Enabling the Effective Teaching and Learning of Advanced Robotics in Higher Education using an Active TUI Framework

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ABSTRACT

This paper presents a tangible user interface (TUI) architecture to help mitigate the educational difficulties in teaching and learning abstract and complex concepts in Software Engineering and Robotics. The tailored design and development of this innovative framework address the unique challenges faced in higher education to actively engage students in technical concepts required to develop smart knowledge infrastructures. The novel integration of active tangible components on TUI tabletop architectures is presented within this paper and evaluated for its effectiveness as an educational technology to explain Robot Operating System (ROS) based sensor network topologies. Analysis of assessed results highlight the aptness and effectiveness of the proposed TUI framework in delivering a knowledge gain of 14.6% over traditional educational technologies. This illustrates the aptness and suitability of integrating tangible technology for abstracted software and robotic engineering concepts within higher educational institutions.

CCS CONCEPTS

• **Applied Computing** → Interactive Learning Environment • **Computing education** → *computing education programs*; Computer engineering education • **Human-centered computing** → collaborative interaction • **Computer systems organization** → *embedded and cyber-physical systems*; Robotics

KEYWORDS

Educational Technology; Robot Operating System, Embedded Interaction, Higher Education, Active Tangible User Interface.

1 INTRODUCTION

The implementation of Internet of Things (IoT) networks within cities is growingly recognized as a critical enabler to the development of smart knowledge cities which would allow the gathering and sharing of data through distributed robotic networks [26]. Emerging countries are in a prime position to capitalize on the implement of the communication infrastructure and software engineering needed to support the proliferation of smart sensor devices and networks [25]. In spite of this intrinsic advantage, the existing knowledge gap in engineering skills experienced in these countries poses significant challenges for the successful development and adoption of the required technology [33]. neglected.

Such instances have increased the pressure in emerging countries for the advancement of Science, Technology, Engineering and Mathematics (STEM) education in higher educational institutes (HEI) [17, 22] to support the need for research development and innovation [7]. These educational goals help to further the sociocultural development targets in countries within the Middle East and North Africa (MENA) region [39] as well as augment local knowledge and expertise in engineering problem-solving capabilities [37]. This has led to an increase in regional and continental educational initiatives within MENA countries, which aim to engage teenagers and university students in technical challenges designed to foster creativity and ingenuity within participants [23].

The adoption of alternative pedagogies in the dynamic STEM educational domain quickly led to the adoption of more engaging methodologies for teaching and learning technical concepts [9]. The inclusion of robotics within curricula presents intriguing learning gains based on the ability of the topic to enthral students' problem-solving and thinking skills [4, 5]. The peculiar nature of robotics education interweaves computer hardware and software integration, providing a combined insight into cross-discipline knowledge domains such as; mechanical, electrical, electronic and software engineering [2, 12]. Apart from engaging the simultaneous use of creativity and technical skills, the combined knowledge skillset required in the domain intrinsically presents an opportune instance for the development of communication and collaborative skills [1]. The complexity in amalgamating these skillsets when teaching and learning advanced robotic concepts within HEIs, however, poses

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several difficulties for educators, leading academics to seek abetment from education technologies within their delivery [2, 5].

2 Educational Technology for Robotics

The integration of educational technologies within robotic concepts has long been sought after for its innate ability to interactively engaging students within education and freeing the way in which instructors and students interact [3]. The adoption of technology aids to bridge the gap between narration and simulation of robotic concepts, enhancing and augmenting students' learning experience [11]. This has been achieved in past literature by providing students with the ability to visualize their operational concepts using web-based simulator tools such as algorithmic flowcharts [24] and digital logic circuits [18] to aid in the design of robotic elements whilst simplifying other development aspects. The use of Graphical User Interface (GUI) simulators facilitates the familiarization with complex concepts such as those experienced in embedded microcontroller programming, hence allowing novice students to engage and progress further in understanding the subject [35].

