Using Tangible User Interfaces for Teaching Concepts of Internet of Things: Usability and Learning Effectiveness

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Abstract—Internet of Things (IoT) has recently gained significant attention due to the opportunities it is expected to bring within diverse fields. In order to meet industry needs, higher education institutions are integrating IoT-related courses into programmes. A key challenge to teach IoT concepts through conventional lectures is reduced interaction that can diminish student interests for learning this subject. An interaction technology that promotes interactivity while stimulating learning and creativity skills of students is Tangible User Interfaces (TUI). However, limited research has been undertaken to explore the use of TUI to teach IoT concepts and consequently, two fundamental aspects remain unexplored, notably usability and learning effectiveness. Whilst studying usability provides essential information on how pleasant it is to utilize such system, delving into learning effectiveness provides key information about whether TUI can help students to learn and understand concepts being taught. As part of this study, a TUI-based system was implemented following which evaluation was conducted involving 40 participants. Results showed a positive usability score although limitations were identified, based on which recommendations have been made towards improving usability of such solutions. Likewise, students who utilized the TUI-based system performed better in post-tests as compared to the control group.

Keywords— Internet of Things, Tangible User Interfaces, Usability, Learning Effectiveness, Teaching, Interaction.

1. INTRODUCTION

During recent years, Internet of Things (IoT) has gained much attention within both industrial and academic fields as this innovative technology is expected to offer numerous opportunities in various sectors including healthcare and energy (Kouicem, et al., 2018; Ammar, et al., 2018; Li, et al., 2015). IoT is a term used to describe an environment containing massive collection of physical items (referred as things) that are connected to the Internet and interacting autonomously (da Cruz, et al., 2018). With the emerging opportunities that IoT are bringing to the business world, it has become vital to prepare graduates with the necessary knowledge and skills (Ali, 2015). Taking cognizance of the needs of the industry, courses related to IoT are being provided. This include online courses on platforms such as Coursera and Udemy. However, the use of such platforms was found to reduce interaction among learners thereby preventing students from developing practical skills (Cavanagh, et al., 2015). In addition, within some Information Technology (IT) related programmes in higher education institutions (HEIs), IoT has been introduced within curriculum as core or optional modules (Aldowah, et al., 2017).

However, learning and teaching these concepts pose different challenges (Burd, et al., 2018). A key challenge is that teaching IoT concepts through the use of conventional lectures can reduce student interaction (Chilwant, 2012; Lei, et al., 2017), thus making it challenging for them to comprehend both the theoretical and technical aspects, thereby reducing interest and motivation for learning this subject (Hilas & Politis, 2014). Within such courses, it has been recommended that the curriculum includes practical activities that promote active participation in the learning process, while improving knowledge retention (Michael, 2006; Freeman, et al., 2014). Furthermore, IoT-related courses make use of various fast-changing and dynamic platforms as well as tools and devices that have the potential to become obsolete quickly (Burd, et al., 2018). Consequently, it is challenging for HEIs to provide students with access to all resources, thus hindering delivery of some lab sessions (Kortuem, et al., 2013). Moreover, many concepts crucial to IoT include coding and distributed systems are difficult to grasp (Lechelt, et al., 2016).

In order to address these challenges, an interaction technology that could potentially be used is Tangible User Interfaces (TUIs) (Schneider, et al., 2011). TUI is an innovative form of interface that enables end-users of systems to interact with the digital world via the manipulation of real-life physical objects instead of the traditional use of mouse and keyboard as input devices (Markova, et al., 2012). This interaction technology can address the discussed challenges since improved tangibility through manipulation of physical objects was found to enhance learning, decision-making and retention of concepts, among others (Ishii, 2008). Teaching using TUIs also means that expensive devices involved in practical sessions can be replaced with relevant models thereby reducing costs. Due to these advantages, TUI has gained attention in the educational fields during recent years (Shaer & Hornecker, 2010). Using TUIs to learn IoT concepts can enable a more interactive and physical display that would stimulate learning and creativity skills of students (Schneider, et al., 2011; Marshall, 2007).

Nevertheless, limited work has been undertaken involving the use of TUI to teach IoT concepts and consequently, different aspects are yet to be investigated in this area. Amongst, usability of such tools for teaching IoT concepts is yet to be explored. As a key part of user experience, usability is a quality attribute that evaluates how easy and pleasant it is to utilize features of a system (Nielsen, 2012). This quality attribute is essential to study since a recognised method to foster adoption and utilization of systems is through enhanced system usability (Lacka & Chong, 2016). In addition, usability assessment can provide insightful information on practices and design criteria that can be enhanced in order to improve user experience and adoption of systems. Another aspect that is essential to study is whether learning IoT concepts using TUIs is can effectively help students to learn and understand being taught. Exploring such criterion can provide relevant information on the extent to which this technology can boost the learning process towards potential integration in the labs for teaching IoT. Based on these gaps, the following research questions (RQ) become relevant to study:

- RQ1: What insights can be derived following usability assessment of a TUI-based system that teaches IoT concepts?
- RQ2: How does the use of a TUI-based system influence learning of IoT concepts?

As such, this paper explores the use of TUI for teaching IoT concepts while focusing on two aspects, notably, usability and learning effectiveness. The results revealed in this study are expected to help the research community, course designers and tutors comprehend the prospects of using tangible user interfaces for teaching and learning of IoT concepts. For instance, answering RQ1 can help to identify design-related best practices that designers and developers of TUI-based systems can take on board when creating such educational systems. Similarly, RQ2 aims at providing valuable information about whether the use of TUI-based system can effectively enhance knowledge on IoT concepts. Inspired from the findings of this study, educational solution providers could consider commercialisation prospects of this technology to innovate in teaching and learning, while also building-up on limitations identified within this study.

2. Review of Literature: Tangible User Interfaces and Learning

Over the years, technological innovations have enabled the development of distinct methods of interaction between human beings and the digital world using various techniques including the Graphical User Interfaces (GUIs) that involve interaction with devices such as mouse, trackpads or smartphone touchscreens, in addition to voice interfaces that entail speech recognition systems. Similarly, Tangible User Interfaces characterise the concept of intertwining digital technology into objects of the physical environment, and are represented by a graphical display that is coupled with physical objects that a user can interact with in order to provide feedback to a system (Ishii, 2008). A major goal in the development of TUI systems is to foster collaboration, learning, and design through the use of digital technology while at the same time taking advantages of human abilities to handle and control physical objects (Ishii, 2008). TUI-based systems adhere to three essential principles, where the first one involves computational coupling of tangible representations to digital information (Hornecker & Buur, 2006). In addition, tangible objects are embodiment of mechanisms for interactive control and finally, there is perceptual coupling of tangible and intangible representations. A popular example of a TUI application is the instrument board[1], where a set of markers are utilized within an interface to create audio and sound effects as the user interacts by changing position, movement and rotation of objects. These objects utilized in such TUI-based applications have certain symbols known as fiducial markers or fiducials, which are recognized by some software connected to cameras in order to distinguish between objects.

TUIs have shown the potential to be integrated into different teaching methods due to the increased engagement opportunities provided to students, which is determined by interaction between individuals and the environment (Wigfield & Guthrie, 2000; Cuendet, et al., 2015). This interaction technology has the shown the ability to foster cognitive learning through the manipulation of physical objects (Zhou, 2015), towards helping students to better comprehend concepts by active participation and engagement in the learning process (Schneider & Blikstein, 2015). Consequently, with active participation and student engagement, learning experience is enhanced, whereby also helping to improve student performance (Knight & Wood, 2005). However, even with the benefits in terms of teaching and learning, limited studies have been undertaken that relate to the exploration of the application of TUI for teaching IoT concepts.

