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Seamless Multi-Modal Interactions across Computing Devices for Enhancing Engineering Education—Gesture Interaction*

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Advances in the technologies and evolving human computer interaction culture are adding new dimensions in the overall education customs. With the human-computer interaction model moving from traditional input methods to more natural, ubiquitous input techniques, there is a need for us to understand and increase the richness of the user experience with seamless integration and functionality of these types of technologies. The focus of this paper is on identifying aspects of the input technology that increases the impact of the device by enhancing the user experience with higher integration and functionality of these types of technologies. The paper also identifies aspects of social behavior and actions of social interactions for multi-modal input technology across different form factors.

Keywords: multimodal interactions; gesture interaction; engineering education

1. Introduction

The modern educational techniques and technologies have been focused on modularizing the education system for effective knowledge acquisition and retention in the students. Also, the advances in digital media consumption are driving the need to design technology that is easily consumable by students. With the technology adoption and education modularization comes the opportunity to not only tailor the reading experience of individual student needs, but also to enrich the collaborative reading and learning experience such as inductive learning methods through different sensor technology. Inductive learning methods are not only allowing the scope of all the technology integration but also allows for active knowledge building [1–6]. In the inductive learning process, the students work on the problems or in the unfamiliar learning environments individually or with the help of their relative groups. Together, the students are engaged in addressing the questions in a collaborative or cooperative effort [7, 8]. At this stage, the instructors shift their teaching modes to the different teaching techniques and hence there is a vast scope for the application of the teaching models to come to the effect. The instructor can provide the students with the peripheral information about the project and let the students actively participate in solving the problem [1, 4, 5, 9]. Students try to learn the concepts based on the knowledge they try to gain while solving the problem by themselves. The struggling zone or the region between the students' independent learning and the instructor assisted learning is called as the zone of proximal development (ZPD). In the ZPD, the students struggle to build the active knowledge and try to make some sense out of it. The students can use several self educating sources in this zone and this technique is called as scaffolding. Effective scaffolding can help students build an active knowledge around themselves and make some integral and constructive sense out of it [10–12]. Scaffolding is a technique which could be employed by providing the references to the active knowledge building sources. A solid technological support could be introduced for the students to get hands on convenience to the educational tech-tools [1, 8, 10–15].

The focus of this paper will be on identifying the aspects of the input technology that will increase the impact of the device by enhancing the user experience with higher integration and functionality of these types of technologies. Through the structured experiments we carried out at the Interactions design and modeling lab, Wright State University, we have made an attempt to understand the effectiveness of the learning methods using multimodal learning technology vs. the classical instructor-student-classroom interactions. The technology in use for this particular experiment is the small form factor device which is a part of modern lifestyle. This paper will also identify aspects of social behavior and actions (including motivations) of social interactions in multimodal input technology.

2. Engineering education challenges

In his talk on Educating Engineers for 2020 and Beyond, Vest [16] argued that in order to retain and excite engineering students, it is important to focus

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on the environment to drive their passion and curiosity and to engage them actively to help them learn ideas and be inspired. Over a few years, the National Science Foundation (NSF) has been reporting a serious decline in the number of engineering enrollment and the number of successful engineers graduating from educational institutions [17]. According to the Accreditation Board for Engineering and Technology (ABET), the engineering graduate does not only require the student to have proficiency with the concepts of science, technology, engineering and mathematics (STEM) but also need to understand the global and economic impact of the gained knowledge. In addition, the accreditation criteria also require that with the help of improved communication skills, the engineer should be able to apply these concepts in a social context with the help of a multidisciplinary team [1]. In order to drive the passion and excitement in engineering education, the main challenge is to understand and drive technology faster and better. Fig. 1 shows the key issues, in descending order, that are globally present, as identified by the *British Journal of Engineering Education* (Rushby 2011) [18]. As seen in Fig. 1, the top five issues are on mobile learning and the different areas of mobile computing, such as social networking, changing learning environment, and collaborative learning. The key issues are not surprising as advances in sensor technology, software algorithms, and computational methods provide easy access to informal learning across different computing devices such as smartphones, tablets, and netbooks. Mobile is no longer a small-scale Internet platform. With the ecosystem that has developed around mobile devices, there are a lot of applications available that help to foster learning and to provide a rich interaction medium. Early access to such technologies at an early stage of development expands education opportunities and helps in building the nation's pedagogical future.