Nevertheless, the use of GUI simulators for educating robotic concepts has been critiqued for its inability to engage students and provide effective opportunities for skill development and deep learning that can alternatively be obtained whilst problem-solving tangible aspects of robotic design and programming [38]. Furthermore, Mitnik *et al.* [21] argue that most GUI tools employed in robotic education lack direct focus on the teaching of intrinsic concepts of robotic architectures, but rather focus on supporting closely related topics such as mechatronics and computer programming. In addition, GUI architectures impose an uncoupling of action and perception in Human Robotic Interactions (HRI), thus reducing the intuitiveness and concentration ability of engaged students [10].

Consequently, Tangible User Interface (TUI) has garnered increased interest as an educational technology which is capable to mitigate these limitations whilst naturally interweaving the physical and digital domains [32]. By going beyond traditional computer peripherals, TUI architectures allow users to interact with digital information through manipulation of everyday physical objects and triggered behaviours [14, 31]. This technology resonates with robotics education by encouraging collaborative and playful learning [20], whilst inherently embracing students using multisensory perception channels including; vision, auditory and touch. Furthermore, the experimental nature of TUI setups provide students with an interactive opportunity to develop a constructive understanding of underlying concepts by actively engaging with their learning process [19].

The use of constructive assembly TUI architectures has enabled educators to introduce children to robotic concepts normally considered beyond their abilities [34], by providing educational setups that allowed students to connect and configure programmable LEGO^{TM} blocks sequentially. Similar laboratory robotic kits were also successfully employed by [38] and [8], whereby children that designed and created robotic artefacts via collaborative interaction, obtained a deeper and more hands-on understanding of the taught subject [6]. These results concur with the observations of [36] on playschool children, whereby the use of TUI systems delivered logic and programming concepts more effectively than conventional GUI educational technologies.

Whilst the experience of integrating learning in an attractive, fun and interactive manner provided positive results for children, TUI systems fail to scale with equal effectiveness when utilized with adult higher-education users [29, 30]. The need to deliver more abstract and complex engineering concepts further requires TUI architects to provide more advanced manipulations as well as the ability to visualize detailed information [32].

3 Proposed TUI Framework

The contribution of this paper aims to address the necessities and limitations outlined in literature by proposing a novel TUI framework for teaching and learning advanced concepts. Moreover, this research makes its contribution by analyzing the suitability and effectiveness of TUI systems to educate undergraduate students in conceptual theory and practical knowledge when designing and developing a distributed Robot Operating System (ROS) architecture [27] for data fusion within an IoT infrastructure.

3.1 Physical Overview

The proposed tabletop TUI architecture model illustrated in Fig. 1, was designed to amalgamate the conceptual Model-Control-Representation (physical and digital) (MCRpd) interaction model [13] together with the computer-vision based reacTIVision framework [16]. This TUI adaptation interfaced the physical and digital domains via an interactive surface which allowed users to interlink tangible and intangible representations on physical objects as detailed in [28].

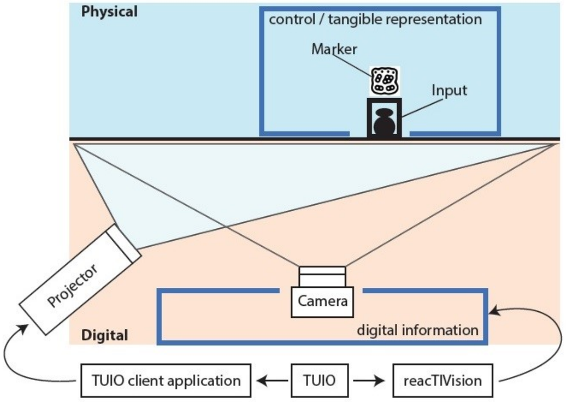

Figure 1: **Tabletop tangible interaction architectural model.**

The tabletop architecture was designed to allow the ability of multiple adult users to visualize and interact with the TUI system simultaneously in a lecture/seminar environment. To this end, design considerations were implemented to maximize the workable area of the interactive surface, whilst retaining an overall setup height of 90cm to ensure comfortable accessibility by users. The ability to support these requirements was achieved by making use of a short-throw digital projector and a wide-angle CCD camera to yield a 1.4m^2 (1.3m x 1.1m) interactive surface in 4:3 aspect ratio, as shown in Fig. 2. The latter, composed of a 3mm semi-transparent acrylic glass, was chosen to enable the capture and recognition of physical objects, whilst still providing an optimal visualization of the digital projection to the user.

