Coupling Haptic Learning with Technology To Advance Informal STEM Pedagogies

Dr. Mohamed ElZomor, Florida International University

Dr. Mohamed ElZomor is an Assistant Professor at Florida International University (FIU), College of Engineering and Computing and teaches at the Moss School of Construction, Infrastructure and Sustainability. Dr. ElZomor completed his doctorate at Arizona State University (ASU), Ira A. Fulton Schools of Engineering. Prior to attending ASU, Dr. ElZomor received a master’s of science degree in Architecture from University of Arizona, a master’s degree in Engineering and a bachelor of science in Construction Engineering from American University in Cairo. Dr. ElZomor moved to FIU from State University of New York, where he was an Assistant Professor at the college of Environmental Science and Forestry. Mohamed’s work focuses on Sustainability of the Built Environment, Engineering Education, Construction Engineering, Energy Efficiency Measures and Modeling, Project Management, and Infrastructure Resilience. Dr. ElZomor has extensive professional project management experience as well as a diverse cross-disciplinary academic knowledge. Mohamed, distinct expertise supports fostering interdisciplinary research in addition to embracing innovative pedagogical approaches in STEM education. Dr. ElZomor has been integrating innovative and novel educational paradigms in STEM education to support student engagement, retention, and diversity.

Prof. Omar Youssef, University of Arizona

Dr. Omar Youssef is a Lecturer at University of Arizona (UofA), College of Architecture, Planning, and Landscape Architecture, and the School of Sustainable Built Environments. A Building Scientist in the Institute on Place and Wellbeing Performance. An Architect in Practice focusing on Environmental Application within the Industry. Dr. Youssef has extensive industry experience of constructed large-scale projects. Omar’s interdisciplinary background combines between Architecture Practice, Environmental Sciences, Health and Wellbeing. His teaching responsibilities are focused on Environmental Technology as well as Design and Energy Conservation, the core of the School’s STEM programs. Dr. Youssef has introduced cutting edge technology and virtual reality to his classes (both in person and online) and currently plays an active role on the School’s Technology Stream Committee, Digital Technology Committee, and the University Level Digital Technology Advisers.
Coupling Haptic Learning with Technology
To Advance Informal STEM Pedagogies

Abstract
Research in the field of engineering education highlights the ineffectiveness of one-way, lecture-based teaching and strongly advocates that faculty adopt new pedagogies that integrate technological tools. Such strategies actively engage learners and support their understanding. To revolutionize the traditional haptic learning pedagogy, Virtual Reality (VR) can be incorporated to support science, technology, engineering, and mathematics (STEM) students’ level of learning, advance their communication skills and enhance problem-solving skills. VR is a technological tool that immerses students in the real built environment and utilizes different parts of the brain to access auditory and visual data. This ongoing, work in progress, research study describes the process of interweaving between engineering, technology, architecture and building sciences, through integration of VR. VR was used to leverage a seamless virtual application thus complementing theories with unlimited interactive pedagogies, which kept learners engaged, interested and ultimately fosters retention particularly in haptic courses. Specifically, this study integrates the VR technology into an Environmental Science Laboratory to support teaching, enhance students’ understanding, and increase retention as well as triggering an interactive educational environment. This paper focuses on the method of advancing haptic learning with VR through introducing and analyzing five modules taught in a building sciences laboratory course in addition to sharing limitations and some lessons learned of this pedagogy. Consequently advancing an unorthodox pedagogical approach that not only provides students with a unique educational experience but also equips them with know-how and knowledge to utilize emerging technologies.

Project Goals and Objective
The goals of this research are to (1) incorporate VR to revolutionize learning through experiential simulations; (2) advance students’ engagement through modeling various spatial representation of data to align with building sciences; and (3) foster an informal learning environment that provides technological knowledge to advance our future workforce requirements. The research objective is to demonstrate an opportunity to implement a novel haptic learning environment, which increases learners’ engagement, supports course completion that reflects an indirect gauge to retention and facilitates understanding complex engineering concepts through technological simulations.