Among the related works, a previous study investigated and developed a TUI-based system to teach abstract networking principles (De Raffaele, et al., 2016). Although results indicated learning improvement by almost 25% as compared to traditional techniques thus outlining the potential to teach abstract and complex concepts, this study focuses on student engagement towards augmenting familiarity with networking components and does not venture into teaching IoT concepts. Correspondingly, another study explored an IoT toolkit called Tiles (Mora, et al., 2017) that applies card-based design tools for the domain of IoT as tangible learning experiences. Even though the study deviates from the application of TUIs, it offers challenging questions to trigger creativity of end-users by using the concept of teaching and learning via tangible objects in the form of cards. In addition, another study investigated teaching and learning of Artificial Intelligence (AI) concepts using a tangible framework and proposed an interactive table-top design to help undergraduate students learn Artificial Neural Networks (De Raffaele, et al., 2018). Even though the study helped to improve understanding of such concepts, its focus was not related to IoT. As such, with limited works undertaken to explore the use of TUI to teach IoT concepts, this study becomes essential to conduct, and RQ1 and RQ2 given earlier become relevant to study. The methodology is discussed in the next section.

3. METHODOLOGY

In order to answer RQ1 and RQ2, a combination of the build and experimental methodologies are used in this study. An aggregation of these methodologies are common in Computer Science related research where similar approach has been utilized in different studies involving the development and use of prototypes to investigate research issues (Thanacoody, et al., 2019; Bekaroo, et al., 2018). The build research methodology entails development of an artefact and in this study, a TUI-based system is designed and implemented for the purpose of answering the two research questions. On the other hand, the experimental methodology is utilised in order to evaluate the new solution for the problems being addressed towards resolving RQ1 and RQ2. Based on these methodologies, the research process was conducted in three stages, notably, prototype design and implementation, preparation for data collection and evaluation. These phases are described as follows towards explaining how the two research questions were answered:

3.1 Prototype Design and Implementation

Owing to the lack of existing solutions that relate to teaching IoT concepts using tangible user interfaces, a TUI based system called IoT Tangible Trainer (IoTTT) was developed. IoTTT aims to teach IoT concepts to students who are part of undergraduate-level IT programmes. The system integrates features to enable students use various interactions in order to manipulate the TUI application and at the same time learn IoT concepts. In the process, learners are able to experiment with IoT application scenarios and creatively apply ideas while accessing further

[1] Jordà, S., Geiger, G., Kaltenbrunner, M. & Alonso, M., 2005. Reactable - MTG Music Technology Group (UPF). [Accessed 30/3/2019].
Available at: https://www.upf.edu/web/mtg/reactable

instructions, thus dwelling deeper into the IoT knowledge base. When designing the solution, particular attention was given to designing the curriculum of the IoT course to be provided. The learning content and structure was investigated and derived from a detailed analysis of existing courses offered by HEIs as well as reputed online learning platforms.

After scrutinized the identified courses, content selection was performed and, in this process, four common topics in IoT courses were chosen namely, introductory concepts, networking protocol, architecture, and application scenarios. The introduction of the concept was purely based on common norms that encompass everyday objects and the useful applications[2, 3] of the up rise in IoT. In addition, contents were included pertaining to networking and protocols that relate to implementation within the IoT environment and can aid in managing the processing capabilities, power management, storage and so on (Tan & Wang, 2010; Al-Sarawi, et al., 2017). Furthermore, different courses[4,5] integrate contents on IoT architecture to provide a detailed outlook on components that are crucial towards development of an IoT environment as well as the interconnection between each component. As such, IoT architecture was included in the curriculum of the IoT course and was structured into four different stages[6] that address the fundamentals of each layer/stage including the functions, availability, scalability and maintainability. Finally, application scenarios included to provide an understanding on where IoT is used and key scenarios included were based on setup of an Arduino-based system as well as automated home[7]. After the design phase, TUI-based solution was implemented where the sequence of tangible interfaces are as follows:

i. Startup and menu

Once the system is started, a welcome screen followed by a menu is provided to the end-user. The menu contains five options where the first four relate to learning about IoT and the fifth option provides information on the system (help and information on authors). For selecting menu items, the end-user has to rotate an arrow object and drag towards the chosen item, as illustrated in Figure 1.

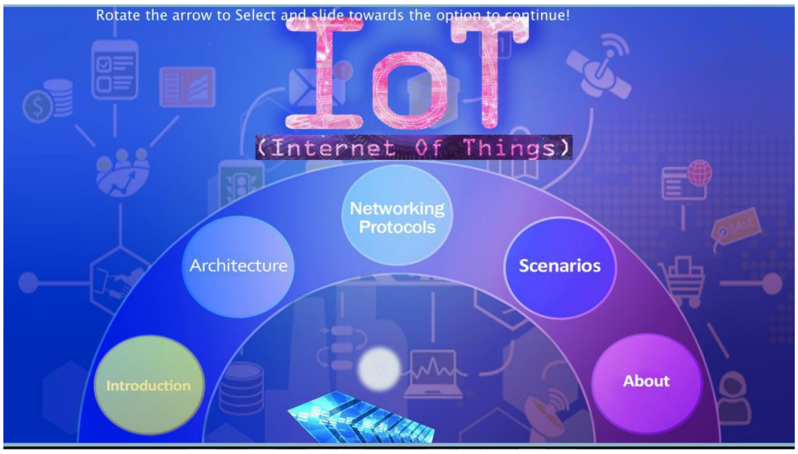

Figure 1 - Menu screen of IoTTT

ii. Teaching Introductory Concepts in IoTTT

Upon selecting the first option in the menu depicted in Figure 1, the tangible interface related to teaching introductory concepts of IoT is provided to the end user. To start with, an introduction to the IoT world is given in an

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[2] EdX, 2019. Introduction to the Internet of Things (IoT). [Accessed 30/3/2019].
Available at: https://www.edx.org/micromasters/curtinx-internet-of-things-iot#courses
[3] Coursera, 2019. Introduction to the Internet of Things and Embedded Systems. [Accessed 7/3/2019].
Available at: https://www.coursera.org/learn/iot?specialization=iot
[4] University of Bradford, 2019. Internet of Things (IoT). [Accessed 2/7/2019]
Available at: https://www.bradford.ac.uk/courses/pg/internet-of-things/
[5]Coursera, 2019. Architecting Smart IoT Devices. [Accessed 7/2/2019].
Available at: https://www.coursera.org/learn/iot-architecture
[6] Stokes, P., 2018. 4 Stages of IoT architecture explained in simple words. [Accessed 3/7/2019].
Available at: https://medium.com/datadriveninvestor/4-stages-of-iot-architecture-explained-in-simple-words-b2ea8b4f777f
[7] Udemy, 2019. Internet of Things (IoT) - The Mega Course | Udemy. [Accessed 2/7/2019].
Available at: https://www.udemy.com/internet-of-things-the-mega-course/

interactive manner. The introduction section is divided into three parts where the first part introduces the IoT concept following which an interactive application scenario is provided to the end user as shown in Figure 2. In this application, the end-user has to manipulate the brightness of a phone using a knob and at the same time is exposed to concepts regarding the use of sensors in daily life (Beigl, et al., 2004). In the same interface, the second interaction illustrates the application of modern sensor based the FaceID feature on the iPhone where the user is able to use one out of three provided faces for biometric facial recognition. The last interaction involves the use of accelerometer/gyroscope sensors and their relevance are explained. After this application, a demonstration of the application of IoT within a healthcare system is given where the end user interacts using different sensors including the pulse oximeter, respiratory sensor and temperature sensor, as illustrated in Figure 3.

