Teaching and Learning Queueing Theory Concepts using Tangible User Interfaces

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Abstract—**Tangible User Interfaces (TUI) have emerged in the past years as effective computing platforms that intertwine digital information and visualization with physical interactivity. Whilst successfully capitalizing on these properties within primary education to engage and educate children in an entertaining manner, TUI systems have seen limited deployment in more complex scenarios. To this end, this paper investigates the aptness and effectiveness of implementing TUI systems to enhance teaching and learning within higher educational institutes in order to aid the understanding of complex and abstract concepts. The proposal augments mere simulation processes by developing a table-top architecture to allow the real-time interaction and visualization of queuing theory concepts. The paper describes the deployment of the TUI framework within an undergraduate computer networks degree whereby the quantitative effectiveness of this system is assessed from a teaching and learning perspective within an engineering pedagogy.**

Keywords— Computer Aided Instruction; Higher Education; Tangible User Interface; Queueing Theory

I. INTRODUCTION

Within the disciplines of Science, Technology, Engineering and Mathematics (STEM) a solid introduction to queueing theory has long served as a staple foundation for the eventual introduction to computer modelling and simulation modules [1, 2]. Albeit being entrenched within the realm of probability theory however, the applicability of queueing theory is far reaching and thus is frequently encountered also within business-school courses such as management science and operations research [3]. This diverse audience commonly exposes the problem in which students, with a weak understanding of mathematics and probability, struggle to grasp the elementary stochastic aspects of this theory and hence fail to obtain the fundamental elements of this concept [4].

As a means to avoid spending an inordinate amount of time explaining the mathematical aspects of queuing theory [5], educators commonly resort to the use of computer simulations to accommodate the students' diversity in prerequisite knowledge [6]. The instructional delivery of queuing theory using computer-based technology has been well discussed in literature [5, 7-10] with notable success reported for bridging the cognitive gap in student cohorts [11, 12]. This has been achieved in Higher Educational Institutions (HEIs) via both a repertoire of dedicated simulation packages [13], or alternatively by the development of spreadsheet models. The latter allow the construction and utilization of worksheets and macros with minimal programming knowledge hence making them more appealing to less technically oriented students [14].

Whilst the deployment of technology in such instances serves to attest to the effectiveness of information dissemination within teaching and learning [15], ensuring that proper insight is obtained by students on the underlying concept is more elusive [2]. This echoes the concern that unless technology is properly and systematically employed within classrooms, the resultant effects would not align to aspired expectations [16, 17]. Hence, positive impact on teaching and learning using technology requires educators to explicitly take the aspects of content and pedagogy into account [15, 18].

This concern is critically present within engineering curricula whereby the understanding of queuing theory and simulation modeling provides a peculiarly intertwined dependency which cannot be overlooked [19]. Although simulation is often emphasized as an alternate tool for queuing theory evaluation, skimming over the mathematical analysis and derivation of parameters results in very limited apprehension of the complex system dynamics which in turn hinders the necessary understanding used within simulation modelling [20].

In light of this requirement, this research aims to present a novel technological framework which directly aligns with the pedagogy of engineering education for the teaching and learning of queuing theory. The proposal presents the adaptation of Tangible User Interfaces (TUI) to provide computer networks students the ability to visualize, understand and interact with the underlying concepts of queuing theory. Central to the efficacy of this methodology is the inherent alignment with inquiry-based and active learning models, both of which value student interaction via experimental and collaborative learning as core of their effectiveness [19, 21]. Thus, in stark contrast to the reviewed work, the proposed framework is designed to capitalize on the following valuable aspects;

- Active participation in understanding concepts rather than students acting as passive recipients to the delivery of facts.

- Tangible relations and interactions with the queuing system components in real time, hence diminishing the perceived operational complexity.
- Visualization of the mathematical calculations and resultant effects of parameters, effectively reducing uncertainty on system functionality.
- Simplification of the computational aspects providing the ability to more effectively understand the problem concept.
- Exposure to realistic and applicable queuing theory examples which aid knowledge assimilation.

To this end, this paper is structured so that Section II presents an analytical review of TUI-related articles in education. This is followed by a formalization of the proposed design in Section III with elaboration on the system functionality and operation. Section IV details the implementation of the proposed research framework within a university programme and discusses the obtained results. Finally, a brief conclusion is outlined in Section V.

II. TANGIBLE USER INTERFACE SYSTEMS

TUI systems have steadily gained interest in the past years as a technological platform able to deliver enhanced user interactivity and visualization [22]. This unique Human Computer Interaction (HCI) provides users the ability to interact with digital information through the manipulation of conventional physical objects, thus blurring the boundary between physical and digital domains [23]. Therefore, in direct differentiation from conventional Graphical User Interface (GUI) systems, TUI platforms are not restricted to conventional computer peripherals such as keyboards and mice, providing users the ability to semantically embody and assimilate digital attributes within familiar tangible objects [24]. The active interaction with such devices instigates users to take advantage of their innate spatial and environmental skills whilst interacting with TUI systems [25], attributes which have been correlated with a heightened sense of user engagement and higher order cognitive tasks such as attention and inquisitiveness [26].