Introduction and Motivation
The President’s Council of Advisors on Science and Technology encourages developing innovative teaching practices, to improve student retention and enhance their learning experiences [1]. Research reveals that STEM and building sciences are taught in a straightforward way based on fragmented concepts rather than embracing technology and creative problem solving skills [2]. Although problems related to innovative pedagogies that train STEM students have been enhanced through for example vertically integrating courses that support students learning and trainings [3], there remain challenges associated with student engagement that has led to less STEM graduates in recent years. Therefore, it has become necessary to address student engagement by fully immersing learners in real world context to
develop more challenging examples that relate their coursework to real life experiences [4]. Another concerning fact is that between 400 to 800 Million of today’s jobs will be automated by 2030 [5], which means that technology will become a vital tool that students must master. US Department of Commerce projects that 40% of existing jobs are in danger of shifting to automation within 10 Years [6]. It is imminent that educators realize that the timeworn pedagogies do not encourage student engagement, nor prepare for their future careers. Therefore, transitioning to technological pedagogy that integrates different engagement activities supports teaching vital skills to future workforces.

The revolution of technology has brought paradigm shift in the way instructors teach and students learn in STEM through technology specifically VR [7]. VR is an emerging technology that enables learners to immerse into different built environments by observing three-dimensional (3D) model [8]. Research has been supporting informal and immersive learning environments due to their effective educational impacts [9, 10]. Haptic learning is one solution to advance learners’ understanding through physical interactions [11]. However there remains a gap in the educational implementations that combine technology and haptic learning specifically in STEM. This study fills the literature gap by demonstrating an ongoing pedagogy that combines haptic learning with VR into one learning environment. This technological haptic learning implementation was incorporated into an Environmental Science Laboratory, thus supported teaching, enhanced students’ understanding, increased course completion retention and triggered an interactive educational environment.

**Implementation of five modules to developing Haptic learning into Building Sciences**

The authors categorized this implementation as work in progress as it requires further supported and developed data analysis. However, the study is an ongoing research incubator, specifically as it integrated best technological practices and established learners’ interest. The integration of VR into Building Sciences was implemented four times. These four identical implementations are the pilot approach Fall 2015, initial implementation Fall 2016, the full implementation Fall 2017, and Best Practice implementation Fall 2018 which will be the focus of this paper. The course content, including the below five modules as well as all deliverables, has been identical throughout the four years of this study. This section presents and analyzes the five modules of the built environment that were integrated into Environmental Science Laboratory along with planned future work for modules three, four and five. The five modules are (1) NATURAL VENTILATION - Visually Experiencing Air; (2) THERMAL COMFORT – Visually Experiencing Heat; (3) AUDIBLE COMFORT- Visually Experiencing Sound; (4) DAYLIGHT - Visually Experiencing Light; (5) SHADING - Visually Experiencing Shade.

To implement these modules, various technical tools and laboratory equipment were utilized to successfully develop haptic learning modules (Table 1). Table 1 demonstrates the equipment associated with each module, its usage and proposed future equipment that might enhance the haptic learning pedagogy.
Table 1: Equipment & Tools for each module, its usage and proposed future amendments

<table>
<thead>
<tr>
<th>Module #</th>
<th>Used Equipment</th>
<th>Usage</th>
<th>Proposed / Future Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HED Wind Tunnel</td>
<td>26' long open circuit boundary layer contractionless wind tunnel</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>6-Sided Cave Cube</td>
<td>Real-Time 3D Stereo Immersive Graphics</td>
<td>Add Synchronized Fans, that would simulate the flow of air to demonstrate xxx method</td>
</tr>
<tr>
<td>3</td>
<td>FLIR T1020 HD Thermal Imaging Camera</td>
<td>Thermal images</td>
<td>FLIR UAS Thermal Imaging Solutions for Airborne Imaging, to replace three different equipment Instruments with one</td>
</tr>
<tr>
<td>4</td>
<td>PROTEMEX MS6708 Digital Sound Level Meter Noise Meters Decibel Tester</td>
<td>A Mannequin Head</td>
<td>3Dio professional binaural microphones that are the premier 3D audio recording device for ASMR, virtual reality (VR), field recording and recording studios as this device is optimized for 3D audio capturing.</td>
</tr>
<tr>
<td>5</td>
<td>Overcast Sky Simulator + Li-Cor light sensors mounted to a 12 channel Megatron data logger</td>
<td>3.8K Rylo 360° Action Video Camera with Helmet Mount</td>
<td>GoPro 360 Fusion camera will be coupled in this contraption as it provides an opportunity to mask all the equipment, which were semi-seen in the initial attempt.</td>
</tr>
<tr>
<td>6</td>
<td>Shading HelloLux</td>
<td>Enscape + HTC Vive</td>
<td>Future work: this module may be further enhanced when integrating Rhino 6 + Mindestek 2.0.0 + Grasshopper XR + Honeybee + Radiance for simple daylight analysis in VR. The purpose of the complexity will lead students to change variables through real-time and experience real-time light mapping of these spaces specifically on two planes (horizontal and vertical).</td>
</tr>
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</table>