Figure 2- Introduction to Internet of Things concept

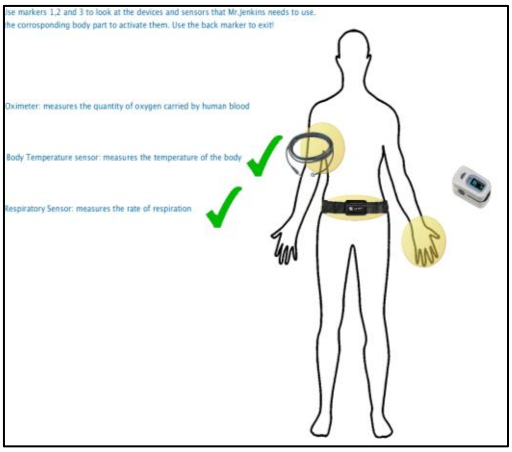

Figure 3- IoT based HealthCare system Screen

iii. IoT architecture concepts

This option opens an interactive screen to display information panels using a tangible scroll gesture. The information provided is based on curriculum content design discussed earlier (Abdmeziem, et al., 2016). This interface provides key stages of IoT development, represented by sensors, actuators, data aggregation, Edge IT and cloud computing. Each of these stages contain information relevant to the technologies and their functions within the stages during which the user has to interact with devices present, as illustrated in Figure 4.

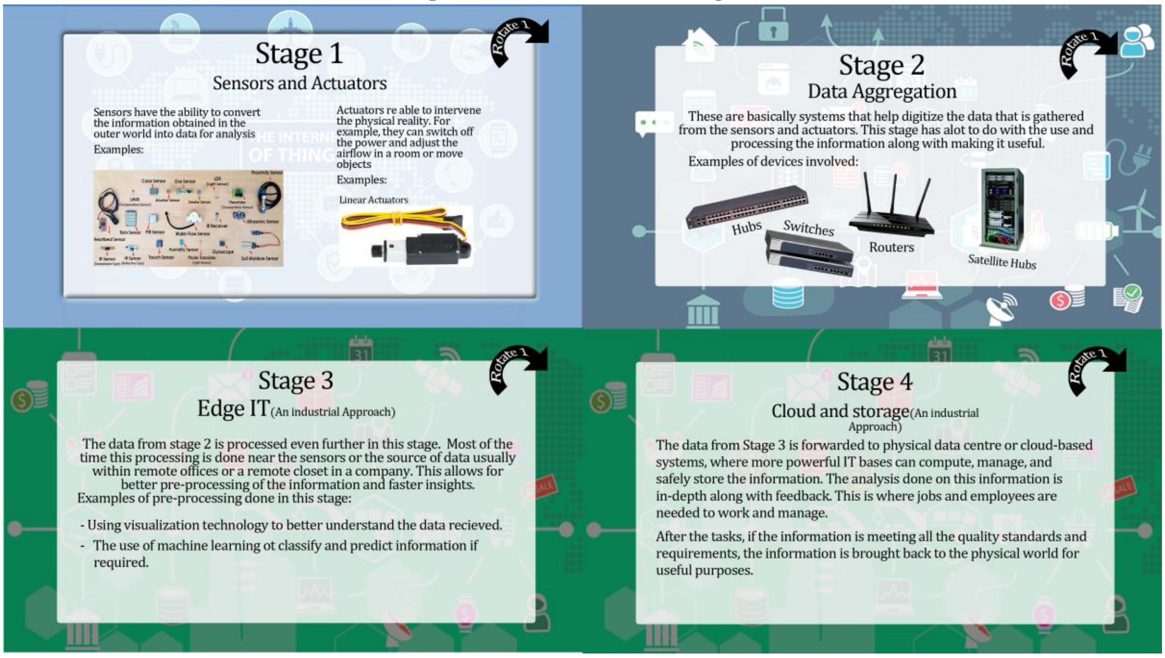

Figure 4 - IoT Architecture in IoTTT

iv. Networking Protocols

Similar to interaction in the previous section, this part of the TUI-based system teaches networking and networking protocols in the context of IoT using multimedia at the same time. The importance of networking protocols[8] relies on their usage within the IoT environment as this technology depends on networks, especially the Internet so as to operate. The tangible interface in this section (as depicted in Figure 5) provides information on five key IoT protocols, namely, Bluetooth, ZigBee and near-field communication (NFC), Message Queuing Telemetry Transport (MQTT) and Constrained Application Protocol (CoAP).

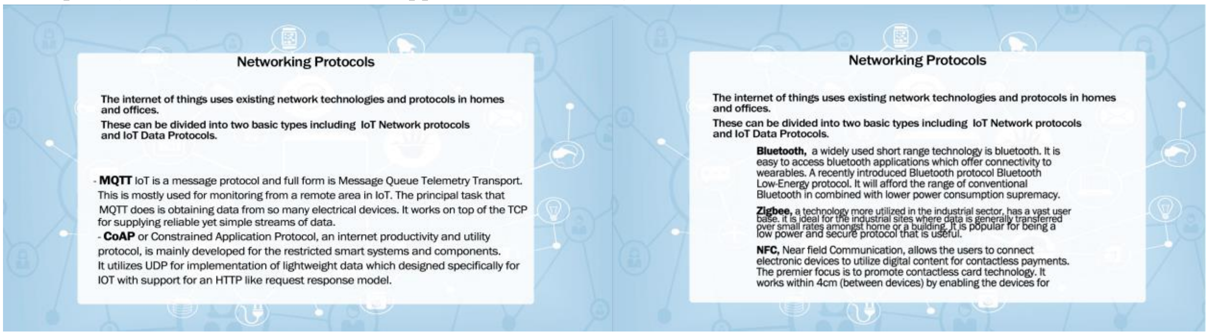

Figure 5 - Networking Protocols Section

v. IoT Application Scenarios

In this section, real life scenarios and applications of IoT is provided. Two areas of experience are provided, namely, home automation or Arduino configuration. The former allows the user to experience a secure IoT-based home that provides security and accessibility allowing users to interact and engage within it. The importance of this scenario relies on the fact that home automation is acquiring increased attention and the benefits of such a system is apparent (Baraka, et al., 2013). In this scenario (illustrated in Figure 6), a security-related feature is provided where the camera detects a user's character object in front of the camera after which the door unlocks. In this process, the mobile phone of the user can be utilized to activate/deactivate appliances at home. The Arduino[9] is an important component that forms part of the IoT learning process and is useful for a variety of personal as well as major projects, and is hence the basis of the second scenario as shown in Figure 7. In this scenario, end-users are able to connect sensors to the board through tangible objects and obtain information on functions and uses of the sensors with the Arduino. The sensors present are, the Ultrasonic distance sensor, the Sound sensor and the PIR Motion Sensor.

Figure 6 - Home Automation Scenario

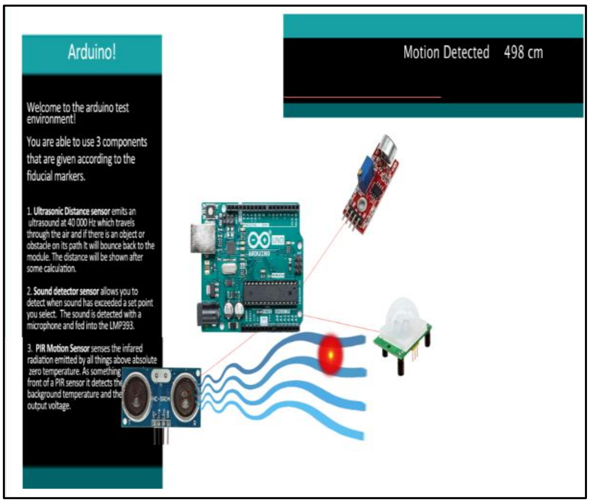

Figure 7 – Arduino Configuration Scenario

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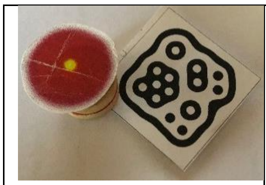
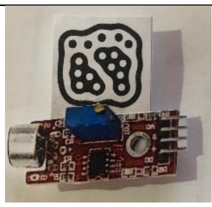
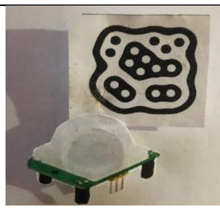
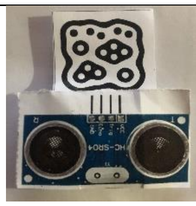
[8] Stanford, 2019. Introduction to Internet of Things. [Accessed 30/3/2019]
Available at: https://online.stanford.edu/courses/xee100-introduction-internet-things

[9] Arduino, 2019. Arduino - Introduction. [Accessed 7/2/2019].
Available at: https://www.arduino.cc/en/Guide/Introduction

In IoTTT, three key forms of user interaction are present and for this, the framework proposed in a previous study was implemented (Koleva, et al., 2003). The first form of interaction involves directly choosing and placing physical objects on the monitor. Secondly, the end user can move and position objects on specific locations and finally, objects can be rotated whereby angles are changed. The same framework was utilized to create the tangible objects while attaching a unique fiducial on each physical object. A list of objects used within IoTTT is given in Table 1.