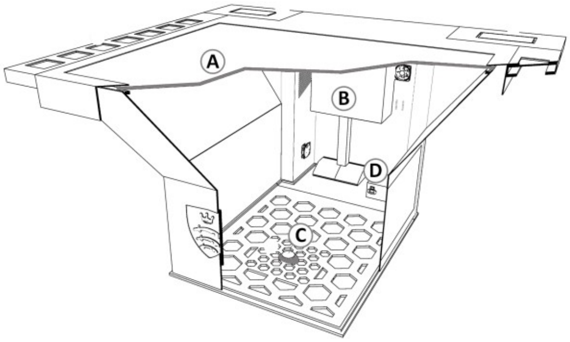

Figure 2: Construction cross-section of the proposed smart TUI system design:
a) Tabletop interactive surface,
b) Short-throw projector,
c) Wide-angle CCD camera with IR band-filter,
d) Processing server.

3.2 Tangible Manipulatives

The proposed framework incorporates the novel introduction of active tangible objects within the field of tabletop TUI architectures. Tangible objects were mounted to a 3D printed cylindrical base, underneath which 'amoeba' reacTIVision markers [16] were attached as shown in Fig. 3a. The unique rotation-variant fiducial patterns on these markers allow the framework to discriminate and identify each object from the captured video stream, whilst tracking their respective physical position and orientation. The 7.4cm wide by 4cm high cylindrical base was carefully designed to promote the ergonomic use of rotation on tangibles, providing the user with an instinctive interaction option.

The active tangible concept was achieved by making use of autonomous computational units that are able to wirelessly communicate with the processing server. Hence, as pictured in Fig. 3b, each base unit embedded within an Arduino Nano$^{\text{TM}}$ microcontroller chip together with a battery, a communication module, LED status lights and a vibrator motor. The latter components provided an additional layer of interaction, whereby the proposed TUI framework provided feedback by either altering the LED light colour or via haptic vibration during tactile interaction. Using a 2.4Ghz RF transceiver, information could be independently transmitted and received from the server processor via a serial communication protocol, enabling the framework to provide real-time input interaction and feedback visualization.

The design and selection of intuitive and familiar tangible objects provide a foundational advantage for TUI systems which can support students to associate apriori knowledge and functionality to the TUI models. To this end, commonplace robotic network components deployed in microprocessor-based ROS architectures were utilized to represent computational nodes and sensor modules as shown in Fig. 3c and Fig. 3d respectively.

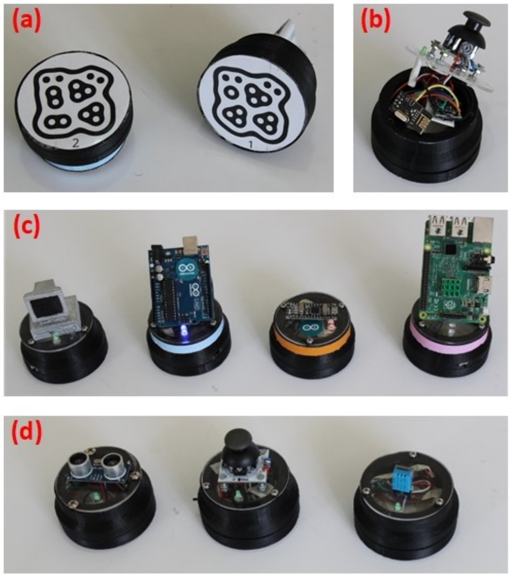

Figure 3: Design of active TUI manipulatives:
a) reacTIVision 'amoeba' fiducials [16],
b) TUI base unit with active processing components,
c) ROS-based microprocessor nodes,
d) Robotic sensor modules.