• **Module One: (NATURAL VENTILATION)- Visually Experiencing AIR**

The first module describes Computational Fluid Dynamics (CFD) technology to analyze airflows within the building geometry then use VR for post-processing to effectively communicate with non-CFD experts thus helping students visualize such complex concepts. To achieve this, students were asked to immerse in an environment where they could experience visual simulations of airflow and temperature distribution in the built environment. Two different configurations were tested. The first reflects an outdoor environment scenario where students are able to design and place in real-time wing walls and other elements to redirect, increase or obstruct the flow of air, as learners study the aerodynamic properties of the building envelop. The second reflects an indoor scenario where students are able to manipulate the design properties within a section of a space as they study the importance of introducing denser cool air towards the bottom of spaces where typically humans occupy a space. Thus understanding the typical flow of air into the built environment. Learners take into account the fact that as cool air becomes warmer it stratifies and travels upwards; thus students presented scenarios where they were able to design spaces that direct cool air towards the bottom and drive the warm air through their ceiling design outwards in both residential and commercial spaces. An example that


students’ experience is a relevant simulation conducted in a hospital room with the implementation of raised floor systems with displacement ventilation and return vents above patient beds. This module develops mastery of natural ventilation and its possibilities to reduce energy use through utilization of a boundary layer contractionless wind tunnel apparatus, equipped with turbulence development and test chambers. Figure 1 demonstrates the three-dimensional airflow, which was overlaid onto a 3D modeling software and visualized through a backlit cube and mirrored projection. The 6-sided CAVE, i.e. a cube (2.5 m x 2.5 m x 2.5 m) with real-time image projection on all six sides. By means of an electromagnetic tracking system the viewer can move in (or around) the visualized object. This installation is preferably for one viewer. The effectiveness of this application was due to no real-time between the visualization and the CFD-simulation, where the geometry and boundary conditions could be changed through the learners’ controllers as they navigate the space.

![Figure 1: The Wind Tunnel and a unique 3D stereo immersive graphics visualization system](image)

**Module One Procedures:**
1. Select/Design a space to investigate Natural Ventilation and identify the region of study; 2. Analyze the climatic data to identify the bioclimatic needs for that region, with a special focus on designing for indoor and outdoor spaces using specifically designed architectural features; 3. Build/Test two types of models to visually re-investigate both the “quantity” and quality of natural ventilation (a. A scaled physical model (painted black to contrast the available white smoke) to be placed in a boundary layer contractionless wind tunnel apparatus, equipped with turbulence development and test chambers, where students will access a 2-dimensional laminar air flow to test the effectiveness of their design; b. A computer generated model (using any 3d software selected by the student) where a 3-dimensional airflow will be overlaid onto their design and projected in the 6-sided CAVE. Students will visually see air as it flows around and in their spaces); and 4. Document both processes in a report for handout and prepare a graphical oral presentation.

**Module Two: (THERMAL COMFORT) – Visually Experiencing HEAT**

Typical areas that affect the human thermal comfort or thermal performance of spaces are visible to the naked eye. However through the application of VR and other technological apparatus the following fundamentals were explained in class: (1) Heat transfer; (2) Infiltration/exfiltration; (3) Internal gain; (4) Insulation; and (5) Electric leaks/wiring gaps/electric shortcut. This module was divided into two portions (Figure 2). The first was an opportunity to demonstrate the importance of the thermal environment that was accomplished through FLIR VR Simulator, which is an interactive experience that transported students from the classroom into a simulated
real-world scenario. Students were also able to prepare a deliverable in this module via YouTube 360°, where students used Google Cardboard viewers for head tracking 360 video experiences. The main goal of this module is the visual demonstration of heat transfer between devices and materials. The haptic learning was further honed to explain internal gain and insulation through the VR experience. Furthermore, students were able to realize the importance of insulation in construction. The second portion of this module was to use the FLIR T1020 HD Thermal Imaging Camera and assembling climate stations to capture environmental variables of selected sites with the aid of drone photogrammetry. Afterwards, with the use of VR technology learners were required to digitally illustrate the human response to thermal comfort.