Table 1 - Representation of physical objects with attached markers

 Red Orb Pointer	 Rotation Object	 Brightness Knob	 Pulse Oximeter	 Temperature Sensor
 Respiratory Sensor	 Smartphone	 Figure 1	 Figure 2	 Face 1
 Face 2	 Face 3	 Sound sensor	 Motion Sensor	 Distance Sensor
 Menu Rotation Selector	 Common Back Object			

For developing the TUI-based system, Agile software development methodology was used as it creates the basis for an improved system in every iteration (Erickson, et al., 2005). In terms of software, Processing and ReacTIVision were utilized. Processing is a Java-based software sketchbook and language that has been implemented for allowing to program in a visual context. On the other hand, ReacTIVision enables movement tracking of tangible objects that have been marked with a set of pre-defined fiducial. This tool detects different characteristics (e.g. change of location or angle) of fiducials using images obtained from a webcam. In addition, required visuals were created using Photoshop and for sound editing, Audacity was used. In addition, the TUIO protocol was utilized for communication between the application and the tangible table-top controller (Kaltenbrunner, et al., 2005).

As for the hardware setup, an adapted version of the architecture used in a previous research involving TUI was utilized due to its relevance to this study (Waldner, et al., 2006). This entailed the use of a screen, webcam, tripod in addition to a light source. The screen is used to display the contents of IoTTT while providing digital feedback to the end-user. It is attached to a computer connected via the HDMI cable to the main system, where the computer is meant to run IoTTT through Processing and ReacTIVision. A downward-facing webcam is also connected to the computer and mounted through a tripod. This device enables the capture of the markers glued to the physical objects (as in Table 1). In addition, a light source or flashlight is used to ensure consistent light intensity while avoiding to disrupt the view of the camera. Also, the light source is used for negating the effects of the screen which causes some markers to be undetected as the intensity of the screen interferes. A representation of the physical setup of the system is given in Figure 8.

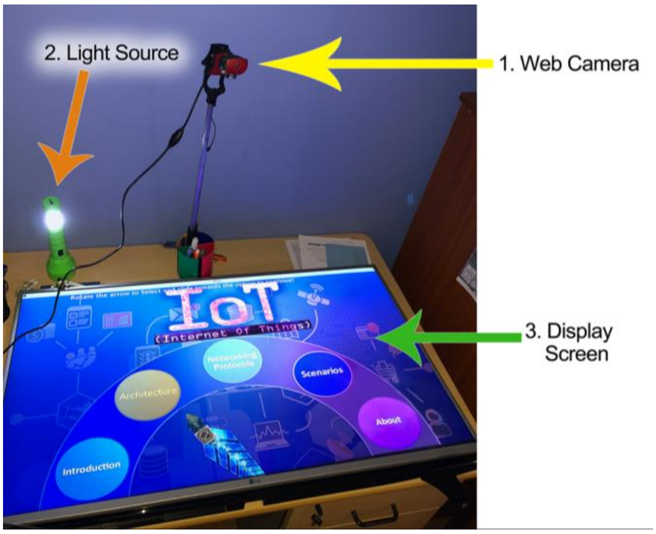


Figure 8 - Physical Setup of System

3.2 Using IoTTT in the Teaching and Learning Process

In order to implement IoTTT for teaching and learning IoT-related concepts, the physical setup illustrated in Figure 8 is replicated within labs with a single setup of the system utilized by students individually or in small groups of three. Whilst the use of the system by students individually increases per student utilization time, it reduces collaboration and can be costly to implement for larger cohorts. On the other hand, having more students to utilize a single setup can cause distractions while also reducing per student utilization time as different students also take varying amount of time to acquire knowledge. As such, decision on the number of students per setup is left to the teacher who can decide based on resources available and cohort size. The use of TUI-based system for teaching and learning IoT-related concepts promotes the constructivist and sociocultural theories of learning instead of the behaviourist theory of learning. When interacting with IoTTT, students learn IoT concepts by exploration while also making use of the physical objects depicted in Table 1. This also means that teachers are expected to only be facilitators of the learning process. In other words, rather than conducting presentations to teach IoT related concepts, teachers are expected to assist students in utilizing IoTTT systems within labs and answer key queries during sessions.

3.3 Preparation for Data Collection

In this stage, the approach used for investigating the usability (RQ1) and learning effectiveness (RQ2) was planned. For the former, a usability assessment was planned and for this, Nielsen's principles were utilized due to its relevance and popularity for usability assessment (Ramrecha, et al., 2017). As per Nielsen, usability consists of different attributes where among them, memorability was not considered since measuring this attribute necessitates use of the system at least twice, which was beyond scope of this study (Nielsen, 2012). The usability attributes assessed were:

- *Learnability*: This attribute relates to the extent to which users of a system feel that it is effort-free to utilize the system.

- *Efficiency:* This attribute measures how quickly end-users can perform tasks once having learnt about the design of a system.
- *Errors*: This attribute relates to the type of errors encountered if any and how easy it is to recover from any errors.
- *Satisfaction*: This attribute relates to how pleasant it is to utilize the design of a system. It is about freedom from discomfort and positive attitudes towards using a system.

Whilst the above criteria altogether evaluate the usability of a system, different measured items are present for each quality attribute (Nielsen, 1994). For compiling the measured items for each attribute, previous studies that applied the same model for usability evaluation were considered and are as listed in Table 2 (Hussain, et al., 2018; Nurhudatiana, et al., 2018). For evaluating each measured item, the Likert-5 scale was used where 1 represented strongly disagree and 5 meant strongly agree. Subsequently, the Nielsen's Usability Heuristics (NUH) questionnaire was prepared as data collection instrument for RQ1 based on the measured items as listed in Table 2.

Table 2 – Usability Evaluation Criteria

Usability Attribute	Measured Item
Perceived Learnability	L1 - It was easy to learn to use the TUI based system for the first time
	L2 - I was able to learn to utilize the TUI application quickly
	L3 - I could use the application without referring to a user guide.
	L4 - Most users will be able to learn to use the TUI system without any issues.
Perceived Efficiency	E1 - The learning experience could be completed quickly.
	E2 - The learning experience was efficient.
	E3 - l was able to use the TUI application smoothly.
Errors	R1 - No errors were encountered when using the TUI system.
	R2 - The TUI system could still be used even after encountering small errors
	R3 - Recovering from any errors was easy.
	R4 - No critical error was encountered that stopped me from completing the learning experience.
Perceived Satisfaction	S1 - I am satisfied with the ease of learning to use the TUI system.
	S2 - I am satisfied with the ease of use of the TUI system.
	S3 - I am satisfied with the amount of time it took to complete the learning task given.
	S4 - I am satisfied with the design and overall look of the TUI system.
	S5 - Overall, I am satisfied with the TUI system.

