main assembly trial. This was a simple ‘pick up and put down’ task *(Fig. 2).* Participants were asked to pick up the cube and place it down, users were guided by force feedback to the ‘x’ marked cues on the floor of the environment.

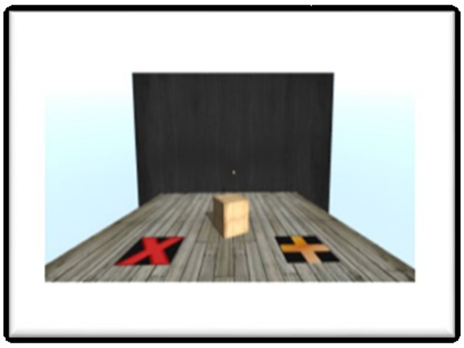


Figure 3.Preliminary training ‘pick up and put down task

4.1 Experiment and settings procedures

Prior to the test, a chair prototype was designed, 3D scanned and 3D printed to create a physical 3D model of the chair (shown in Fig 2). The 3D chair prototype was presented to each participant prior to the prototype assembly tasks. NS-VI participants were handed the 3D printed chair to touch to gain an understanding of the shape to assemble. All participants were also shown how to connect the module shapes via the push technique, simply pushing the shapes together with a single digit in manual mode and in virtual mode using the stylus to push in the centre of the shapes to lock them together. The following describes the test protocols, conditions and assistive adaptions added to the interface. All participants completed a) test protocol followed by b).

a) **Manual Prototype (MP) test:** Participants were seated at a table and presented with *four 25 x 4 x 23mm* (palm sized) foam rubber shapes (1x arch 3x cuboids). At the beginning of MP test 2 block shapes were set 1) a (fixed) foundation (yellow) cuboid, 2) a red cuboid set slightly apart from the foundation block. Participants were requested to then pick up two further shapes from a wooden box, one at a time, and assemble the predefined 'proforma'. Each assembly was timed by a digital stopwatch, and collisions between shapes were recorded.

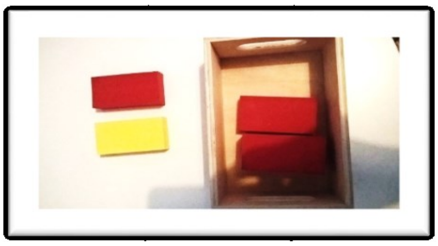


Figure 4 Manual block set up

b) **Virtual Prototype (VP) test:** Participants were seated at a desk and presented with a single monitor. The monitor showed *two blocks 25 x 4 x 23mm* foam rubber *(simulated)* shapes placed on the floor of a bounded environment, 1) a fixed yellow foundation cuboid and b) a red cuboid set slightly apart from the foundation shape. Participants could request a new shape by depressing the space bar on the keyboard, which then activated a new shape to drop from the ceiling to the floor in line with the two starting shapes. Users were requested to move shapes by using a push action, they were only requested to 'pick up' the final arch shape and they did this by tapping the stylus on the arch shape and lifting upwards. The arch would then be easily stacked on top of base yellow cuboid. Participants were timed digitally via the haptic interface and collisions were recorded between shapes.

c)

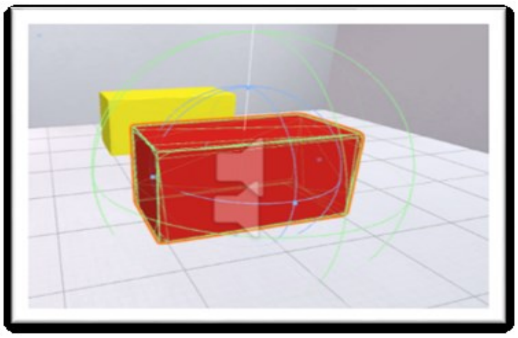


Fig. 3. Virtual Test environment.

All participants were requested to complete each MP/VP prototype assembly tasks within 5 mins; the industry norm' for sketch prototype construction. If the participants went over the allotted 5 minutes, in MP mode they would be stopped and in VP mode the system would close down.

Participants were also requested to move as quickly as possible to assemble the prototype, whilst also being aware of minimizing the collisions between shaped blocks. Participants were asked to also to assembly the shapes as neatly as possible, to result in a smooth prototype profile.