The qualities elicited by TUI technology together with the inherently attractive aspect of physical engagement, quickly led TUI systems to gain exposure within primary education [27]. The survey conducted by [28] presents a plethora of TUI deployments for early-stage education, in which learning is directly combined with educational toys to entertain children while introducing concepts relating to robotics, linguistics and colors in a playful manner. A similar system also managed to introduce young children to the mathematical notions of volume and the surface area of 3D objects by making use of a Smart Blocks system [29].

Conversely, the utilization of TUI systems for more elaborate learning has been quite limited with literature with more complex adaptations being primarily targeted towards industrial practice rather than education [30]. As an example, the TUI system named URP (Urban Planning) achieved successful use within architectural domain to simulate the effects of wind and shadow casting on buildings [31]. Similarly, in computer networking, an industrial collaboration led to the creation of a TUI platform on-top of OPNET software [32] to simulate data traffic and bottlenecks within networks [33]. Within the medical domain, a 3D tangible interface was employed to represent a human brain, whereby practical training was undertaken by neurosurgeons with positive comments on the ability to train collaboratively [34]. Similar outcomes were also obtained in the adaption of Strip'TIC system which provided air traffic controllers the ability to practice collaboratively whilst visualizing and understanding events within a simulated airspace [35].

III. PROPOSED TUI SYSTEM

The TUI framework described in the paper contrasts from current literature by making a novel contribution in the adaption of tangible systems within higher education. More specifically, the research aims to investigate the suitability of TUI systems, by evaluating their efficacy and aptness for the explanation of abstract concepts within HEI contexts such as queuing theory.

This cross-discipline topic was chosen due to its characteristically lengthy and complex mathematical equations [5], which present a demanding challenge on undergraduate students [1]. Moreover, the subtle dependences amongst the random variables involved [36] together with the abstract connection between the different queueing models and their stochastic operations regularly confound students [11]. The underlying principles of queuing theory thus present a compelling scenario for the designed TUI framework which aims to directly contribute to facilitating the teaching and learning aspects involved.

The proposed system would be employed to model queuing systems in various configurations. Queues were classified using Kendall notation of A/S/c/K [37], where "A" and "S" describe the interarrival time distribution and service time distribution respectively. "c" denotes the number of servers available to give service whilst "K" defines the buffer's capacity. In line with the curriculum of computer network undergraduates, the simulation considered Poisson distributions (abbreviated as "M" - Markov) for arrival and service rates, and supported the consideration of both single-server ($c = 1$) and multi-server mode ($c <= 3$). Furthermore, for each option, the queue size "K" could be set to either infinity or a range of finite sizes.

A. System Overview

The proposed TUI framework designed was based on the Model-Control-Representation (physical and digital) (MCRpd) interaction model [38] illustrated in Fig 1. This framework extends the Model-View-Control (MVC) typically used within GUI interfaces by separating the "view" component into tangible and intangible representations [39]. The latter serves as a digital feedback to the user via video projection and/or sound, whilst the former component is tightly integrated to the control component and provides a tangible and physical representation of the system state.

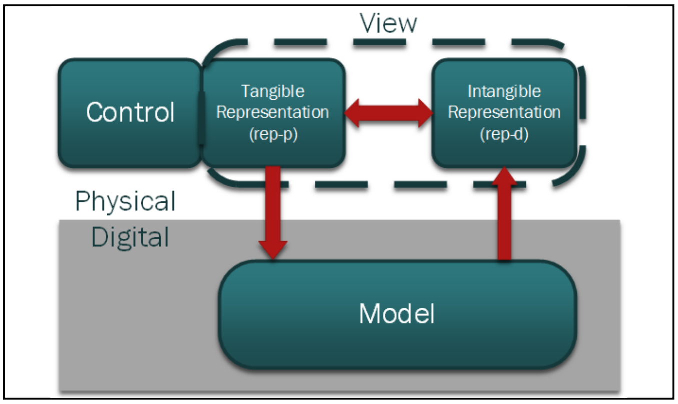

Fig. 1. MCRpd Interaction Model for TUI framework (*adapted from* [38])

The functional model of the developed system was based on the reacTIVision optical tracking framework [40] depicted in Fig 2. This interactive table-top implementation was selected based on its inherent ability to support collaborative experimentation whilst providing a clear understanding of the system functionality via both tangible and digital representations [41].

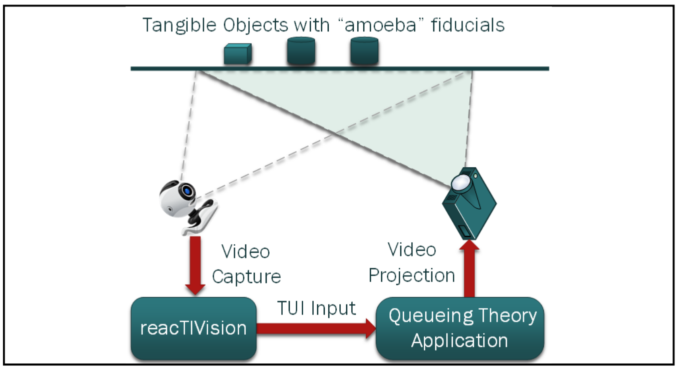

Fig. 2. ReacTIVision architectural framework (*adapted from* [40])

The amalgamation of these two frameworks is outlined within the Sequence Diagram in Fig 3. The model outlines the characteristics imparted by the MCRpd framework in which tangible objects optically tracked via reacTIVision fiducials are used to provide controlling inputs. The underlying queuing theory model subsequently conveys feedback back to the user by alterning the digital representations using the underlying projector view.