As for evaluating learning effectiveness (RQ2), learning assessment was planned where a common approach is by conducting pre-tests and post-tests (Lundberg, et al., 1980; Ball & Blachman, 1991). The pre-test is conducted before the teaching or learning approach in order to assess level of knowledge in order to provide an accurate understanding of awareness before going through the learning process. On the other hand, post-test is conducted after conducting learning sessions to assess how effectively concepts were learnt. Similar approach has been utilized in previous studies involving learning assessment involving use of TUI (De Raffaele, et al., 2016; De Raffaele, et al., 2018). In this endeavour, a direct comparison of TUI-based learning against traditional lecture-based teaching (using presentation slides and verbal speech as the mode of transmission) was targeted. As such, focus in this stage was to prepare the presentation slides to reflect same contents as in the TUI application. In addition to the presentation slides, questionnaires for the pre-utilization test and post-utilization test (or post-test) were prepared. Two multiple-choice questionnaires were drafted, each containing ten questions relevant to the concepts taught. The post-test contained different questions of a level higher in difficulty, but still conforming to the curriculum of the courses provided. The multiple-choice questions (MCQs) part of the two questionnaires are given in Table 3, and were used to collect data pertaining to RQ2.

Table 3 - Multiple Choice Questions for Pre-Test and Post-Test

No.	Pre-Test Questions	Answers	Post-Test Questions	Answers
Q1.	________ in Internet of Things is one of the key requirements and important for many projects.	a) Things b) Cables c) Magnets d) Connectivity	A device that takes electrical input and turns it into physical actions, like a motor or hydraulic system is also known as ____________.	a) Sensors b) Things c) an Actuator d) Wi-Fi module
Q2.	________ provide the means to reflect awareness of the physical world and people in IoT.	a) Sensors b) Actuators c) Things d) Connectivity	An elderly person, would greatly benefit from the use of a _________.	a) Voice Home assistant b) Amazon Delivery Services c) Vehicle Tracking d) Data aggregation
Q3.	________ detects orientation in a smartphone.	a) Proximity Sensor b) Accelerometer c) Internet d) Things	In an industrial setting, in-depth analysis is done to data in ____________:	a) Laptops b) Remote Office c) Edge IT d) Cloud based systems
Q4.	Internet of things is the ________ of computing devices embedded in everyday objects, enabling them to send and receive data.	a) Security b) Privacy c) Interconnection d) Sensors	_________ detects whether sound has exceeded a threshold value using a microphone in the chip. It can detect the sound intensity in ambient environment.	a) Earphones b) Sound Detection sensor c) Vibration Sensor d) Camera module
Q5.	__________ layer is the communication layer that can connects the IoT devices with Wide Area Networks.	a) Internet layer b)Application layer c) Sensor layer d) Network layer	A communication protocol which is utilized more in the industrial sector to create efficient networks is ______:	a) Bluetooth b) NFC c) RFID d) Zigbee
Q6.	__________ detects the presence of nearby objects.	a) Touch sensor b) Proximity sensor c) Gyroscope d) Internet	Which are important protocols for IoT? (2 options)	a) HTTP b) MQTT c) XMPP d) CoAP
Q7.	__________ is a widely used short ranged technology offering connectivity to many devices. Including IoT based wearables.	a) Cellular b) Internet c) Zigbee d) Bluetooth	NFC operates at very long distances.	a) True b) False
Q8.	Home automation projects with IoT based devices cannot be used over the internet.	a) True b) False	IoT objects can be activated and utilized through Smartphones?	a) True b) False
Q9.	An example of a known microcontroller board, which can be useful for an IoT project for home automation is ____________.	a) Arduino b) Keyboard c) Router d) Bluetooth	_______ is where data is collected and digitized from sensors, making it useful.	a) Data aggregation b) Machine learning c) Actuators d) Cloud Storage
Q10.	Whilst elderly care being a major concern, can IoT potentially benefit and improve their lifestyle?	a) Yes b) No c) Not Sure	_________ is where IoT is designed to be used on a single user or family.	a) Personal IoT b) Commercial IoT c) Industrial IoT

As target audience, since teaching IoT concepts is relevant to IT related programmes, undergraduate students from such programmes were targeted. The minimum number of users recommended for such quantitative studies with statistical accuracy is 20 (Nielsen, 2006), especially for such usability studies and hence, this population size was targeted. Initially, with the aid of four volunteering students for the lecture and TUI-based approaches, a pilot study was conducted which helped to finalise the questionnaires and evaluation procedures.

3.4 Evaluation

For the data collection phase, the study population was split into two groups of 20 students, for comparing the conventional lecture and TUI-based learning. The participants were first and second-year students enrolled in BSc (Hons.) Information Technology and BSc (Hons.) Computer Science (Systems Engineering) courses at Middlesex University Mauritius on a full-time basis. For the lecture-based approach, 4 small groups of 5 students were gathered on different schedules, especially after classes. The groups were briefed on the purpose of the study and informed consent was sought from participants to participate in the study. Subsequently, the pre-test was conducted with the participants, who were given 20 minutes to complete the test, after which scripts were collected for marking. Then, the lecture was conducted with each group using the prepared slides and during the session, questions raised by the audience were addressed. After the one-hour session including question and answers, the post-test was conducted using similar process as the pre-test. The same process was repeated with the other three groups to complete the lecture-based approach.

Similar process was involved for the second part of the evaluation involving learning IoT concepts but this time, use of the TUI prototype was involved. After briefing the participants on the purpose of the research, informed consent was sought following which, the small group of students had to do the pre-test. Then, each student had to individually use IoTTT fully by going through all contents and scenarios available in the prototype. The same application was deployed on five computers while making use of the same physical setup discussed above and with same set of physical objects given to the participants in order to speed up the evaluation process. Also, the physical objects were placed on a guide sheet which included a reference to each of them. While using IoTTT, participants had to individually interact with the system and manipulate respective physical objects in the system to progress with the learning process. Guidance was only provided in case of support needed. Such approach was implemented in order to gather appropriate feedback regarding usability of the prototype. On average, it took 1 hour 15 minutes for the participants to complete the scenarios, following which there was a short question and answers sessions for any clarifications needed on concepts. Finally, the post-test was conducted using similar process as the pre-test and then the participants had to fill-in the usability questionnaire. At the end of the test, each participant was thanked individually and de. The same process was repeated with the other three groups and each time, the application was reset while re-arranging the physical objects containing the fiducials.

Overall, the data collection process lasted two weeks in order due to varied availability of participants. The final stage of evaluation involved marking of all scripts and analysing the data. After gathering and sorting all the questionnaires by participant IDs, results were analysed using SPSS. Using this tool, results were translated to the form of visual graphs and percentages to determine the results of this study. Furthermore, the Cronbach's Alpha computed for the variables was 0.83 thereby depicting that the collected data was consistent and reliable for further analysis.

4. Results and Discussions

Using the methodology defined in the previous section, findings of the study are presented as follows where insights on usability (RQ1) are provided before enlightening on learning effectiveness (RQ2):

4.1 Nielsen's Usability Heuristics

The results of the NUH questionnaire are split into four attributes and these are discussed in the following sub-sections towards answering RQ1. In addition, strengths and weaknesses of the IoTTT are also discussed.

- ***Perceived Learnability***

Data analysis revealed that 75.0% of the students agreed that it was easy to learn to use IoTTT for the first time. This is a positive finding given that all participants were exposed to a TUI-based system for the first time. However, 10.0% of participants also disagreed about L1 and this was particularly because of the use of similar objects (e.g. Face and Figures in Table 1) which caused some confusions according to these users. To address such confusions, more insightful information could have been provided, either by labelling objects further or by adding complementary information on screen. Moreover, participants also mentioned that the inclusion of voice-based feedback and animations helped to complement the learning process. This is also why a positive score was obtained for L3 where 75.0% agreed or strongly agreed about the ability to use the application without referring to a user guide.