5 Results and analysis

The following outlines the analysis of qualitative and quantitative results, qualitative initially analyses data from Think-Aloud technique recordings, and post-test Lickert questionnaires. All qualitative analysis was analyzed through NVIVO (v 10). The quantitative duration of assembly task, and collisions recorded for MP and VP, SPSS (v21) was used to analyze all quantitative data.

5.1 Qualitative analysis

Qualitative results reflect the results, obtained via the Think-Aloud technique were transcribed, then coded using NVIVO showed themes emerging. The themes were set around the words **accessibility, complexity and immersion**. Participants seemed to hold the view, prior to the trials, that the haptic device would be too complex for them to use and only highly trained engineers would be able to manage to use it well. Thereby a lot of the think-aloud discussion was set around thoughts such as one non-sighted participant stated:

> Do you know, I really thought using this would be more tricky, look I am just picking that up as I would normally[sic]

First level data translation showed the most commonly repeated word used was **easy'.** The most common word to come from the Think-Aloud technique analysis was 'understandable' and 'interesting'. Further refined thematic analysis was undertaken, analyzing post- trial qualitative feedback. Themed headers used were, usability, understanding, and fit for purpose. The theme of usability, was the most common theme to trigger user fed back. Particularly the NS group participants wanted to record their appreciation at being able to gain access to a technology enhanced learning tool which could aid their computer access via an innate sensory interaction.

- **Usability/Understanding**

There was a consensus between NS participants that the haptic device was easier to control than previous thought. They could see the potential use within engineering and design for prototyping and they were very perceptive of the reasoning behind using the haptic in accessibility terms.

Participant NS9 [7] stated:

> It was satisfying accomplishing something which I had thought impossible/very difficult in a relatively easy manner.

He went on to say:

> Moving from a mental picture to actually creating a prototype was satisfying. Without the interface I can't conceive how the task could be accomplished on my own. Only [sic] other alternative would have been a sighted assistant to do all the work.

- **Usability/Understanding**

There was also a shared agreement (NS/FS) of how easy it was to use the haptic device and interface interaction by both groups [7]. However one participant NS8 [8] indicated an innate need to use both hands to interact with the 3D objects he stated:

It was also somewhat confusing at the cognitive level, that while holding the pen in the right hand and clearly feeling a virtual wall, the left hand did not feel anything.

FS group showed that there was an agreement on how the haptics offered more sensitive touch feedback than initially expected, participant FS5 [9]commented:

> … the device was easy to hold and intuitive to use. I was impressed by the feel of the boundaries in the interface when converted to resistance in the device. Being able to feel the weight of the object was also a pleasant surprise.

- **Fit for purposes**

Recordings from the Think-Aloud technique revealed one NS10 participant stated that "the device is up to task" [10]
Overall the consensus of feedback was that the haptic device and interface was useful and usable for the speedy assembly of a prototype, but both groups offered they would like more options to make the assembly task personalize the process e.g. change the colour or texture of the shapes and feel the textures of the shapes.

Two different metrics were assessed from this trial, time taken to complete the prototype assembly, termed here as *duration*, and number of collisions during task performance, here termed as *nCollision*. For the MP/VP video recordings of each participants tasks were created, coded and analyzed by two raters, the second rater's sample size was calculated at *80%* coding sample to observe collisions. Cohens Kappa (*k*) was performed to achieve a moderate agreement result *(0.50),* showing that between two raters, there was a moderate agreement of the collisions made. The collisions were examined and a collision defined when a single block collided with another block whilst in the process assembling the prototype

Results from duration and collision count did not have a normal distribution. Thus, non-parametric statistical models are used for further analysis. In this case, the Mann-Whitney U tests were performed to analyze whether there would be any significant difference between groups, between haptic modes and between haptic modes specifically examining the *duration* and *nCollisions* in both modes, this was done to ascertain whether haptic VP mode would add any further time or collisions to the assembly task.

Table 2. Mann-Whitney U test results.