Reading is not a monolithic process. Instead, it varies by age of reader, reading intention and reading environment. For these reasons, reading in the classroom for learning purposes is quite different than an adult pleasure or information reading experience. While reading in general can be divided into three stages: pre-reading, reading and post-reading, it is rarely a linear process. In the case of adult pleasure reading, some of the more difficult processes of reading happen during the selection and acquisition of reading materials. For young students, the knottier processes happen as they read as a group and aim for comprehension. When these different realities are mapped, reading looks more like Fig. 2. This figure is based on the study conducted by the investigator at Intel Corporation. The objective of this study was to understand the reading market and the Spanish-language publishing industry to identify market potential and product definition of a digital device for reading in Mexico and Hispanic North America. In order to achieve the objectives, an ethnographic research was conducted. Whatever people read, they ideally want their reading to be simple and convenient, following a linear route in the three reading stages. At each reading stage, convenience is evolving into another value—accessibility at pre-reading, usability for reading, and flexibility in post-reading. Educational readings then offer unique opportunities for digital technology to better tailor reading for comprehension and learning purposes.

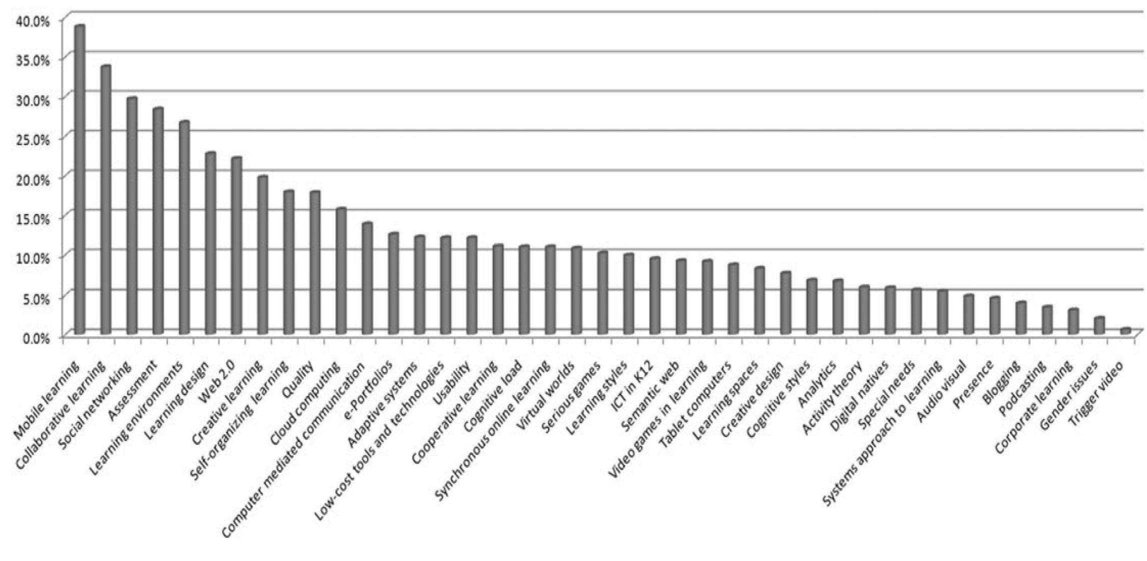


Fig. 1. Key issues in 2011 (n = 1139) (Note: all figures are given as percentages of the total number of respondents) [18].