![Image](image.png)

Figure 2: This module provides a thorough understanding of methods of investigating human thermal comfort indoors and outdoors using data acquisition systems.

Module Two Procedures: 1. Select a pre-determined location on campus to investigate factors that impact outdoor human thermal comfort; 2. Build and Assemble climate stations to be placed; 3. Measurements of atmospheric conditions will be documented (a. Material types; b. Wind speed; c. Solar radiation (thermal camera) and dry bulb temperatures; d. Daylight); 3. Students will model their pre-assigned outdoor space using a 3d modeling software of their choice. (a. Materials documented on site will be assigned accordingly; b. Windflow will be assigned in 3d modeling software to simulate tree movement appropriately; c. Heat map to demonstrate temperatures, and solar radiation will be overlayed on the model; and d. Daylight will be used to demonstrate the sun location, sun brightness, and overall model brightness in the model); 4. The VR will be used to experience all pre-documented observations in the space; 5. Students will need to change features of their model to change experiences to suite a thermally comfortable outdoor environment; and 6. Document both processes in a report for handout and prepare a VR accessible human responses presentation.

• Module Three: (AUDIBLE COMFORT)- Visually Experiencing SOUND

Students used binaural recording to record noise in spaces that could be mapped in a 3D environment. Students created a contraption where they were able to place two PROTOMEX MS6708 Digital Sound Level Meter Noise Meters Decibel Tester on each ear of a mannequin along with a microphone. This creates an opportunity to visually map the corresponding noise/sound level with the actual sound. A 5.8K Rylo 360° Action Video Camera was mounted on a helmet to 3D map the surrounding area of the projected human experience. The use of technology in this module, supports analyzing the sound data logger to test urban noise, then use an Oculus Go Device to help learners experience changes in various sound levels in real-time. To create a dynamic learning environment, students were encouraged to develop architecture acoustic barriers to block noise or reflect sound that would advance sound levels beyond the
The introduction of different levels of sounds at different reverberation times took a new dimension through using 3D audio to immerse learners into virtual environments. This module is not as elaborate as other modules as the process is rudimentary compared to the other modules, and is a more exhausting documenting process for the students with less experience. Through this technique students will be able to refine their surrounding environments to minimize noise levels, and enhance intelligent speech.

Figure 3: Analyze site acoustics and identify factors contributing to noise and focuses on noise mitigation strategies

Module Three Procedures: 1. Select/Design a space to investigate sound and noise in your surroundings, and identify the type of location to be studied (person populated, traffic heavy, etc.); 2. Identify the acceptable sound/noise levels in area of select and investigate using assigned sound level meter; 3. Document sound levels in the area; 4. Use a 360 camera to record the surrounding area and document human interaction will simultaneously document the location and associated sound level; 5. Overlay urban sound levels on the recorded environment, and use VR to demonstrate existing conditions; and 6. Document both processes in a report for handout and prepare a graphical oral presentation.

Future work: the authors will integrate a 3Dio professional binaural microphones that are the premier 3D audio recording device for ASMR, virtual reality (VR), field recording and recording studios as this device is optimized for 3D audio capturing. This process is conducted by capturing audio using two microphones that are shaped like human ears. Binaural microphones capture audio the same way as humans' ears hear sounds. The ears (pinnae) dramatically alter the incoming sound waves, but our brains understand these alterations as directional cues. When students listen to binaural recordings using headphones, the result is a natural three-dimensional sound that provides the listener with a sensation of being in the space where the audio was recorded. In addition, a GoPro 360 Fusion camera will be coupled in this contraption as it provides an opportunity to mask all the equipment, which were semi-seen in the initial attempt. These upgrades will result in a more realistic experience that immerses learners to an advanced engagement through module three.