Test	Z result	P value
Both groups, VP, Duration	-2.27	0.82
Both groups, VP, Collision	-1.43	0.52
NS Duration VP & MP	-1.06	0.28
FS Duration VP & MP	-1.37	0.17

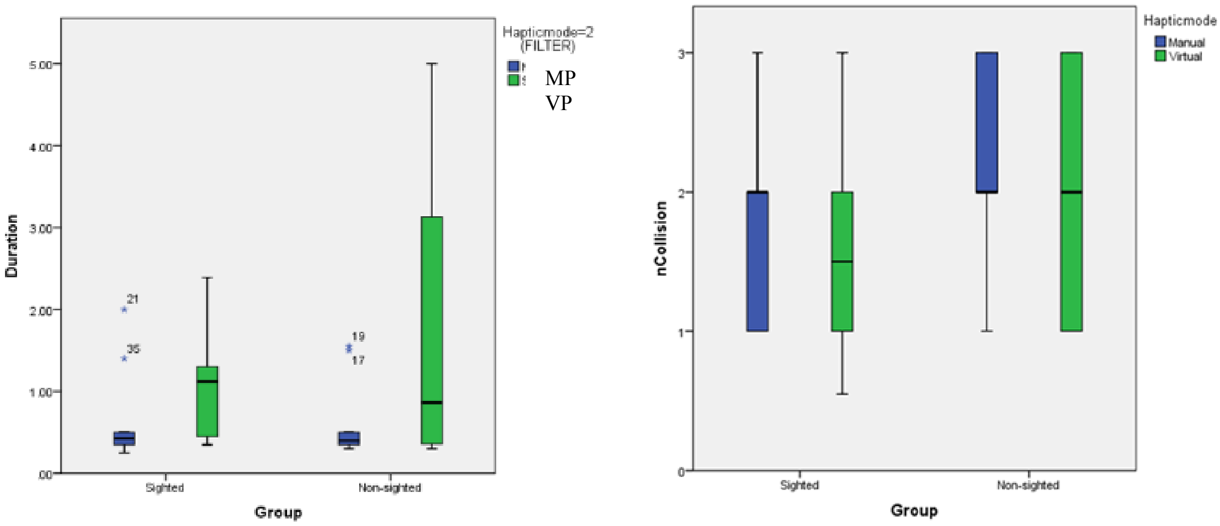


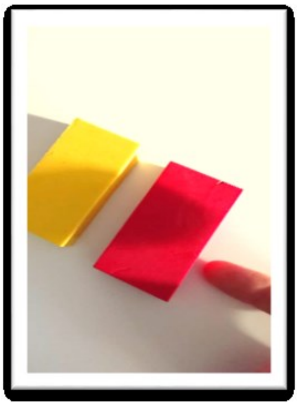
Table 2 the Mann-Whitney U tests present statistical data performed to analyze differencing between participants duration and collisions. To that end it is clear that there was no statistically significant difference between groups, between modes and collisions between modes and groups, as shown by the p values and Z value.

The box plot shown above in Fig. 5, revealed that the MP mode between groups resulted in very little difference in time taken to complete the prototype task. Sample data for VP between groups again showed contextually a small difference of time, with the longest duration shown as an out layer (NS).

6 Discussion

When comparing the performance between sighted and non-sighted participants, we observed that in MP task, they had a similar performance reflected by the *duration* and *nCollision* parameters. This was similar for the haptic task. This said, box plots show that while statistical significance in difference was not achieved, there was a marked difference in the variation of *duration* and *nCollision* between MP and VP. This variation is thought to be due to the learning curve for using the haptic device, and future work can consider additional exposure sessions, while observing the variation.

As there was an insignificant difference shown between groups, between MP and VP, reflected by both *duration* and *nCollision*, then we can agree with the hypothesis that haptic VP has enabled both groups (N-VI&FS) enough to level the playing field, through the prototype shape assembly task. Further to this, all participants have assembled the prototype well within the accepted industry norm (5mins), and with limited difficulty, as shown through the collision (error) results.