On the other hand, a relatively smaller group of participants agreed or strongly agreed to be able to learn to utilize the TUI application quickly (L3). 40.0% of participants were neutral about this statement where some of them even described it as time consuming since some navigation and detection issues rendered the process slower. Furthermore, some users had the tendency to cover the fiducials at times with their hands when manipulating the physical objects, whereby preventing the webcam to effectively detect fiducial markers. Finally, 65.0% of students agreed that others could learn without issues, while 25.0% stayed neutral and 10.0% disagreed, which indicated that although users could possibly learn, it is possible that some people would need assistance to effectively complete the learning process while using such interface. Overall, an average score of 3.9 was obtained and results are given in Table 4.

Table 4 - Learnability of IoTTT

Attribute	***Strongly Disagree***	***Disagree***	***Neutral***	***Agree***	***Strongly Agree***	***Average Score***
L1 - It was easy to learn to use the TUI based system for the first time	0.0%	10.0%	15.0%	50.0%	25.0%	3.9
L2 - I was able to learn to utilize the TUI application quickly	0.0%	5.0%	40.0%	20.0%	35.0%	3.9
L3 - I could use the application without referring to a user guide.	0.0%	10.0%	15.0%	50.0%	25.0%	3.9
L4 - Many users will be able to learn to use the TUI system without any underlying issues.	0.0%	10.0%	25.0%	55.0%	10.0%	3.7

- ***Perceived Efficiency Results***

As shown in Table 5, 60.0% of students agreed that the prototype made efficient use of physical objects for navigation and interaction. However, 35.0% were neutral about this statement and this was because this group felt that the same objects could be used for the figures and faces (as shown in Table 1). Moreover, according to three participants, more standard size of objects could have been selected as some objects were bigger than others, thus affecting interaction. Slightly more positive result was obtained for E3 where 60.0% of participants either agreed or strongly agreed that the application ran smoothly and efficiently throughout. This was due to the performant computers utilized during the experiment. However, according to the remaining participants, some lagging occurred when using multiple objects and at times due to animations, or when multiple libraries are used in the Processing environment. More significantly, 85% of participants perceived to agree or strongly agree to be able to have completed the learning experience efficiently and overall, an average score of 3.9 was obtained for this attribute.

Table 5 – Perceived Efficiency of IoTTT

Attribute	***Strongly Disagree***	***Disagree***	***Neutral***	***Agree***	***Strongly Agree***	***Average Score***
E1 – The prototype made efficient use of the physical objects.	0.0%	5.0%	35.0%	50.0%	10.0%	3.7
E2 - The learning experience was efficiently completed.	0.0%	5.0%	10.0%	60.0%	25.0%	4.1
E3 – The application ran smoothly and efficiently throughout.	0.0%	5.0%	35.0%	40.0%	20.0%	3.8

- ***Errors***

Errors relates to any type of bugs encountered when running the system and about how easy it was to recover from any errors. Results for this attribute is given in Table 6, where 60.0% of participants agreed or strongly agreed that no bugs were found during the use of IoTTT (R1). However, the remaining 40% were neutral or disagreed with this statement particularly due to the issues with fiducial detection and lagging as discussed earlier. Moreover, even with the lagging issues, 75.0% of the students agreed that IoTTT could be used even after errors were encountered and that recovery was easy (R2 and R3). Consequently, 85% of students agreed or strongly agreed that no critical error was encountered which stopped participants from completing the learning experience (R4). Overall, an average score of 4.0 was received for this attribute.

Table 6 – Errors

Attribute	***Strongly Disagree***	***Disagree***	***Neutral***	***Agree***	***Strongly Agree***	***Average Score***
R1 - No errors were encountered when using the TUI system.	5.0%	10.0%	25.0%	35.0%	25.0%	3.7
R2 - The TUI system could still be used even after encountering small errors.	0.0%	5.0%	20.0%	50.0%	25.0%	4.0
R3 - Recovering from any errors was easy.	0.0%	0.0%	25.0%	45.0%	30.0%	4.0
R4 - No critical error was encountered which stopped me from completing the learning experience.	0.0%	0.0%	15.0%	35.0%	50.0%	4.4

- ***Perceived Satisfaction***

From Table 7, it could be found that 70.0% of participants agreed or strongly agreed to be satisfied with the learning content of the system (S1) and this was because of the interactive scenarios according to the end-users. There was mention that the interactive scenarios helped active learning process whereby helping to understand practical applications of key concepts. Likewise, similar response was received for S2 where participants were mostly satisfied with the ease of use of the TUI system and the key reasons pertained to the use of a combination of text, voice and animations for providing feedback to use the system. One participant found it a bit difficult to interact with the system due to confusions between objects as highlighted earlier. Moreover, a relatively lower score was obtained for S3 where only 35.0% of participants agreed or strongly agreed to be satisfied with the amount of time it took to complete the all tasks in the application. This was because the participants were utilizing such interaction technology for the first time where it took time to decide which object to utilize, how to manipulate them, while learning at the same time.

On the other hand, 80% of participants agreed or strongly agreed to be satisfied with the design and overall look of the TUI system (S4). The remaining participants who were neutral highlighted some inconsistency with the design of the interface that changed the way objects need to be manipulated, thus also increasing duration of use. Overall, 80% of the participants were satisfied with the system (S5). Only one participant disagreed with this statement and this was because the student mentioned that the system could be made more dynamic where learning scenarios could be changed every time a user is utilizing the system in order to improve intention for future use of the system. Overall, a mean score of 3.8 was obtained for this attribute thus showing general satisfaction of the end users.

Table 7 – Perceived Satisfaction

Attribute	***Strongly Disagree***	***Disagree***	***Neutral***	***Agree***	***Strongly Agree***	***Average Score***
S1 - I am satisfied with the learning content of the TUI system.	0.0%	5.0%	25.0%	35.0%	35.0%	3.5
S2 - I am satisfied with the ease of use of the TUI system.	0.0%	5.0%	25.0%	50.0%	20.0%	3.9
S3 - I am satisfied with the amount of time it took to complete the all tasks in the application.	10.0%	20.0%	35.0%	20.0%	15.0%	3.1
S4 - I am satisfied with the design and overall look of the TUI system.	0.0%	0.0%	20.0%	40.0%	40.0%	4.2
S5 - Overall, I am satisfied with the TUI system	0.0%	5.0%	15.0%	45.0%	35.0%	4.1

- ***Overall Usability of IoTTT***

The investigated criteria collectively add up to a positive score of 3.9 for the usability (RQ1) of the TUI-based system and this implies an acceptable system according to the participants. Among the constructs, errors had the highest average score of 4.0 due to the lack of critical errors that could affect the system drastically and overcoming errors encountered could be swiftly done. Such capabilities of the application could be deemed having positive standing and possess a level of robustness. The lowest score among the perceived criteria point to the satisfaction of the students. Satisfaction encompasses the comfort, simplicity, time saving and effectiveness of the system (Nielsen, 2012) had the lowest mean score of 3.8. This was particularly due to the amount of time it took to complete the tasks within the application. Otherwise, the rest of the attributes under this criterion maintained relatively high scores with reduced variance. The distribution of the mean scores is given in Figure 9, based on the same Likert scale ranging between 1 and 5.

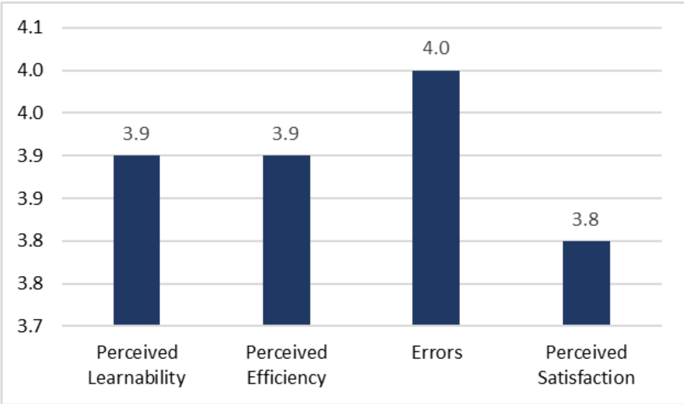


Figure 9 - Usability Scores

When assessing usability of the proposed solution, different issues were unveiled and recommendations are hereby proposed towards improving such systems. These recommendations could also be considered by the research community and developers of TUI-based systems to enhance their designs.