These components provide students with the ability to configure and design a ROS-based smart sensor architecture employ a variety of microprocessor nodes such as Ardunio$^{\text{TM}}$ and Raspberry Pi$^{\text{TM}}$. Moreover, the active nature of the designed tangible objects affords yet another interaction domain to the proposed TUI framework by allowing the real-time data input following users' interaction with the sensed environment. To this end, a range of sensor modules including; an ultrasonic distance sensor, a temperature/humidity sensor and a dual-axis joystick controller were electronically connected to the base units, which enabled the transmission of captured sensed information to the TUI processing server).

3.3 Digital Interaction

The digital augmentation of these physical models is primarily obtained via the perceptually and computationally coupled projection of visual information on the tabletop interactive surface. The graphical software was developed in C# on the Unity game engine environment with the integration of the reacTIVision framework established via the TUIO library and protocol [15]. The proposed framework allowed the embodiment of physical objects with digital information by spatially multiplexing output data in the perceptual proximity of the tangible manipulatives. Spatial freedom was provided by the developed software which allowed the unbounded placement of artefacts to enable users to experimentally construct ROS enabled IoT architectures. Furthermore, digital feedback considerations were embedded within the software architecture to indicate progress and pervasively guide users in understanding the underlying ROS operational concepts. Visualization of abstract and dynamically complex information relating to network component is coupled by displaying of information structures adjacent to tangible objects.

As shown in Fig. 4a, the internal topological table contained and updated within the master node controller of a ROS architecture is visualized to students and enables facilitated understanding by means of colour coding and structured graphics. This allows users to understand imminently the current state of the topology as well as the mode of operation of individual elements. Furthermore, this information is computationally coupled with the tangible object and is made available to users only on utilization and system detection of the assigned ROS master controller.

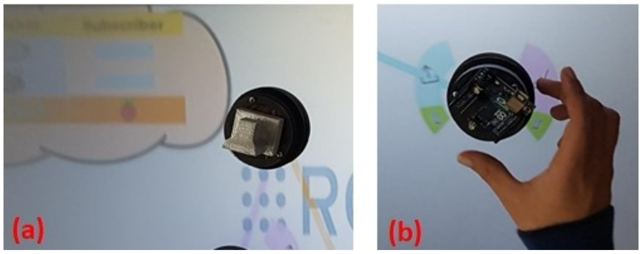

Figure 4: Perceptually and computationally coupled digital feedback projection:
a) Visualisation of abstracted information on objects,
b) Embodiment of rotational information menu.

Each IoT microcontroller nodes are augmented digitally by visualization of a configuration selection wheel, illustrated in Fig. 4b. This visualization prompts the user to instinctively interact by rotating a digital pointer and consequently assign and alter the mode of the node set into either publishing or subscription mode for available data transmission topics. Once a node becomes active within the topology, this triggers a link visualization between the node and the master controller, which students apprehend via colour-coded registration links, shown in Fig. 6a, as well as vibration and LED light feedback.

The detection of sensor modules triggers different animations which relate to the state of the data sensor and its connection status. As visualized in Fig. 5a, a data loss animation characterizes unconnected sensors together with a directional arrow suggesting to the student the direction of the closest node. Once the sensor is physically shifted to within the proximity range of a microcontroller node, the user is provided positive feedback via the light blinking of the status LED together with a haptic vibration pattern to signify a successful sensor unit connection. As pictured in Fig. 5b, the visual projections are also triggered and a serial data transmission animation is displayed emanating from the sensor. Moreover, a graphical symbol sequence illustrated in Fig. 5c interactively updates to reflects the user input value on active sensor measurement by altering graphical aspects in the thermometer colour or measuring tap distance.