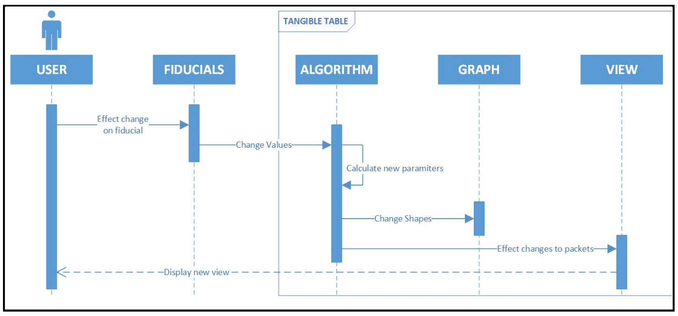

Fig. 3. Sequence Diagram for the proposed TUI framework

The physical construction of the TUI system, pictured in Fig 4, was composed of a wooden table topped with an acrylic glass sheet. The interactive surface covered an area of 1m x 0.7m within which tangible objects were continously tracked using a wide-angle camera at a frame-rate of 30Hz. The height of the setup was designed at 80cm from the floor, which provided easy accessability and visability of the interactive surface to a cohort of students surrounding the table. This table-top surface was also illuminated, as visualised in Fig. 4 by a short-throw projector which augmented with physical objects with digital information.

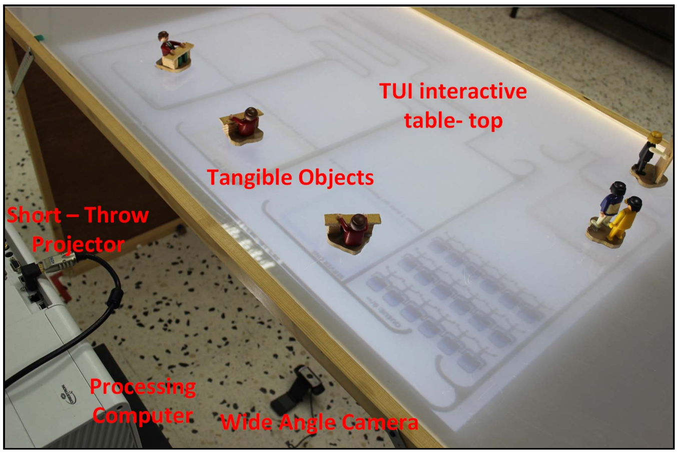

Fig. 4. ReacTIVision architectural framework (*adapted from* [40])

B. *Tangible Interactions*

Underlying the functionality of the proposed TUI system is the ability for students to interactively engage with the queuing scenario using a set of tangible 3D objects. Manipulation of these physical representations would thus allow the configuration and modification of queuing theory parameters in order to alter the presented models in real-time.

The selection of tangible devices was undertaken with the intended aim to inherently symbolize the queuing system components and hence exploit the familiarity of students with these items. In line with a computer networks perspective, physical models such as routers, data buffers and servers were used as depicted in Fig 5a. These capitalized from the intrinsic assimilation by computing students who could easily relate to their technical foundations. Furthermore, students were able to associate each tangible component with a set of functionalities typical of the representative device, and thus aid in the understanding of the queuing system when learnt within the networking domain.

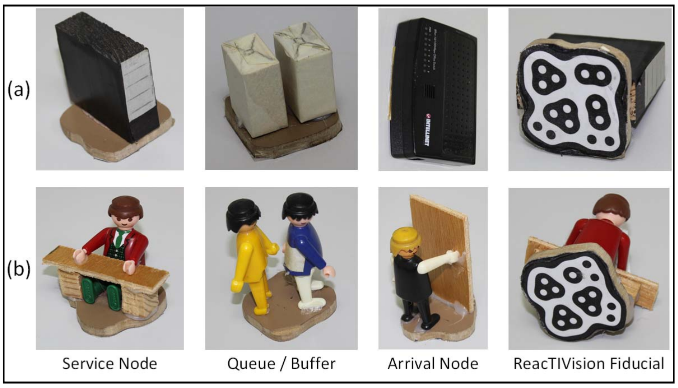

Fig. 5. Design and selection of tangible objects representing arrival, buffer/queue and service tasks in a queuing model for;
a) Computer networks packet processing,
b) Client servicing business organisation.

Owing to the vast applicability of queuing theory with real-life experiences [1] and to facilitate the understanding of the abstract concepts to non-technical students, the TUI framework could easily be adapted towards a commercial client-server scenario. Taking advantage of the inherent flexibility and functionality of TUI systems, an alternate set of tangible objects were developed to represent an organizational queuing case scenario as illustrated in Fig 5b. Human figurines from the Playmobil® toy sets were used to represent the various roles within a service firm queue. A set of figurines wearing formal attire where thus used to represent employees (advisors/servers) whilst an alternate set of casual wearing figurines represented clients either entering the queue system (opening a door) or waiting in line to be served (queue buffer).

Each tangible element was placed onto a wooden platform, which apart from provide stability also served to attach a scaled image of a reacTIVision "amoeba" fiducial [40] as shown in Fig. 5. These high-contrast symbols are orthogonally optimized for unique identification using the installed camera. This allows the developed application to detect, discriminate and locate the center-point of each individual object used. Apart from affording the system with spatial object tracking, the employed "amoeba" symbols are rotationally variant, hence allowing the gathering of rotational angle for each placed component on the interactive surface.