• Module Four: DAYLIGHT - Visually Experiencing LIGHT

An alternative environment for the assessment of adequate daylight distribution in spaces, and identifying potential areas of glare or other forms of visual discomfort. Students coupled the use of an overcast sky simulator measuring light intensity inside a module with 6 cosine corrected Li-Cor light sensors mounted to a 12 channel Megatron data logger. A GoPro camera was mounted inside the simulator to provide visual support of the infinite mirror reflector condition.
where students placed their actual built models. After this first exercise students achieve a baseline that could be used as a reference to measure towards and a 60fc benchmark to achieve throughout the space. Students modeled their spaces using various 3D modeling software and used Lumion to export a 3D scenario where other learners and professors would have an opportunity to be immersed in the designed environment and then rate their visual perception of the space (Figure 4). The space that was selected for students to design was an art gallery and were required to demonstrate areas of exhibition that had no direct light, which may impact the exhibit.

![Figure 4: Using the Overcast Sky Simulator to understand critical factors of successful implementation of daylight into the built environment](image)

Module Four Procedures: 1. Students will investigate the effective window placement in an art gallery to create even light distribution in the space, without compromising wall real-estate; 2. Construct a scaled model that represents the space and explore its daylight variations; 3. An overcast sky simulator will be utilized for the assessment of light distribution patterns through photometric measurement of model interior; 4. Students to build a 3d model using Sketchup or REVIT software and export model to Lumion rendering to simulate interior light conditions. Then render/export VR accessible videos that will demonstrate the daylight experience in the space; 5. Focus on design proposal to promote light intensity and distribution inside the space; and 6. Document both processes in a report for handout and prepare a graphical oral presentation.

Future work: this model can rely on an integration of plug-in software that would run a series of computer generated scenarios to test the light conditions, and document space responses according to the strategies the students are testing. This module may be further enhanced when integrating Rhino 6 + Mindesk 2.0.0 + Grasshopper XR + Honeybee + Radiance for simple daylight analysis in VR. The purpose of the complexity will lead students to change variables through real-time and experience real-time light mapping of these spaces specifically on two planes (horizontal and vertical).

• **Module Five: SHADING - Visually Experiencing SHADE**

Students were required to precisely design shading devices that created shadow lines using profile angles to demonstrate exact shading techniques for building fenestrations. Students were divided into groups and each team use corresponding profile angles to effectively size horizontal and vertical shading devices that will fully shade a 4x4 window for the period April 21st to August 21st from 9:00AM to 3:00PM solar time. The steps of this activity were as follows: Firstly, students build physical model to create a basecase scenario that would be verified using a
shading heliolux and azimuth protractor. Secondly, students used Sketchup and Revit Modeling software to create their models and changing the software time to solar time and not clock time. Thirdly, models were imported to Enscape 2.0 where students created a series of scenarios to display their work. Finally, students provide real-time rendering and VR mode workflow inside Enscape to be viewed through HTC Vive. Students used seated mode to change the time of day and thus change the shadow perceptions of the space and ultimately be able to visually experience the expected full shading result (Figure 5).

Figure 5: Understand fenestrations, building shading and their effect/s on energy use and comfort

Module Five Procedures: 1. Students will investigate the most effective way to reduce solar radiation on building fenestrations and to intercept direct radiation from the sun. This process will overlook both building shading and precise window shading; 2. Use a 3d software (to be selected by students) to generate preselected model by instructors. (Based on theoretical information provided in class, students to design preliminary shading devices, they expect to provide complete shading); 3. Models to be imported to Enscape, and run through VR. Students should use sun location tool in software to test their predesigned shading devices; and 4. Document both processes in a report for handout and prepare a graphical oral presentation.

Future work: this module may be further enhanced by implementing techniques to experience augmented reality specifically for this module where students would not need to work on an actual physical model to create their basecase but rather use a Microsoft Hololens to build group based 3D models, and demonstrate the real-time changes in both the architectural features and shadow conditions.

Results and Discussions

This section presents results from the implementation assessments. To address the research question, understanding the effectiveness of implementing technological haptic learning on learner’s performance, the study compared students’ grades in one deliverable. This deliverable was assessed by the same instructor and thus a comparison between the grades in a semester without integrating VR (Fall 2014 semester) was compared to students’ grades when VR was included. Although the instructor’s learning curve when implementing VR in the course differed from one semester to the other, the course content has been identical throughout this study. Figure 1 documents student grades on one deliverable; students’ grades have been increasing on
average when VR is introduced. Specifically, the letter grade “A” increased from 47% of students to 85%, while the Letter grade “B” decreased from 35% to 15% and the letter grade “C” dropped from 17% to 0%. Comparing the deliverable grade between the two student bodies show that students registered through the haptic learning environment received a better grade than those not introduced to this implementation. Although each semester has its own unique students’ performance pertaining to this deliverable, the grades show a consistent overall improvement. The instructors believe that integrating technology into the laboratory course, makes the different modules interesting as well as enhances students’ engagement levels and in return supports their course performances.