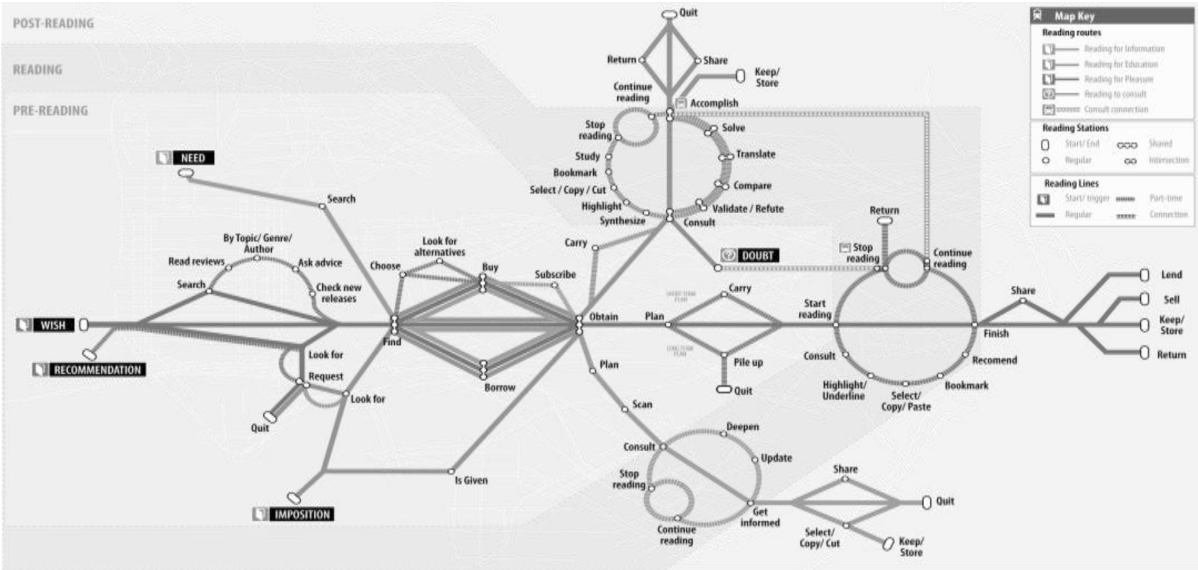


Fig. 2. Map of reading practice.

3. Multi-modal input technologies

The advances in the technologies and evolving human computer interaction culture are adding new dimensions in the overall education customs. With the human-computer interaction model moving from traditional input methods to more natural, ubiquitous input techniques, there is a need for us to understand and increase the richness of the user experience with seamless integration and functionality of these types of technologies [19]. There have been many recent developments in the field of multi-modal user interaction that provides the opportunity for providing alternative means of input such as gestural input devices (e.g. Wii, iPhone, xBox Kinect). There has also been a significant improvement in speech recognition algorithms and software sophistication combined with computational power that allows natural language inputs to be useable. These inputs combined with command language and natural language can provide a rich user experience in terms of seamless interaction of the human and computing devices depending on the choice of the technology.

Each of the input modalities can enable different and important experiences. Voice input allows easy navigation and searching without a keypad. Voice can also be used to add precision to the manipulation of information [20]. More research is also needed to understand the guidelines for combining context-aware computing factors (such as physical environment, location, user identity, and computational environment) with recognition-based interaction (such as multi-touch, gesture, and/or voice) to provide a rich user experience for the end-users. The primary tenet of an integrated input system is that its use increases the effectiveness of information presentation and management in situations where the computer can support and enhance human interactions [19].

Hence there is a need to gain general understanding of the role of digital media in enhancing the learning experience through technology. There are various issues associated with seamless integration of advanced learning technologies in classrooms for example: (a) the digital content should be made easily available (b) the technology should not only allow easy access but also enable communities and sharing, and (c) hyper-textual nature of digital reading and the cognitive processes change to adapt to the non-linear acquisition of knowledge [21].

Although research has focused on introducing technology into the classroom, they are silo solutions. There are still potential areas of research to understand the usefulness of the technologies which could be applied in the didactic practices across the board as a part of education domain. The potential lies in the area of understanding the points across the didactic culture where the assistance of the technology can be effective. In order to understand the user preference for different input modalities (gesture and touch) for interaction devices we conducted a user experience study. Findings from the study are presented as guidelines for the preference of a particular modality for informal learning.