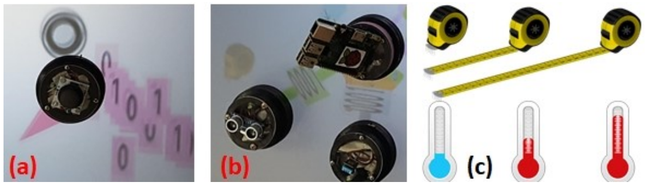

Figure 5: Sensor module status and visual feedback:
a) Unconnected sensor with data loss and directional guidance for link establishment,
b) Active sensor transmitting binary data to a node,
c) Animated imagery providing real-time measurement feedback from active sensor data.

Within the ROS architecture, once an active IoT node is receiving data from sensors, this can be configured to publishing mode, whereby a data topic gets broadcasted with the acquired real-time sensor measurement. The proposed framework aids the understanding of abstracted processes such as node data-fusion by providing animated illustrations of data transmission between distributed nodes. This occurs for every active node unit that is configured to subscribe to the same data topic. As shown in Fig. 6b a visualization is triggered that illustrates data packets flowing through topic links and subsequent information fusion occurring at the node prior to retransmission. Thus, the topologies in Fig. 6 illustrate the physical and digital integration provided by the proposed TUI framework which allows students to collaboratively configure and experiment with ROS-based IoT architectures whilst interactively understanding the underlying conceptual functionality.

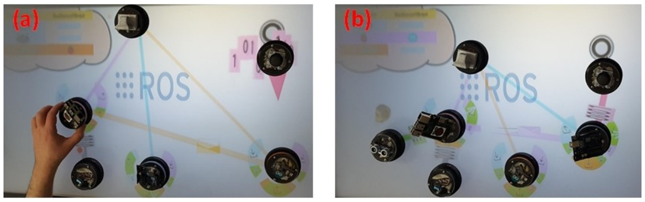

Figure 6: ROS-based IoT architectures communicating data.

4 Evaluation

The proposed TUI framework was evaluated via deployment within an undergraduate programme at Middlesex University Malta. Thirty-three (33) students reading a degree in Software Engineering were selected for the study based on their enrollment within a 'Systems Engineering for Robotics' module. The introduction to Robot Operating System (ROS) concepts forms a threshold concept within the progress of this module and impacts significantly on the student's capabilities of achieving the intended learning outcomes. To this end, the evaluation session was coordinated as to coincide with the appropriately scheduled lecture delivery within the module.

4.1 Evaluation Methodology

An evaluation methodology was implemented which was designed to yield a quantitative as well as observational analysis of the effectiveness of the proposed TUI framework. The former data was obtained by preparing assessment questions which covered both theoretical as well as practical design aspects of ROS architecture development. Observational information was acquired by developing a check sheet list of behavioural cues which would be noted during educational sessions. Fig. 7 outlines the sequential flow of student evaluation stages and split groups.

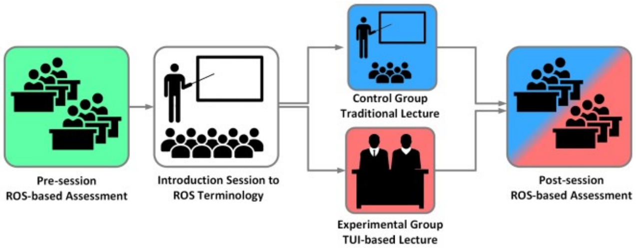

Figure 7: Evaluation stages designed for implementation within an HEI context.

To remove potential bias from student's apriori knowledge and exposure to advanced robotics concepts, all students were provided with a timed pre-assessment of ROS knowledge. A series of seven (7) questions were provided which covered a combination of theoretical knowledge, detail understanding as well as problem-based topology design. The results from this examination provided an individualistic knowledge baseline for each student prior to formally undertaking tuition.