The TUI system capitalized on these aspects by employing the notions of object placement and rotation to impart different controls. Whilst sustained object presence detected the inclusion of an additional parameter or server within the system, the rotational angle of each object was directly linked to the respective parameter. This allowed the increase or decrease of input values for the queuing theory equations by physically rotating objects in clockwise or anti-clockwise directions. Thus, allowed the system to adapt the simulation parameters in real-time whilst aiding students in collaboratively experiment with queue's attributes to understand the implicit interactions between each variable.

C. *User Interface*

The augmentation of tangible devices by interweaving the physical aspects with digital information is one of the innate advantages conveyed by the proposed TUI system. As illustrated within the setup of Fig. 4, perceptual coupling is attained by the system by visually projecting the system's output onto the same interactive surface utilized for input control. The spatial multiplexing provides the ability to embody digital information to the tangible devices, by projecting data adjacent to the physical component. Moreover, the dynamic nature of the developed GUI is able to react instantly to the received physical input and hence provide positive feedback to the user via alteration of the projected view. This closed-loop element ensures computational coupling exsists between the tangible input and the underlying digital model as modeled in "View" component of Fig. 1.

In order to provide real-time implementation, the system's behavior was implemented in Java which employed reacTIVision libraries for TUIO tracking [40] and interfaced with JavaFX for graphics handling and animations. This combination allowed the proposed system to efficiently develop a variety of GUI options to alter the user's attention such as; data highlighting, color alterations and dynamic information changes.

Upon programme startup, the initial GUI design of the proposed system is presented as illustrated in Fig. 6. The projected GUI is designed to spread along the entire interactive table-top, which apart from aiding visibility allows for the clear designation of the four main segments highlighted in green within Fig. 6. These areas are further laid out to provide a flow continuation of the queuing process in a clockwise movement as illustrated using red arrows stages.

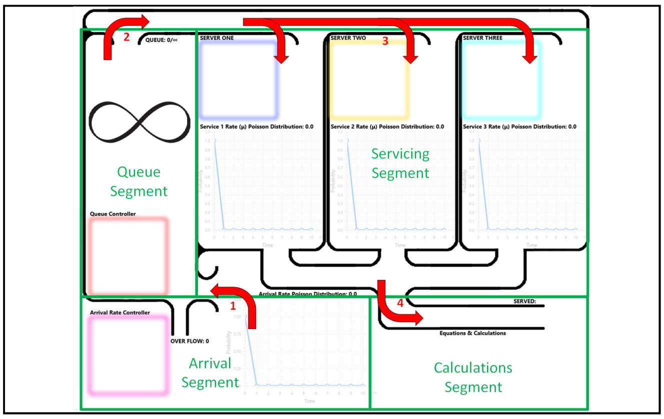

Fig. 6. Initial GUI design segmented according to the distinct queue model areas with superimposed flow indicators.

Perceptual coupling was also employed within the GUI system to subtly instruct students on the operation of the proposed TUI system. By means of colored square placeholder sections, users were made aware on the ideal locations within which tangible objects should be placed. Moreover, these segments were dynamically highlighted during operation, as visualized in Fig. 7a in order to attract user attention to the respective area as well as to provide localized indications to the required actions. Visual indications were also employed by the system to indicate to students the available manipulations on each object. As depicted within Fig. 7b, this is achieved using four animating arrows which are displayed rotating in clockwise and anti-clockwise fashion adjacent to the recognized TUI objects.

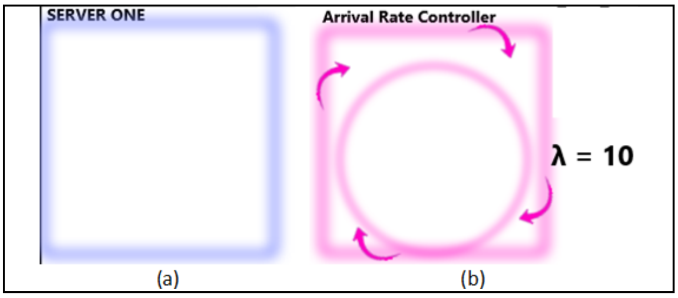

Fig. 7. Graphical animations are used in order to provide perceptual feedback to users on the TUI systems functionality.

D. *Algorithmic Design*

A prerequisite to understanding the conceptual operation of queuing theory is the ability for students to interpret the stochastic distributions on arrival and service rates, denoted by λ and μ respectively. This process presents an abstracted challenge to students since, although analyzed and quantified statistically within equation (1), precise prediction of the arrival/service pattern is not possible due to its inherent random nature at any given time. For a time occurrence *i* and an arrival rate λ, the Poisson distribution can be characterized as;

$$p(i,\lambda) = \frac{e^{-\lambda}\lambda^{i}}{i!}, \tag{1}$$

where *e* is the Euler's constant.