4. Research methods

The purpose of this study was to gather the knowledge of student perception details and the learning preferences through a qualitative form of data. This study was done across different device form factor (tablet like device, laptops, and larger screen). Our goal is to test the effectiveness of the multimodal technology on knowledge acquisition and retention compared to the educational practices. The human subjects were asked to interact with applications available on these devices to do mathematical manipulations or science concepts. The experiment conducted was a repeated measure ($2 \times 2 \times 2$) within subjects design, with eight subjects. The within-subject independent variables included: Scenario (Math Concept, Science concept), and Type of System (iPad, Monitor/TV), Type of interaction (Gesture, touch interaction).

4.1 Participants

Eight participants were tested in this experiment. The subjects were selected from a pool of engineering students. All of them were student volunteers from Wright State University. All participated in all levels of treatment. To be considered for the study, the participants were required to have normal or corrected-to-normal acuity, a fairly good knowledge about Windows-based applications, and familiarity in operating a mouse and keyboard. These students studied in the traditional classroom settings and in hybrid educating settings where there is a slight blend of technology in the classrooms. These students have also experienced distance education technology. The users were tested through the tests described below and were free to share their thoughts and feelings about the tests and the content of the tests through think aloud method. The responses were video recorded for the entire test session. These responses were transcribed to quantitative scale to understand the learning preferences, effectiveness of the multimodal learning, effectiveness of the use of smaller form factor and usefulness of the interactive content.

4.2 Apparatus

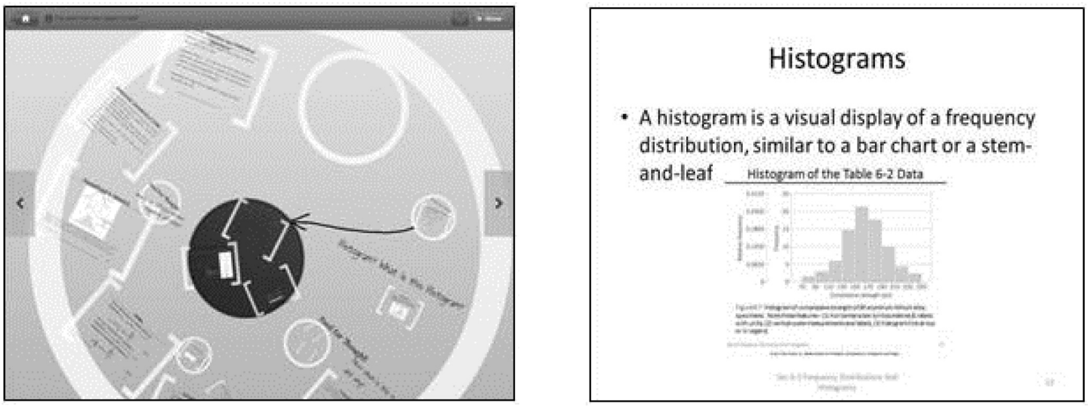
The experiment was conducted using iPad and a 23" monitor. There were presentations that were created on the iPad that was interactive and non-interactive. The purpose of the presentations and applications was to get feedback on the type of interaction mechanism that students prefer especially to learn concepts related to math and science. Also, it was a useful test to understand the interest level of the users in the use of multimodal interactions in education settings.