Subsequently, as shown in Fig. 7, students attended together a short introductory session. This was delivered in conventional lecture format, whereby basic terminology and foundation principles were introduced. Following this session, the students were randomly split into two quasi-equal groups which composed the control and experimental groups respectively. The control session was designed to cover the explanation of ROS concepts using traditional educational technology making use of a smartboard, digital projection, and whiteboard fixtures. Following a lecturing session, students were provided with a case-based example on which they collaborated in pairs to solve the example problem on an active smartboard. On the other hand, the experimental group collectively attended a session covering the same content, yet explained using the proposed TUI framework. Similarly, to the control group, students were provided with the same case-based example problem, which they were encouraged to collaboratively solve by interacting on the TUI architecture in pairs. To reduce the potential of experimental bias, both sessions were timed to be of equal duration, observed using identical criteria, delivered by the same lecturer, and used the same topic slides. At the end of each session, students were once more assessed with a different assessment that again covered the same conceptual and practical knowledge of ROS principles.

4.2 Analysis of Results

Analyzing the combined pre-test scores from both groups in a means independent-sample t-test, highlights that no statistical difference or bias was present between the apriori knowledge of students ($p > 0.798$). This validates the randomness of the group split which shows that no statistically significant bias was present in the average technical knowledge between student groups prior to the lecturing session.

Making use of unique student IDs, the obtained results from post-tests were compared on an individual basis to the pre-test score for each separate student. These were subsequently analyzed using a paired-sample t-test. Thus, as illustrated in Fig. 8a, the control group, who initially held an average score of 41.1% (σ: 21.7), improved their average understanding to a post-test mean score of 69.4% (σ: 12.62) after the traditional lecturing session. Whilst the effectiveness of using traditional educational technology to teach and learn ROS concepts was evidenced in this cohort, even more, significant improvements were noted within the TUI experimental group. The latter, who initially held a similar level of knowledge about the subject (pre-test mean difference of 39.8%, σ: 17.1), registered an average post-test score of 82.3% (σ: 7.9). This substantial knowledge gain was further confirmed using an independent-sample t-test on both populations which, as shown in Fig. 8b confirmed at a 95% confidence interval ($p < 0.05$) that the proposed TUI framework yielded a net increase in ROS understanding by 14.6% (σ: 6.9) amongst the different lectured class groups.

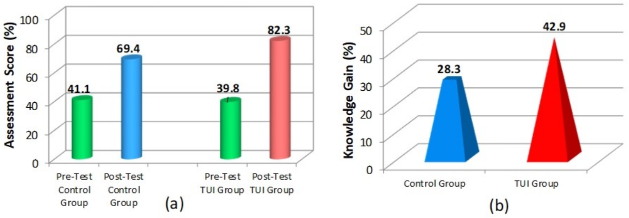

Figure 8: Evaluation results from both groups indicating:
a) Average score improvement in assessment,
b) Average knowledge gain from both pedagogies.

Furthermore, the behaviour analysis undertaken during both sessions outlined substantial differences in the level of engagement amongst students. In contrast to the traditional lecturing approach, TUI students were less easily distracted with personal devices and showed higher interest in interacting with the lecturing session. The latter was observed in both a heightened amount of investigative questions during delivery as well as significantly higher collaborative interaction between pairs of student whilst solving an IoT architectural oriented problem-based question. Positive behavioural observations were also instinctively noted from the lecturer, which whilst delivering the ROS session could make use of a much more intuitive and efficient educational technology for aiding explanation and conceptualization.

4 CONCLUSIONS

In light of the augmented demand for system and software engineering students in emerging MENA countries, this paper presents a novel TUI framework adapted for teaching and learning advanced robotic concepts in HEIs. A tangible framework was proposed which allowed the easier and more effective understanding of IoT network architectures, as well as aid in the design and development of Robot Operating Systems (ROS) topologies for these sensor networks. This was achieved by incorporating the innovative use of active tangible interaction on tabletop architectures for providing a blended physical/digital representation of input and feedback. The suitability of the proposed TUI system was objectively evaluated and quantified with respect to the effectiveness of traditional educational technologies. This paper further outlines the potential of TUI architectures to mitigate challenges in teaching and learning abstract and complex concepts within HEIs.

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REFERENCES

[1] Andruseac, G.G. and Iacob, R. 2013. Exploring the potential of using educational robotics as an effective tool to support collaborative learning. *E-Health and Bioengineering Conference (EHB)* (2013), 1–4.