Within the GUI's calculation section, this equation is shown together with its the appropriate results. Moreover, in order to further aid with the teaching and learning of this aspect, the proposed TUI system graphically displays dynamic Poisson distribution graphs. These are projected directly adjacent to the respective arrival and service tangible objects, as visualized in Fig 8a. Upon rotating the angle of the respective physical objects, students can alter the corresponding rate parameter and consequently this results in a dynamic alteration of the distribution shape as seen in Fig 8b. Furthermore, in each stochastic instance, the system generates a random number for the interarrival/service delay of the simulated element, which is subsequently conditioned according to the appropriate distribution. To assist students in visualizing this process, an animated element represented as a dark dot, is made to move along the graph until it reaches the calculated time, at which point the animation changes the elements' color and shifts it to the subsequent queue segment area. This allows students to inevitably appreciate the probabilistic nature of stochastic events, and understand the eventual natural distribution of elements following a number of iterations.

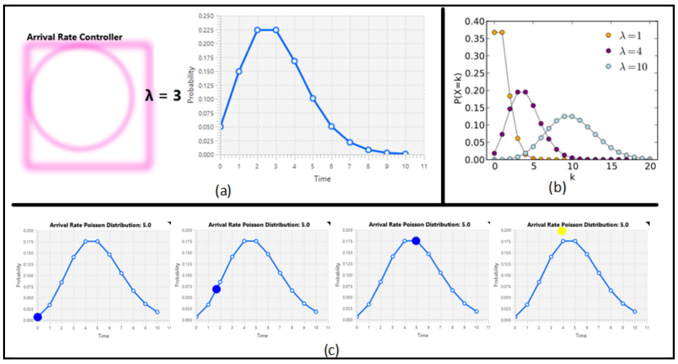

Fig. 8. a) Graphical display of Poisson distribution curve adjacent to tangible object
b) Variation of stastistical distribution according to the configured rate parameter.
c) Animated sequence of element following a distribution delay

Assuming an infinite buffer-size (K=∞), the element would flow directly into to the service modelling sector of the queue. The layout of this segment is designed in a similar manner to the arrival segment with a TUI placeholder and corresponding Poisson distribution curve in its adjacency. An animation sequence is also undertaken in a similar fashion to the captured images of Fig 8c, hence allowing students to solidify their understanding of stochastic processes accordingly.

$\alpha + \beta = \chi.$ (1) (1)

The proposed system initializes the queuing model upon establishing of the first service rate (μ_1) is via a tangible server. Within this mode the system commences an M/M/1/K operation and displays to the users the mathematical calculations for this model within the equations segment. These include the system utilization factor (ρ), the average amount for elements in the system (N) and the average waiting time elements spend in the system (T) defined respectively as:

$$\rho = \frac{\lambda}{\mu}, \tag{2}$$

$$N = \sum_{n=0} n(1-\rho)\rho^{n} = \frac{\rho}{(1-\rho)}, \tag{3}$$

$$T = \frac{N}{\lambda} = \frac{1}{(\mu-\lambda)}. \tag{4}$$

These allow students to understand and visualize in real-time the theoretical system parameters whilst understanding the mathematical models defining the queue's operation. The proposed TUI system is then able to automatically shift towards an M/M/c/K model once the users introduce the second or third server, whereby the queuing model distributes the buffered elements sequentially to available servers according to their individually configured service rate (μ_c). Consequently, equation (4) is amended in order to account for a multiple-server scenario using the calculation:

$$T = \frac{1}{\mu} + \left[\sum_{k=0}^{c} \frac{\lambda^{k}}{\mu^{k} k!} + \frac{\lambda^{c}}{\mu^{c} c!} \sum_{k=c+1}^{K} \frac{\lambda^{k-c}}{\mu^{k-c} c^{k-c}}\right]^{-1} \left[\frac{\rho(cp)^{c}}{\lambda(1-\rho)^{2} c!}\right]. \tag{5}$$

The simplicity of physically constructing and configuring the TUI system allows students to appreciate the repercussions of the developed models via simulation, whilst at the same time understand the underlying mathematical foundations as depicted in Fig 9b. This is made possible via the intrinsic interlink between the digital model and the physical realm. As evidenced within the comparative images of Fig 9, students are able to manipulate the object based topology whilst concomitantly visualize the digital functionality and computations.

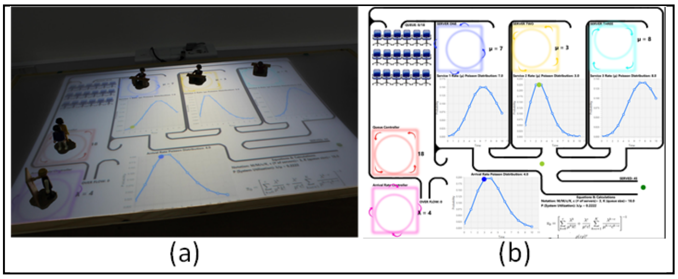

Fig. 9. Simultaneous configured queuing model within a) the physical domain, and b) the digital domain

The queue/buffer parameter (notation "K") of the simulated model is presented as an optional attribute to the system. Until students explicitly utilize the respective tangible object within the corresponding placeholder area, this parameter is considered as infinity (∞) and the model behaves as an M/M/1 or M/M/c queue. Once quantified the queue/buffer size is set to a finite number and this is visually represented as a seating area within the system as illustrated in Fig 10a. Physically rotating the tangible object increases or decreased the queue size, and this is dynamically reflected on the number of "empty chairs" displayed on the interactive surface. The presented queueing theory is computed on a first-come-first-serve basis and on each completed service, the queued elements are visually moved along the waiting line to highlight the buffer operation to students. The equation section dynamically displays to the user the system's probability of blocking/overflowing a packet and this is calculated in the equation section as;

$$P_{block} = \frac{(1-\rho)}{(1-\rho^{K+1})}\rho^{K}, \tag{6}$$

and updates (4) to account for finite buffer capacity

$$N = \frac{\rho}{(1-\rho)} - \frac{(K+1)}{1-\rho^{K+1}}\rho^{K+1}. \tag{7}$$

In instances in which the capacity of the queuing area is reached, newly incoming elements are turned away and these are animated and accumulated within an overflow counter as captured in Fig 10b.