4.3 Procedure

There were three tests designed and each user was tested on every test with randomization to avoid any bias in the testing and interviewing process. The tests were divided in 3 different groups. These 3 groups of tests as described below:

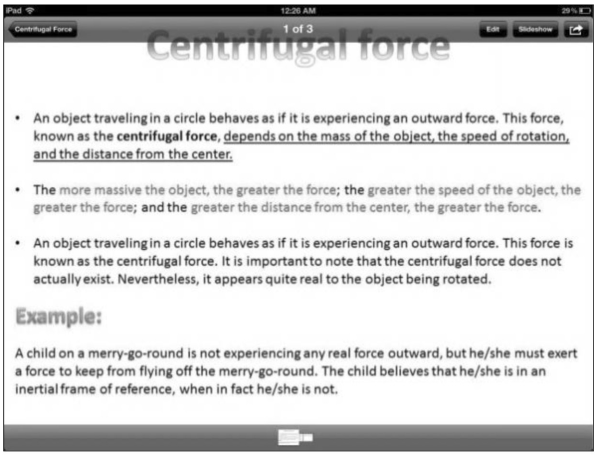
4.3.1 PowerPoint® slides on iPad vs. interactive Prezi® on iPad: Using the iPad, test subjects were given control of going through the course material. Test subjects were allowed to handle iPad and run through the content presented on iPad. The first test consisted of a PowerPoint slide presentation over iPad. The second one was the Prezi content presentation over iPad using an app called PreziViewer®. Similar content was presented using both styles and test subjects were instructed to go through the course content one after the other. The course designed for this task was based on two statistics concepts called 'Normal Distribution' and 'Central Limit Theorem'.

4.3.2 PowerPoint slides on iPad vs. iPad based game: Test subjects were given control to handle iPad in this test with PowerPoint presentation slides. The concept we were trying to test in this



(a) (b)

Fig. 3. (a) interactive Prezi® on iPad. (b) Non-interactive Powerpoint® slides.



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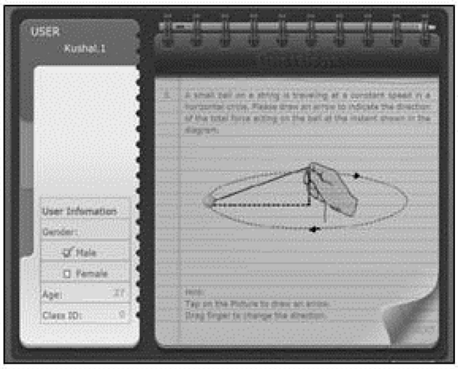

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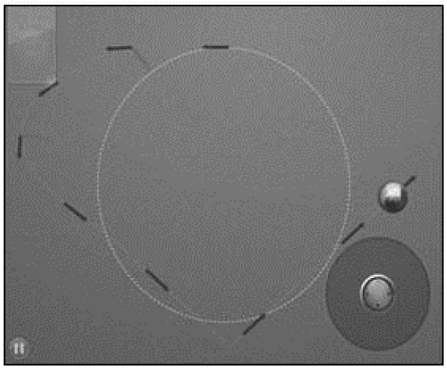
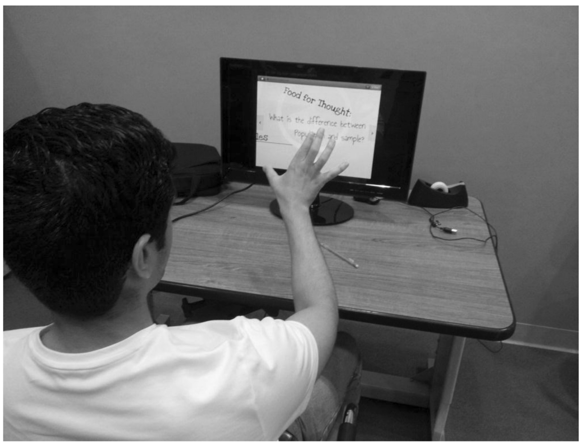


(c)

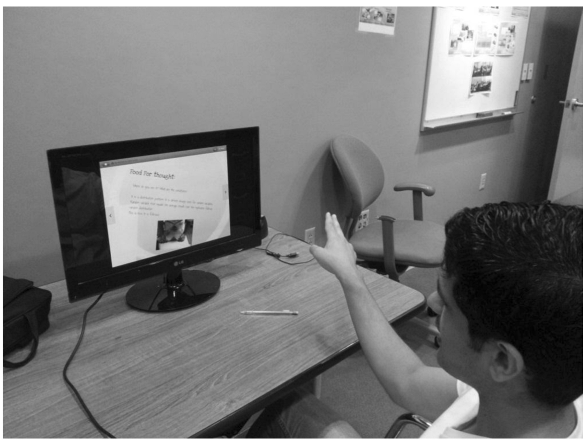
Fig. 4. (a) Concept of Centrifugal force on Powerpoint®. (b and c) Interactive touch interaction for learning the concept of centrifugal force.