[2] Armitage, A.F. 2001. Teaching Multitasking to Electronics and Computing Students. *International Journal of Electrical Engineering Education*. 38, 4 (Oct. 2001), 338–347. DOI:https://doi.org/10.7227/IJEEE.38.4.7.

[3] Astatke, Y. et al. 2016. Improving and Expanding Engineering Education in the Middle East and Africa Using Mobile Learning Technology and Innovative Pedagogy. *Advances in Engineering Education in the Middle East and North Africa.* Springer International Publishing. 235–260.

[4] Atmatzidou, S. and Demetriadis, S. 2015. Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences. *Robotics and Autonomous Systems.*

[5] Benitti, F.B.V. 2012. Exploring the educational potential of robotics in schools: A systematic review. *Computers and Education.*

[6] Ceccarelli, M. 2003. Robotic teachers' assistants - Low cost robots for research and teaching activities. *IEEE Robotics & Automation Magazine.* 10, 3 (Sep. 2003), 37–45.

[7] Clifford, K.L. and Zaman, M.H. 2016. Engineering, global health, and inclusive innovation: focus on partnership, system strengthening, and local impact for SDGs. *Global Health Action.* 9, 1 (Dec. 2016), 30175. DOI:https://doi.org/10.3402/gha.v9.30175.

[8] Cubero, S.N. 2015. A fun and effective self-learning approach to teaching microcontrollers and mobile robotics. *International Journal of Electrical Engineering Education.* 52, 4 (2015), 298–319.

[9] Dyne, M. Van and Fjermestad, J. 2012. Robotics in education: a tool for recruiting, engaging, retaining and educating students. *Proceedings of the 12th WSEAS International Conference on Robotics, Control and Manufacturing Technology (ROCOM '12).* (2012), 196–201.

[10] Fiorentino, M. et al. 2010. Tangible Interfaces for Augmented Engineering Data Management. *Augmented Reality.* InTech.

[11] Giuseppe, A. and Martina, P. 2012. Educational Robotics Between Narration and Simulation. *Procedia - Social and Behavioral Sciences.* 51, (2012), 104–109. DOI:https://doi.org/10.1016/j.sbspro.2012.08.126.

[12] Hernandez-Barrera, A. 2014. Teaching introduction to robotics: Using a blend of problem- and project-based learning approaches. *Conference Proceedings - IEEE SOUTHEASTCON* (2014).

[13] Ishii, H. 1998. Tangible Bits: Beyond Graphical User Interface. *APCHI '98 Proceedings of the Third Asian Pacific Computer and Human Interaction* (1998), xvii.

[14] Ishii, H. 2008. The tangible user interface and its evolution. *Communications of the ACM.* 51, 6 (2008), 32–36. DOI:https://doi.org/10.1145/1349026.1349034.

[15] Kaltenbrunner, M. et al. 2005. TUIO: A protocol for table-top tangible user interfaces. *Neuroinformatics.* (2005), 1–5.

[16] Kaltenbrunner, M. and Bencina, R. 2007. reacTIVision: a computer-vision framework for table-based tangible interaction. *Proceedings of the 1st international conference on Tangible and embedded interaction.* (2007), 69–74. DOI:https://doi.org/10.1145/1226969.1226983.

[17] Kennedy, T.J. and Odell, M.R.L. 2014. Engaging Students In STEM Education. *Science Education International.* 25, 3 (2014), 246–258.

[18] Kuc, R. et al. 2004. Teaching Introductory Autonomous Robotics With JavaScript Simulations and Actual Robots. *IEEE Transactions on Education.* 47, 1 (2004), 74–82.

[19] Lucignano, L. et al. 2014. My hands or my mouse: Comparing a tangible and graphical user interface using eye-tracking data. *Fablearn 2014 (No. EPFL-CONF-204226).* (2014).

[20] Marshall, P. et al. 2007. Are tangible interfaces really any better than other kinds of interfaces? *CHI'07 workshop on Tangible User Interfaces in Context & Theory.* i (2007), 28.