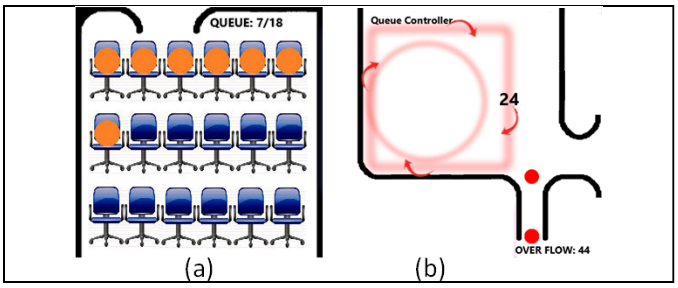

Fig. 10. a) GUI depiction of configured queue capacity b) Overflow animation with acculumation counter

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A. *Evaluation Methodology and Results*

The developed TUI system was deployed for evaluation at Middlesex University Malta within the undergraduate degree in Computer Networks. Queuing theory is harbored as a threshold concept within a second year module named Networking Design and Simulation and thus the TUI system was strategically implemented to coincide with the delivery of this topic. Thirteen (13) students who were reading this degree in part-time mode volunteered for evaluation and were subsequently randomly split into two groups of seven (7) and six (6). The latter would serve as a control group for the evaluation whilst the former group would constitute the experimental cohort.

To eliminate any potential bias within the students' prior knowledge and/or experience with this simulation field in computer networks, all students were provided a timed pretest consisting of fourteen (14) open-ended questions relating explicitly to the technical and conceptual understanding of queuing theory. The results served to compile an individualistic baseline of each students with which improvements in gained knowledge would be measured.

Subsequent to this assessment, the volunteering students were split according to their random group assignment and the control group was provided a short introduction to the concepts of queuing theory using a traditional lecture technique involving projected slides and whiteboard usage. The experimental group was placed in a different classroom, and underwent the delivery of the same material using instead the proposed TUI framework as shown in Fig 11.

Fig. 11. Evaluation session of the proposed TUI system for teaching and learning queuing theory concepts.

To ensure coherent conditions, both groups were instructed by the same lecturer and directly following each session were provided with a second posttest. The latter assessment was also composed of fourteen (14) open-ended questions, which however albeit assessing the same body of knowledge, were structured differently to avoid possible influence from the previous assessment. These results are visualized in Fig 12, whereby the assessment scores for the pre-test and post-test are presented for each student.

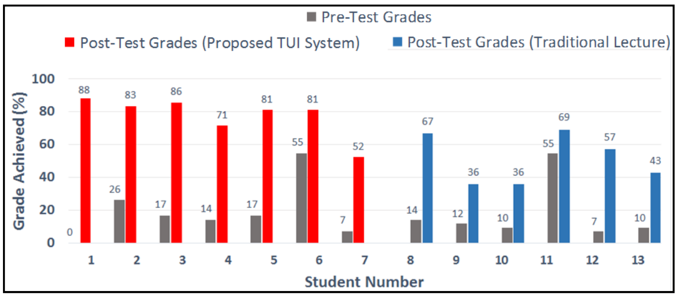

Fig. 12. Student profile comparision of academic assesments prior and following tuition on queuing theory.

The pretest grade distributions (gray) within Fig 12 highlight that the a-priori knowledge on queuing theory by students within both cohorts does not differ significantly ($p>0.8$). This highlighted the fact that no knowledge bias was attributed to the selection strategy and thus the random approach was appropriate.

A paired sample test on the results of the traditional lecture cohort illustrate that following the tuition intervention the control group students increased their assessment grades from 17.8% (SD 18.2%) to 51.2% (SD 15%), hence obtaining an average grade increase of 33% (SD 15.1%). Whilst successful in providing students a basic understanding of queuing theory concepts, the achievement of conventional lectures is paled in comparison to the success registered by students who utilized the proposed TUI system. A similar paired t-test on the experimental cohort registered a score improvement from 19.4% (SD 17.6) to 77.5% (SD 12.3%) hence obtaining a grade increase of 58% (SD 19.3%) in technical questions directly related to queuing theory fundamentals. This disparity was further stressed by an independent sample test which asserted that the difference had a statistical significance of ($p<0.01$).

B. Discussion and Future Improvements

The quantitative evaluation derived from the assessed variance in academic achievement within students thus serves as an objective appraisal for the proposed system. This directly reflects on the efficacy and aptness of employing a TUI framework for teaching and learning of abstract mathematical concepts such as queueing theory within the pedagogy of engineering.

Furthermore, a subsequent qualitative evaluation was also undertaken on the experimental cohort who made use of the TUI system for instruction. Students were asked five generic questions based on their user experience within the session and their interactivity with the proposed TUI framework. The resultant feedback was aggregated and tabulated in Fig. 13.