test was 'Centrifugal Force'. The second part of the test was to learn using a centrifugal force game app from CircularMotion® which allowed test subjects to go through a didactic questionnaire. This questionnaire was followed by a game which forced test subjects to change the direction of applied tangential force to move a ball over a circular trajectory.

4.3.3 Multimodal Interaction (PowerPoint slides vs. Prezi over a screen with gesture interaction): In this test, test subjects were made to sit in front of a



(a)



(b)

Fig. 5. (a) Gesture interaction of pinch and zoom. (b) Gesture interaction of swipe.

screen with a webcam on. The screen had an HDMI connection from the iPad and the webcam was not in use. The gestures were observed and controlled by another controller personnel. It was done by the controller personnel sitting in the other room by observing the test subject actions through a live camera feed. The actual control of the iPad was with the controller. The test subjects were told that the webcam is capturing their gestures and a software is mapping these gestures into actual actions. Therefore, we had created a smoke and screen kind of a setting. Using this setting, test subjects were guided to take the test of PowerPoint course material vs. interactive Prezi material.

These tasks were primarily designed to go through a course content which was available in two different forms. First form was the regular PowerPoint slides and another form was interactive and graphically appealing Prezi^{TM}. Both the presentation styles included the training of two basic statistical concepts called the Central Limit Theorem and Normal Distribution. Using these two presentation styles, users were instructed to go through the first style of course content one after the other. The users were allowed to do the gestures in front of the screen to see the changes occurring in front of them. Users and their gestures were observed through a live feed video camera in the observation room.

5. Research findings

All of the test subjects which were tested had been exposed to classical classroom-instructor settings. From all of the tests conducted, the main observation was that no test subject was ready to replace the classroom-instructor setting with the technology. All of the test subjects appreciated the technology introduction but all of the votes were towards creation of a more compelling experience with hybrid education setting which has a blend of technology and classroom settings.

5.1 Response to Test 1: PowerPoint slides on iPad vs. interactive Prezi on iPad

Most of the test subjects liked the use of the smaller form factor device. They felt more control in handling the slides and presentations on the iPad. All of the test subjects felt a need of creating a real notebook feel by having a note taking area which could be saved as a digital copy with their handwriting. But yet no one was ready to replace the book-paper-pen feel. All of the test subjects felt a convenience of carrying all the classes in the form of digital content but all of them still preferred using pen and paper. No navigation issues were observed when the test subjects were going through the PowerPoint slides on iPad.

In the Prezi test, the test subjects are attracted towards the graphics and the random arrangement of the content with a systematic path connecting all the slides. Everyone appreciated the idea of manipulating every slide as an object and having freedom to view the content the way they needed. In the first hand look, all of the test subjects were attracted towards Prezi content. Later in the interview, the test subjects shared their affinity towards the use of classical classroom settings. The interactive content was preferred by all of the test subjects for the theoretical subjects and few concepts which can be explained by the definitions. Interactive nature of learning was more compelling to use for all the participants. Most of the test subjects had navigation issues when they were asked to access a particular concept. When the question about using this method of learning for math courses, all of the test subjects bent towards the classroom settings. Everyone appreciated the use of technology to assist them in learning but no test subject was ready to permanently replace the classroom settings with technology.

5.2 Response to Test 2: PowerPoint slides on iPad vs. iPad based game

The response of all of the test subjects was the same looking at the PowerPoint presentation to learn the concept of 'Centrifugal force' compared to the earlier math concept experience. Though use of different fonts, colors and highlights brought up some positive responses, there was no real excitement observed.