- *Standard size of objects*

During the experiment, some participants showed concerns when having to manipulate objects due to their varying sizes. Some objects were relatively bigger (e.g. faces and figures) than others (e.g. sensors) where different sizes of fiducials were attached. Consequently, it was challenging to manipulate objects, especially when rotating or moving objects while ensuring that fiducials remained uncovered for effective detection by the webcam. As such, standard sized objects are recommended to make it easier for users to grab without hiding the fiducial markers.

- *Optimum number of objects for interaction*

Similarly, an increased number of objects could consume more time for users to decide and select which one(s) to use. A solution would be to plan an optimum number of physical objects to be used when designing the solution, whereby eliminating unneeded objects.

- *Complementary instructions on interaction*

In some cases, users were confused about which objects to utilize for interaction and to address this issue, complementary on-screen or voice-related information can be provided to the end user. In the guides provided to the user, an image of the object to be used could be displayed in addition to details on the action that needs to be performed. This would be particularly useful for navigation and controls, especially for users who are new to such interfaces and interaction.

- *Shift to marker-less based systems*

As discussed earlier, end-users had the tendency to cover fiducial markers on top of objects with their hands when interacting with the system thereby preventing the webcam to effectively detect objects. A solution would be marker-less based solutions although developing such systems have their own complexities in terms of implementation coupled with limitations of existing development platforms.

4.2 Learning Effectiveness of TUI

In order to assess the effectiveness of TUI for learning IoT concepts (RQ2), pre-test and post-tests were conducted as conferred earlier. The computed Chi-Square test yielded a p-value of 0.01 at a level of significance of 5% which highlights a significant association between type of learning approach and student performance. The compiled results for lecture and TUI-based learning are given in Figure 10 and Figure 12 respectively. For both types of learning, a mean score of 6.40 was obtained in the pre-tests and this implies that candidates had practically the same knowledge about IoT before the learning sessions. Among the 20 students who attempted the lecture-based approach, 8 participants (representing 40%) had a higher score in the post-test as compared to the pre-test.

On the other hand, the pre-test scores for 7 students (34%) were better than their post-test marks. This could be due to the relatively low percentage of correct answers provided for some questions in the post-test where for instance, only 20% of lecture-based students were able to correctly attempt Q3 and 45% of students correctly answered Q6 and Q9 respectively, as shown in Figure 11. In the same figure, it could however be noticed that each question was correctly answered by at least four students in the post-test, where only Q10 of the post-test was correctly answered by 100% of students. The comparison between pre-test and post- test results for lecture-based approach showed an increase of only 0.05 marks on average in the overall grades of students as summarized in Figure 13. This signifies a minimal growth in terms of knowledge gain for this type of learning, thus implying that the lecture-based approach might not be most effective for learning of IoT concepts based on findings in this study.

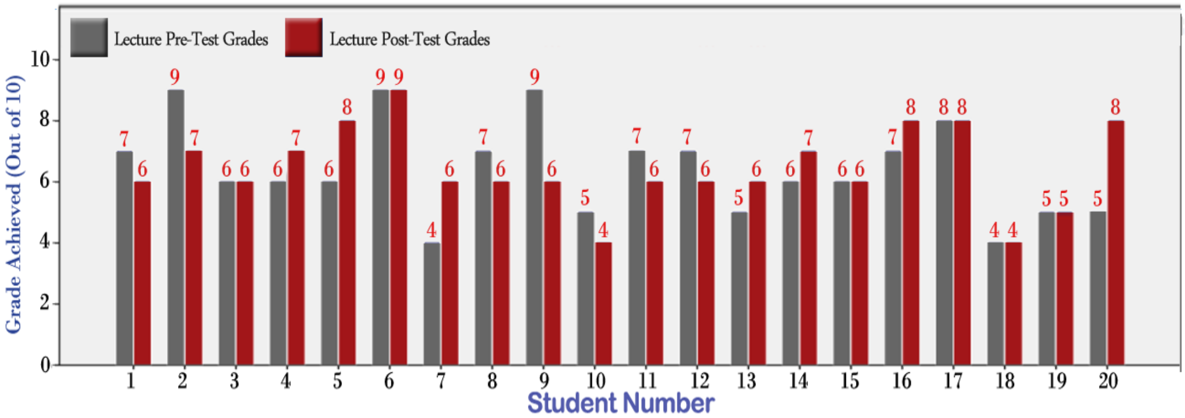


Figure 10 - Student performance distribution in Lecture-based sessions

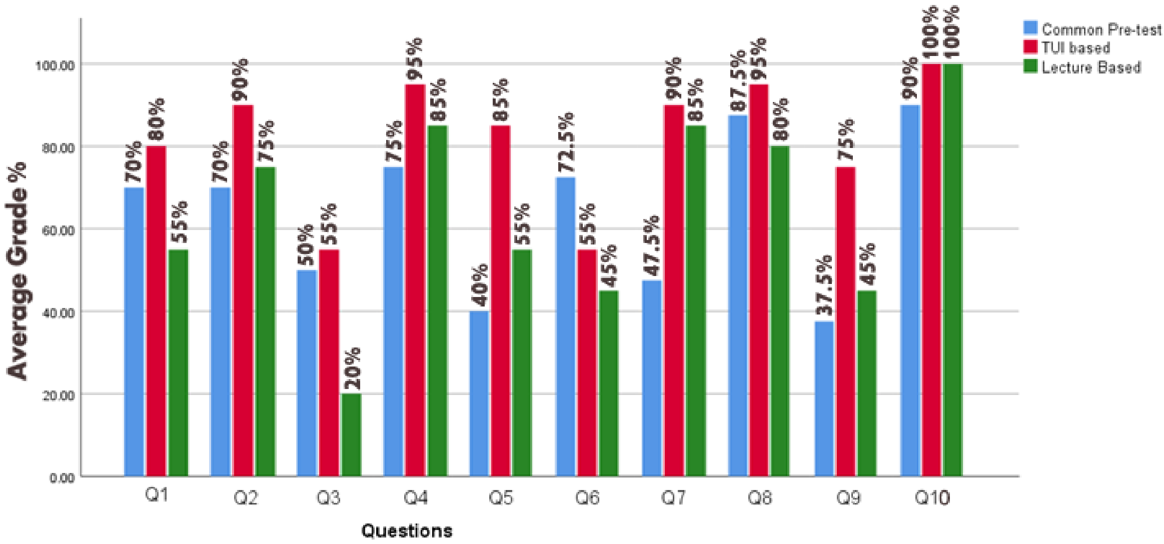


Figure 11 – Performance across questions

As for learning through the TUI-based prototype, a significant improvement in student performance within post-test results was noted as compared to pre-tests. Out of the 20 students who utilized the TUI-based system, 16 participants (representing 80%) had a higher score in the post-test as compared to the pre-test and this statistic is twice higher than students who attended the IoT lecture. For only 2 students, performance in pre-test was better than post-test as shown in Figure 12, which is a relatively smaller percentage as compared to the group who attended the lecture.

Furthermore, as shown in Figure 11, performance in the post-tests for students who utilized the TUI-based system was better as compared to the control group for all questions, besides Q10 which yielded equal performance in both categories of learning. Overall, a significant increase in average marks in the post-test of TUI-based learning from 6.40 in pre-test to 8.20 in post-test could be noted from Figure 13, thereby highlighting a considerable gain in knowledge for students learning through such approach.