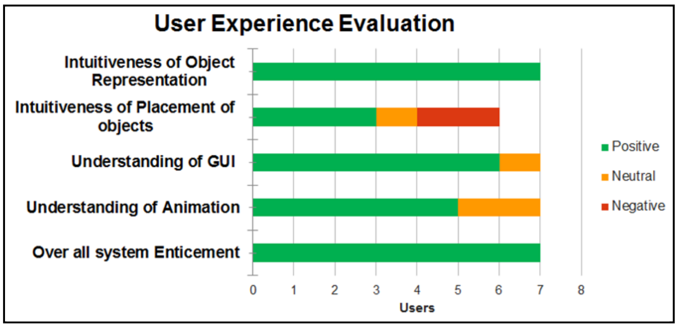

Fig. 13. Aggregated user experience evaluation following the interaction with the proposed TUI system.

The feedback acquired from evaluating students clearly highlights that apart from their academic improvement, which was not communicated at the time, the proposed TUI system was positively received by students and the system enticed students to understand the presented queuing theory concept. The case scenarios used via the tangible objects were also positively received and aided students in assimilating the explained concepts with everyday examples. Future work however should focus on making the GUI more intuitive especially with respect to associating tangible objects with their designated placeholders. Also, the ability to pause or slow down the simulation process in some instances was highlighted to be beneficial as an improvement feature which would allow easier visualization and understanding of underlying processes.

V. CONCLUSION

The paper presents the development and implementation of a novel TUI framework which is adapted for use within HEI contexts. The presented approach aims to aid in the explanation of complex abstract concepts, and focuses on the teaching and learning of queuing theory within the context of engineering pedagogy. The presented approach interlinks the domains of physical interaction with digital representation in order to assist in the visualization and understanding of the subtle dependencies present between parameters of queuing models. Through an evaluation process undertaken within an undergraduate programme, it has been objectively quantified that students were able to obtain 25% higher grades than achieved using traditional lecturing methodologies. This strengthens the aptness and efficacy of the proposed framework to mitigate complex notions in HEI concepts.

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REFERENCES

[1] S. W. Mei and A. K. Cheng, "Introducing Queuing Theory through Simulations," in *The 9th Delta Conference on teaching and learning of undergraduate mathematics and statistics*, Kiama, Australia, 2013.

[2] T. A. Grossman, "Teachers' Forum: Spreadsheet Modeling and Simulation Improves Understanding of Queues," *Interfaces,* vol. 29, no.

3, pp. 88-103, 1999.

[3] M. Liberatore and R. Nydick, "Breaking the Mold: A New Approach for Teaching the First MBA Management Science Course," *Interfaces,* vol. 29, no. 4, pp. 96-116, July-August 1999.

[4] A. Perdos, A. Chatzigeorgiou and G. Stephanides, "Teaching Queuing Systems Modeling Using UML," in *IEEE Int. Confernce on Advanced Learning Technologies*, Joensuu, Finland, 2004.

[5] J. H. Reed, "Computer Simulation: A tool to teach queuing theory," *Experiental Learning Enters the Eighties,* vol. 7, pp. 63-66, 1980.

[6] D. J. D. and M. K. Purvis, "Teaching Service Modelling to a Mixed Class: An Integrated Approach," *Informatics in Education,* vol. 14, no. 1, pp. 35 - 50, 2015.

[7] E. Sánchez, "Teachers' beliefs about usefulness of simulation with the educational software fathom for developing probability concepts in statistics classroom," in *Sixth International Conference on Teaching Statistics*, 2002.

[8] D. Goldsman, "A simulation course for high school students," in *2007 Winter Simulation Conference*, Washington, DC, 2007.

[9] J. Garcia and A. Hernández, "Active methodologies in a queueing systems course for telecommunication engineering studies," *IEEE Transactions on Education,* vol. 53, no. 3, pp. 405-412, 2010.

[10] A. Mandelbaum and S. Zeltyn, "Service engineering: Data-based course development and teaching," *INFORMS Transactions on Education,* vol. 11, no. 1, pp. 3-19, 2010.

[11] S. Fitzgerald and J. Place, "Teaching elementary queueing theory with a computer algebra system," in *26th SIGCSE technical symposium on Computer science education*, New York, NY, 1995.

[12] K. Ang, "Teaching and Learning Mathematical Modelling with Technology," in *15th Asian Technology Conference in Mathematics*, Kuala Lampur, Malaysia, 2010.

[13] J. Swain, "Simulation Software Survey," *OR/MS Today,* vol. 24, no. 5, pp. 38-46, 1997.

[14] C. Ragsdale, Spreasheet Modeling and Decision Analysis, Cincinnati, Ohio: South-Western College Publishing, 1998.

[15] A. Rahman, N. Zaid, A. Z., M. H. and B. Aris, "Emerging project based learning in flipped classroom: Technology used to increase students' engagement," in *3rd International Conference on Information and Communication Technology (ICoICT) 2015* , Nusa Dua, 2015.

[16] E. Alsafran and D. Brown, "The relationship between classroom computer technology and students' academic achievement," *Research in Higher Education ,* vol. 15, pp. 1-20, 2012.

[17] D. Laurillard, Rethinking University Teaching: A Conversational Framework for the Effective Use of Learning Technologies, London: Routledge, 2002.