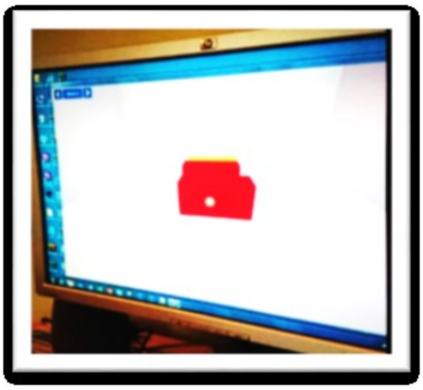


Figure 7. Manual Prototype showing the push technique employed in this test
Figure 8. Virtual Prototype showing push technique employed in this test.

The collisions (errors) in this study showed little difference between groups and between MP and VP modes. It is hypothesized that this was partly due to the shape block selected movement technique, push shown in Fig 7 & 8. Both participant groups were trained in the exact push technique required, meaning that participants were asked to push blocks together with one digit during the MP or the end of the stylus during the VP session. Push action was selected rather over a pick up and put down action to connect prototype blocks due to the simplicity and brevity of this specific action. All participants appeared to easily understand the push technique and successfully used this well throughout the assembly tasks.

Apart from the results shown above, the authors feel that there is a much richer take home message to be disseminated. The main aim of this study was to extend NS-VI and FS design students' access to touch-based technology (haptics) to enable students more meaningful interactions with design prototype process in the virtual realm, thereby offering a better student experience. Previously the building of prototype assembly of design prototype modelling using computer aided design (CAD) would not have been possible, specially to facilitate for NS-VI students at The Open University. The process would either have had to be translated in to another process, or the NS-VI student would be allocated a human accessibility officer to help with CAD model assembly. Often the introduction of another person can confuse the student's agency of learning through CAD. This study was the first of its type, but now it is expected that more like-minded haptic trials will be conducted by the research team. The study has shown qualitatively that specifically NS-VI participants found the trials easy to operate, that they were inspired and moreover interested in the use of haptics to augment touch and to enhance the interactions of design process.

Inclusivity was at the roots of this study and as such the qualitative results were very encouraging, in that there is a great deal of agreement for each of the three themes 'usability, understanding and fit for purpose'. There was a slightly larger agreement under the theme of usability, with understanding and fit for purpose agreements ranked with level the amount of agreements. Throughout the test The Think-Aloud feedback and the post-trial feedback both offered inspiring positive comments from all participants, but the most rewarding comments came from NS-VI participants who were interested to use haptics as part of their own design process going forward.

7 Future

This study was created as a proof of concept haptic rig test. Further development and further iterations of the haptic VP assembly interface is required, to allow it to become part of the module learning tools offered by the Open University.

Acknowledgments

We are grateful to our colleagues in the Open University, more specifically the Esteem group Milton Keynes, UK. Thanks must also go to all of the design group academics, but moreover the greatest thanks must go to all student participants who travelled considerable distances to attend the test trials and gave such frank and open feedback.

8 References

[1] D. Cheshire, M. Evans and C. Dean , "Haptic Modelling – An Alternative Industrial Design Methodology?," in *IEEE*, 2001.

[2] S. Scali, A. Shilito and M. Wright, "Thinkspace," *Eduvac,* 2009.

[3] J. Spector, "The Future of Distance Learning Technology: It's Not About the Technology and It's Not about distance," *Distance Education,* vol. 30, no. 1, pp. 157-161, 2009.

[4] B. Ferri, S. Ahmed, J. Michaels, E. Dean, C. Garyet and S. Shearman, "Signal processing experiments with LEGO MINDSTORM NXT kit for use in signals and systems courses.," in *American Control Conference*, 2009.

[5] Z. Dogmus, E. Erdem and V. Patoglu, "ReACT: an interactive educational tool for AI planning for robotics," in *IEEE trans Edu*, 2015.

[6] NS5, Interviewee, *Haptic assembly shape Lickert scale questionnaire.* [Interview]. 10th November 2017.

[7] N.-S. P. 9, Interviewee, *Shape Assembly Test.* [Interview]. Friday November 2017.

[8] NS8, Interviewee, *Shape Assembly Test.* [Interview]. Thursday November 2017.

[9] F. 5, Interviewee, *Shape Assembly Test.* [Interview]. Wednesday November 2017.

[10] NS10, Interviewee, *Shape Assembly Test.* [Interview]. Friday November 2017.