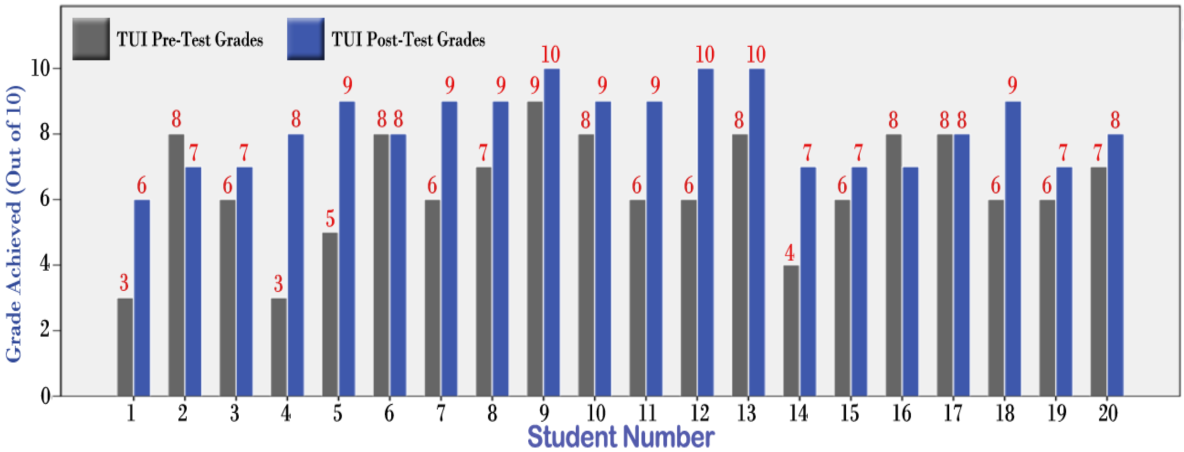


Figure 12- Student performance distribution in TUI-based sessions

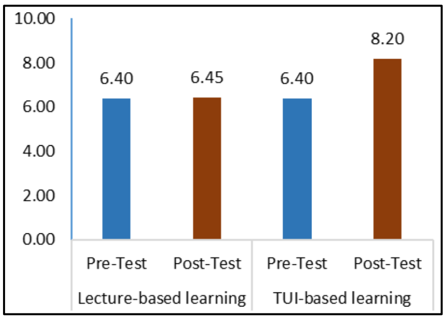


Figure 13 – Student performance summary

Overall, the cumulative result of the all students who obtained correct answers ranged between 37.5% and 90.0% for the common pre-test and between 20.0% and 100.0% in the post-tests, as illustrated in Figure 11. In terms of student performance, an average score of 6.40 was obtained in the pre-test as compared to a mean score of 7.33 in the post-tests among all participants. However, although knowledge gains were revealed in both categories of learning, scores pertaining to utilization of the TUI-based prototype was found to be significantly higher than the conventional lecture-based approach. For the group who attended the lectures, only a 0.5% increase was noted as compared to an increase of 18.0% in terms of knowledge gains for the group who utilized the TUI-based system. The significantly low performance for students who attended the conventional lectures could be attributed to the challenges for teaching such concepts using lectures that can reduce interaction with students, thus making it challenging to comprehend both the theoretical and technical aspects (Chilwant, 2012). On the other hand, using the TUI-based system engaged students with the learning process, while providing them with the freedom to actively learn concepts from the system. The use of IoTTT provided students with the opportunity to apply IoT concepts learnt in an engaging environment and obtained digital feedback to challenges attempted.

4.3 General Discussions

By investigating RQ2, it was found that utilization of the TUI-based system positively influenced learning as the group who utilized IoTTT performed better in the post-test as compared to those who attended the lecture on the same topic. On the other hand, an overall positive usability score was obtained for IoTTT, thus also denoting an acceptable solution for teaching IoT concepts, where for all the constructs investigated (perceived learnability, perceived efficiency, errors and perceived satisfaction), a mean score exceeding 3.8 was obtained. With the positive influence on learning and as a usable solution, TUIs can be utilized within IT-related courses that teach IoT related concepts.

However, bringing such solution to the labs would still entail a few challenges that need to be addressed. Firstly, although it is an opportunity for solution providers to develop TUI-based systems to teach IoT based concepts, curriculum within institutions and courses vary, thus implying that such solutions will need to be tailored to meet syllabus requirements and this entails further time before reaching the lab. Similarly, any updates in the course also means that the software will need to be updated, thus necessitating further development costs. Furthermore, for security reasons, devices within IT labs such as keyboard and mouse are often locked using security cables. However, with new components introduced such as light source and tangible objects within the TUI setups, effective mechanisms would be needed for anti-theft and for maintaining integrity of inventory counts. Also, with use of different objects for interaction, proper solutions would be needed to ensure management, timely repair and replacement of broken objects. With larger cohorts, the integration of IoTTT in labs can be costly since such solution is meant for use by individuals or small groups of maximum five students. As such, for cohort of 40 students, it means at least 8 TUI-based systems need to be present in the lab, consisting of computers, web-cams, projectors, light source and physical objects, among others, which can prove to be costly if these devices not being utilized for teaching other concepts using similar approach. As such, these challenges can hinder the integration of such TUI-based system in labs.

Besides, different limitations were also present that could influence findings of this study. Firstly, for answering RQ1, perceptions of the participants were gathered through the questionnaire that is influenced by demographic factors and studying these factors were beyond the scope of this paper. Furthermore, participants of this study had the opportunity to utilize the TUI-based system individually and group use of IoTTT was not evaluated. Assessing individual against group interaction could provide insightful results on how learning effectiveness and usability varies in both settings. In addition, limitations of Nielsen's usability heuristics also adversely affected results (Faulkner, 2003) and these could be addressed by considering other usability frameworks (Zhang & Walji, 2011). These include the Technology Acceptance Model (TAM) and the System Usability Scale (SUS) which could be applied for obtaining further feedback on the usability of IoTTT. These limitations also provide avenues for future work in the same area in order to further improve IoTTT based on issues identified while answering RQ1. Also, usability of the system can be further investigated while applying frameworks such as TAM and SUS, while also investigating other factors such as user demographics and group interaction.

5. CONCLUSIONS

This paper explored the use of Tangible User Interfaces for teaching and learning Internet of Things related concepts by focusing on two essential aspects, notably usability and learning effectiveness. Owing to the lack of existing solutions that address this issue, a TUI-based system was developed with the aim to teach IoT concepts to students who are part of undergraduate-level IT programmes. Key concepts taught within the proposed system include introductory IoT concepts, networking and related protocols, IoT Architectures and application scenarios. By evaluating the proposed prototype and through answering the two research questions investigated in this paper, two contributions to literature were targeted, notably from usability and learning effectiveness assessment. For evaluating the usability of the prototype, Nielsen's principles were utilized and in this process, four usability attributes were assessed, namely learnability, efficiency, errors and satisfaction. Data was collected through a Nielsen's Usability Heuristics (NUH) questionnaire based on four usability attributes (perceived learnability, perceived efficiency, errors and perceived satisfaction) and feedback were sought from 20 participants following practical utilization of the system.

Results revealed a positive score for the usability of the TUI solution with an average rating of 3.9 for the attributes investigated. Even though this score demonstrated an acceptable solution, different issues and limitations were identified, based on which a set of recommendations have been made for the research and development community to consider when designing similar solutions. On the other hand, for investigating the learning effectiveness, pre-tests and post-tests were conducted with two groups consisting of twenty students each. The first group involved attending conventional lectures on IoT concepts whilst the second one utilized the proposed TUI-system for learning the same concepts. In the common pre-tests, an average score of 6.40 was obtained as compared to a mean score of 7.33 in the post-tests for all participants. For students who attended the conventional lectures, the mean scores in the tests only improved from 6.40 to 6.45. However, knowledge gains were significantly higher for students who learnt IoT concepts through the TUI-based system where performance improved from a score of 6.40 to 8.20, representing an improvement of 18%. Overall, with positive scores for usability and learning effectiveness, use of TUI could path its way into labs for teaching IoT related concepts. However, this will not be without challenges where key ones include the need for tailoring software to meet curriculum needs, effective management and maintenance of objects utilized as part of the solution.

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