Another aim of the four implementations is to develop an appreciation to how the technological skills learned in courses translate into ability to be successful in any future careers as well as support retention, which will be measured through course completion in this study. Specifically in the researchers’ institute, environmental building sciences or architecture students usually not drop form major, but rather transfer between those disciplines. Therefore, the researchers decided to measure the success rate of this implementation through monitoring the number of students dropping from the course, which in turn can be an indirect indication to the retention in the major. Before the VR implementation, two students opted to drop the course; however in the next four semesters where the haptic learning implementations were applied, only one student dropped. A recurring qualitative feedback received by all students at the beginning of each semester is: their interest in learning from this course. Students mentioned their peers’ advice and encouragement to register for this haptic learning experience. Also, students collectively indicated that this class is unique and engaging. Furthermore, students expressed their excitement to receive opportunities to more than a dozen software, instruments, and state-of-the-art technologies. The only negative comment is that this course is very demanding and places learners in more challenging situations.
**Limitation and Challenges**

Although this research intended to develop a transferable haptic learning environment, the implementations included various practice as well as assessment method limitations.

- **Assessment of student performance**: The study used one deliverable as a metric to assess the effectiveness of the implementation for improving student performance. The deliverable is a presentation that is held towards the last third of the course. This deliverable might not be the best representation of students’ development in this course, however it is a uniform assessment that was applied throughout all the implementations.

- **Despite that the same instructor throughout this study evaluated the assessment metric, both the instructor’s familiarity with VR and the student populations changed from one implementation to the other. Thus, their demographics may have also been different, which may have impacted their performance.**

- **Indirectly assessing retention**: The study did not plan for tracking students beyond one semester. However, the fact of zero drop rates across all implementations demonstrated the students’ intent to complete the course, which indirectly reflects staying in the major and thus indirectly implying retention. The drop rate was monitored post the drop and add week.

- **Technology and equipment**: this study depended on integrating equipment and technology to fully integrate an effective haptic learning environment. Purchasing the required equipment to implement the informal learning environment of haptic learning strongly depends on technology. The accessibility and availability of funds to purchase such equipment and tools might hinder this implementation.

**Recommendation for Future Research**

This section discusses the lessons learned from the past four implementations, highlighting the changes in approach and plans for the next implementation.

- **The next implementation will integrate different classes from other universities. This will provide an interdisciplinary education and thus can support accreditations, AEC, that advocate for interdisciplinary components. The authors plan to integrate a sustainable course from another university, which will facilitate a virtual collaborate working environment. This integration will serve interdisciplinary studies, which means different schools will provide different component to a shared project/research rather than replicating modules and/or comparing results.**

- **Due to that universities are gearing towards online education, this framework can provision the different educational modes (online, face-to-face and hybrid) as it promotes VR. Online students will be required to purchase equipment that align with the VR’s requirements to support their learning. Although the expectations of dissimilar students’ educational modes may slightly differ during any offered course, faculty may opt to pair online students with face-to-face ones so that all receive the same learning experiences precisely when conducting experiments. Such course readjustments nurtures peer learning and develops a sense of community to online students thus indirectly support their retention.**

- **Faculty office hours will include an additional hour that will be held virtually, where the faculty will open a VR platform so that students can virtually access the faculty’s office/space during office hours to interact and ask questions. This component complements and supports fully immersing students into a technological learning environment.**
Conclusion

This study integrated an emerging technology, Virtual Reality, to advance the haptic learning in building sciences. VR successfully connected between engineering, technology and building sciences while simultaneously placing students in the context of the built environment. Based on the transferable five modules, STEM and building sciences can implement these modules with similar approaches to enhance student retention in courses. Results suggest that immersing students in informal teaching environments support their engagement, as these encourage students to develop their technological knowledge that is strongly required in our evolving career markets. Advancing haptic learning through technology has provided students with an informal learning environment that supports their active learning and offers a cutting-edge technological knowledge.

References