[18] J. Day and J. Foley, "Evaluating a Web Lecture Intervention in a Human – Computer Interaction Course," *IEEE Transactions in Education,* vol. 49, no. 4, pp. 420-431, 2006.

[19] Y.-Y. Chan, "Teaching Queuing Theory with an inquiry-based Learning Approach: A case for applying WebQuest in a course in Simulation and Statistical Analysis," in *37th Frontiers in Education Conference*, Milwaukee, Wisconsin, 2007.

[20] U. N. Bhat, An Introduction to Queueing Theory: Modeling and Analysis in Applications, Birkhäuser, 2015.

[21] S. Psycharis, "Inquiry Based-Computational Experiment, Acquisition of Threshold Concepts and Argumentation in Science and Mathematics Education," *Educational Technology & Society,* vol. 19, no. 3, pp. 282-293, 2016.

[22] H. Ishii, "The tangible user interface and its evolution," *Communications of the ACM - Organic user interface,* vol. 51, no. 6, pp. 32-36, jUNE 2008.

[23] H. Ishii and B. Ullmer, "Tangible bits: towards seamless interfaces between people, bits and atioms," in *ACM SIGCHI Conference on Human Factors in Computing Systems*, 1997.

[24] L. Garber, "Tangible User Interfaces: Technology You Can Touch," *Computer,* vol. 45, no. 6, pp. 15-18, June 2012.

[25] J. M. Rodríguez Corral, A. C. Balcells, A. M. Estévez, G. J. Moreno and M. J. Ferreiro Ramos, "A game-based approach to the teaching of object-oriented programming languages," *Computers & Education,* vol. 73, pp. 83-92, 2014.

[26] S. Price and Y. Rogers, "Let's get physical: The learning benefits of interacting in digitally augmented physical spaces," *Computers & Education,* vol. 43, p. 137–151, 2004.

[27] E. Ras, K. Krkovic, S. Greiff, E. Tobias and V. Maquil, "Moving towards the assessment of collaborative problem solving skills with a tangible user interface," *TOJET : The Turkish Online Journal of Educational Technology,* vol. 13, no. 4, 2014.

[28] O. Shaer and E. Hornecker, "Tangible user interfaces: past, present, and future directions," *Foundations and Trends in Human-Computer Interaction,* vol. 3, no. 1-2, pp. 1-137, 2010.

[29] A. Girouard, E. H. L. Solovey, S. Ecott, O. Shaer and R. Jacob, "Smart blocks: a tangible mathematical manipulative," in *international conference on tangible and embedded interaction*, Baton Rouge, Louisiana, 2007.

[30] D. Edge and A. Blackwell, "Correlates of the cognitive dimensions for tangible user interface," *Journal of Visual Languages & Computing,* vol. 17, no. 4, pp. 366-394, 2006.

[31] J. Underkoffler and I. Hiroshi, "Urp: a luminous-tangible workbench for urban planning and design," in *SIGCHI conference on Human Factors in Computing Systems*, Pennsylvania, USA, 1999.

[32] R. Modeler, "OPNET Modeler," 28 April 2016. [Online]. Available: https://support.riverbed.com/content/support/software/steelcentral-npm/modeler-index.html. [Accessed 30 April 2016].

[33] K. Kobayashi, M. Hirano, A. Narita and H. Ishii, "A Tangble Interface for IP Network Simulation," in *Human Factors in Computing (CHI)*, Florida, USA, 2003.

[34] B. Schneider, J. Wallace, R. Pea and P. Blikstein, "Preparing for future learning with a tangible user interface: the case of neuroscience," *IEEE Transactions on Learning Technologies,* vol. 6, no. 2, pp. 117-129, 2013.

[35] C. Letondal, C. Hurter, R. Lesbordes, J.-L. Vinot and S. Conversy, "Flights in my hands: coherence concerns in designing Strip'TIC, a tangible space for air traffic controllers," in *SIGCHI Conference on Human Factors in Computing Systems*, Paris, 2013.

[36] P. Harrison, "Teaching M/G/1 theory with extension to priority queues," *Computers and Digital Techniques,* vol. 147, no. 1, pp. 23-26, 2000.

[37] D. G. Kendall, "Stochastic Processes Occurring in the Theory of Queues and their Analysis by the Method of the Imbedded Markov Chain," *The Annals of Mathematical Statistics,* vol. 24, no. 3, p. 338, 1953.

[38] B. Ullmer and H. Ishii, "Emering Frameworks for Tangible User Interfaces," in *Human-Computer Interaction in the New Millenium*, Addision-Wesley, 2001, pp. 579-601.

[39] Y. Yuan, X. Yang and S. Xiao, "A Framework for Tangible User Interfaces within Projector-based Mixed Reality," in *6th IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR '07)*, 2007.

[40] M. Kaltenbrunner and R. Bencina, "reacTIVision: a computer-vision framework for table-based tangible interaction," in *1st Int. Conf. on Tangible and embedded interaction*, Louisiana, USA, 2007.

[41] V. Maquil and E. Ras, "Collaborative Problem Solving with Objects: Physical Aspects of a Tangible Tabletop in Technology-based Assessment," in *From Research to Practice in the Design of Cooperative Systems: Results and Open Challenges*, London, Springer , 2012, pp. 153-166.