[21] Mitnik, R. et al. 2008. An autonomous educational mobile robot mediator. *Autonomous Robots.* 25, 4 (2008), 367–382.

[22] Mondada, F. et al. 2016. R2T2: Robotics to integrate educational efforts in South Africa and Europe. *International Journal of Advanced Robotic Systems.* 13, 5 (Sep. 2016), 172988141665816.

[23] Nel, H. et al. 2017. AfrikaBot: Design of a Robotics Challenge to Promote STEM in Africa. Springer, Cham. 500–509.

[24] Norton, S.J. et al. 2007. Problem solving in a middle school robotics design classroom. *Research in Science Education.* 37, 3 (2007), 261–277.

[25] Perera, C. et al. 2014. Sensing as a service model for smart cities supported by Internet of Things. *Transactions on Emerging Telecommunications Technologies.* 25, 1 (Jan. 2014), 81–93. DOI:https://doi.org/10.1002/ett.2704.

[26] Petrolo, R. et al. 2017. Towards a smart city based on cloud of things, a survey on the smart city vision and paradigms. *Transactions on Emerging Telecommunications Technologies.* 28, 1 (Jan. 2017), e2931.

[27] Quigley, M. et al. 2009. ROS: an open-source Robot Operating System. *Icra.* 3, Figure 1 (2009), 5.

[28] De Raffaele, C. et al. 2017. Designing a Table-Top Tangible User Interface System for Higher Education. *IEEE International Conference on Smart Systems and Technologies (SST)* (Osjiek, Croatia, 2017).

[29] De Raffaele, C. et al. 2017. Explaining multi-threaded task scheduling using tangible user interfaces in higher educational contexts. *2017 IEEE Global Engineering Education Conference (EDUCON)* (Apr. 2017), 1383–1390.

[30] De Raffaele, C. et al. 2016. Teaching and learning queueing theory concepts using Tangible User Interfaces. *2016 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)* (Dec. 2016), 194–201.

[31] De Raffaele, C. et al. 2017. The Application of Tangible User Interfaces for Teaching and Learning in Higher Education. *Innovative Teaching and Learning in Higher Education.* J. Branch, ed. Libri Publishing. 215–226.

[32] De Raffaele, C. et al. 2016. The aptness of Tangible User Interfaces for explaining abstract computer network principles. *Proceedings - Frontiers in Education Conference, FIE.* 1–8.

[33] Ramadi, E. et al. 2016. Engineering graduates' skill sets in the MENA region: a gap analysis of industry expectations and satisfaction. *European Journal of Engineering Education.* 41, 1 (Jan. 2016), 34–52. DOI:https://doi.org/10.1080/03043797.2015.1012707.

[34] Shaer, O. and Hornecker, E. 2009. Tangible User Interfaces: Past, Present, and Future Directions. *Foundations and Trends® in Human–Computer Interaction.* 3, 1–2 (2009), 1–137. DOI:https://doi.org/10.1561/1100000026.

[35] Sirowy, S. et al. 2009. Virtual microcontrollers. *ACM SIGBED Review.* 6, 1 (Jan. 2009), 1–8. DOI:https://doi.org/10.1145/1534480.1534486.

[36] Strawhacker, A. et al. 2013. TUI, GUI, HUI: Is a bimodal interface truly worth the sum of its parts? *Proceedings of the 12th International Conference on Interaction Design and Children* (2013), 309–312.

[37] Tarlochan, F. and Hamouda, A.M. 2016. A Framework for Developing Innovative Problem-Solving and Creativity Skills for Engineering Undergraduates. *Advances in Engineering Education in the Middle East and North Africa.* Springer International Publishing. 161–186.

[38] Weiss, B. et al. 2005. A Case Study In Efficient Microcontroller Education. *ACM SIGBED Review.* 2, 4 (Oct. 2005), 40–47.

[39] Zeidler, D.L. 2016. STEM education: A deficit framework for the twenty first century? A sociocultural socioscientific response. *Cultural Studies of Science Education.* 11, 1 (Mar. 2016), 11–26.