The concept of learning with the help of a game-based approach was introduced after the test subjects had interacted with the PowerPoint presentation. Game-based learning added a totally new excitement and a positive drive in the test subjects to actually learn the subject using this method. Though every test subject was concerned about learning any math intensive course with the help of a game, all of them suggested to learn the Physics courses using a practical approach like this one. The average experience of learning created by game based learning approach was very compelling for all of the test subjects. Game based learning was definitely preferred by all of the test subjects over learning with the help of PowerPoint.

5.3 Response to Test 3: Multimodal Interaction (PowerPoint slides vs. Prezi over a screen with gesture interaction)

Most of the students felt that the gesture recognition was fancy and did not feel much difference compared to using regular PowerPoint slides. Some of the technology lovers mentioned about fanciness about having a private learning center with gesture recognition. Most of the test subjects opted to learn in the regular classroom with the instructor and PowerPoint slides as a learning aid. It was definitely more appreciated than learning through PowerPoint on iPad or on a personal computer. No student appreciated use of this way of learning for math intensive courses.

In the content with Prezi, the test subjects were totally immersed, trying to move, zoom and pan the objects in the presentation. All of the test subjects wanted to learn theoretical subjects using this style of learning. Every test subject preferred use of Prezi with gestures over content with PowerPoint. But they also felt for the issue of navigation to go to a desired slide object when instructed. Given a choice of blend of classroom settings and multimodal interactions, every test subject was attracted towards the idea above all other tests.

From the interviews, it was also evident that, though students are learning in different educational settings, the students need classroom settings. They want to see the technology getting blended into the classes but not actually replacing the classes. The use of iPad as a notes' device is attractive but at the same time it is not fully accepted because it does not provide a necessary tackiness. Use of multimodal interactions was also an interesting way of learning according to all the test subjects. Most of the test subjects also highlighted the necessity of having a facility to revisit the classroom sessions which are saved as digital copies. The conclusion from all the tests was that the test subjects were keener towards seeing a blend of technology and classroom settings.

6. Understanding the impact of form factor on modality of the user

In developing new device classes, it is important to pay close attention to the physical characteristics of the device. These include ergonomics (feel, grip, balance and weight, and hold-position for different hand-sizes) as well as surface texture & screen vs. surround proportions. These design features quickly constrain other aspects of the solution, including: electronics, heat-dissipation, technology components feasibility, and so on. The investigator, in her previous research work on understanding the user preference for screen size vs. thickness vs. weight and aspect ratio, found that users typically shift towards their natural interaction mode. For example, when using a tablet type form factor they want to have a full keyboard if they are using it in the kitchen vs. having it close to their body when using it in a couch. Research should focus on identifying the different modalities based on the context of where, who, and how it is used. The multi-modal interaction needs to be intuitive and instantaneous.

7. Conclusion

Results indicate that multimodal technology introduction needs additional research for the integration into the didactic practices. Students still prefer the classroom-instructor interactions and multimodal interaction can support that non-intrusively. It is important to ensure that the integration is seamless and intuitive with minimum or no delay. The research findings will lead the future framework development that will be guided on the basis of the student preferences for the technology to be integrated. Based on the acceptance measurements for the content, our future research will also be headed towards developing interactive content with more student control and information support at the fingertips. We can also conclude that game-based illustrations are more interesting for the students to understand the concepts which can be explained by hands-on-training or simulations.

8. Future research

Based on the data collected through qualitative and quantitative methods, future will focus on developing a conceptual framework for intuitive multimodal interaction. Methodologies such as cognitive modeling have been used effectively to capture a decision-maker's mental process through techniques such as image theory, operator function model, or task analysis. They have been used successfully in areas such as AI modeling, robotics, and military-based applications. Cognitive modeling provides a framework for understanding user interaction in a system. In the case of this topic, it is important to specify what information the user will need, how it should be combined, and when it should be displayed. The research will focus on developing a model to simulate the different interaction modalities and would test it across the key usage areas. The usage concepts will be tested with the semi-working prototypes in a controlled environment to gather user requirements.

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