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Article

Improving the practical skills of STEM students at a historically black college and university (HBCU)

Yasser Ismail[1,*], Phyllis Okwan[2], Fahmi Khalifa[3], Albertha Lawson[4], Fred Lacy[1]

[1] Department of Electrical Engineering, Southern University and A&M College, LA 70813, USA
[2] Department of Mathematics and Physics, Southern University and A&M College, LA 70813, USA
[3] Department of Electrical and Computer Engineering, Morgan State University, Baltimore, MD 21251, USA
[4] Science/Mathematic Education Doctoral Program and Interim Dean of Graduate School, Southern University and A&M College, LA 70813, USA
*** Corresponding author:** Yasser Ismail, yasser_ismail@subr.edu

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Abstract: Improving the practical skills of Science, Technology, Engineering and Mathematics (STEM) students at a historically black college and university (HBCU) was done by implementing a transformative teaching model. The model was implemented on undergraduate students of different educational levels in the Electrical Engineering (EE) Department at HBCU. The model was also extended to carefully chosen high and middle schools. These middle and high school students serve as a pipeline to the university, with a particular emphasis on fostering growth within the EE Department. The model aligns well with the core mission of the EE Department, aiming to enhance the theoretical knowledge and practical skills of students, ensuring that they are qualified to work in industry or to pursue graduate studies. The implemented model prepares students for outstanding STEM careers. It also increases enrolment, student retention, and the number of underrepresented minority graduates in a technology-based workforce.

Keywords: STEM education; retention; industry skills; Dewey's philosophies; Piaget's philosophies; Internet of things (IoT); robotics; artificial intelligence

1. Introduction

Historically black colleges and universities (HBCUs) play a vital role in shaping the future of underrepresented groups in science, technology, engineering, and mathematics (STEM), given their rich history and cultural significance (Chng et al., 2023; Njenga et al., 2023). There are challenges faced and the solutions crafted to bridge the gap between theoretical knowledge and practical application, contributing to a discourse that aims not only to educate but also to empower the future leaders of STEM. Through a combination of experiential learning, mentorship programs, and tailored curricular enhancements, this initiative seeks to create a holistic learning environment where students not only grasp theoretical concepts but also gain hands-on experience, fostering a comprehensive understanding of STEM principles (Chang et al., n.d.; Neher-Asylbekov and Wagner, 2023). This exploration into the transformative journey of enhancing STEM education at HBCUs contributes to the broader discourse on fostering diversity and excellence in STEM education on a larger scale. The rich history and cultural significance of HBCUs provide a distinct backdrop for educational endeavors, with a commitment to fostering academic success and shaping the future of underrepresented groups in STEM (Bell et al., 2022; Taylor and Wynn, 2019). By delving into the challenges and solutions in bridging the gap between theoretical knowledge and practical application, creating a paradigm that seeks to educate and empower the next generation of STEM professionals is very crucial. This can be achieved through experiential learning, mentorship programs, and tailored curricular enhancements, the initiative aims to create a holistic learning environment where students gain hands-on experience, fostering a comprehensive understanding of STEM principles (Yannier et al., 2020). This exploration into the transformative journey hopes to contribute to the broader discourse on enhancing STEM education at HBCUs and, by extension, fostering diversity and excellence in STEM on a larger scale.

As the industrial landscape continues to evolve, the demand for a diverse and skilled workforce in STEM fields has become increasingly pronounced. HBCUs are emerging as crucial contributors to this demand, offering a unique pool of talent that brings a rich tapestry of perspectives and experiences. Industry leaders recognize the distinct value that HBCU students bring, not only for their academic prowess but also for the practical skills and knowledge they possess. As a result, imperative of equipping students with robust practical skills in STEM education becomes an important demand to fulfill a quality that aligns seamlessly with the dynamic needs of the industry (Jaeger et al., 2021). The HBCU framework is instrumental in fostering diversity, inclusivity, and excellence in STEM disciplines, providing a distinctive edge to students. Every day, the industry acquires specific new practical skills and knowledge from HBCU students, shedding light on the symbiotic relationship between HBCU education and the evolving demands of the workforce (Perez et al., 2023).

HBCUs encounter challenges in knowledge and practical skills development, potentially leading to deficiencies in preparing students for the dynamic landscape of science, technology, engineering, and mathematics (STEM) industries (Mullen, 2014; Raf, 2014). Additionally, practical skills deficiencies can result from a lack of robust experiential learning programs and industry-aligned curricula. These challenges may impede the seamless transition of HBCU students into professional roles that demand theoretical understanding and hands-on expertise. Addressing these issues requires concerted efforts to enhance resources, expand experiential learning opportunities, and establish stronger connections between academia and industry, ensuring that HBCU graduates are well-equipped to meet the demands of the evolving STEM workforce.

This paper explores the development, implementation, and evaluation of an innovative model aimed at enhancing the preparedness of historically black colleges and universities (HBCU) STEM undergraduate students. The model is centered around a multifaceted approach aimed at engaging students in industry-relevant projects within a cutting-edge computer engineering research lab (CERL). Key components of the model include the establishment of the CERL, which serves as a hub for hands-on research projects, and the introduction of a web-based module providing essential learning resources for project execution. Additionally, training programs are developed to empower senior high-school students to undertake industry-related projects in the CERL. The model also includes initiatives to promote the CERL through workshops and activities tailored for students in non-electrical engineering disciplines.

A critical aspect of the model is the rigorous evaluation of learning outcomes, ensuring that students are equipped with the necessary skill sets for success in their careers or further studies. Furthermore, the model aims to increase enrollment and retention within the Electrical Engineering (EE) Department, thereby contributing to a higher number of underrepresented minority graduates entering technology-focused professions. The unique feature of the CERL lies in its emphasis on collaborative, hands-on research projects, fostering innovation and engagement across various levels of undergraduate STEM students within the EE Department. By providing students with real-world experience and practical skills, the model aims to prepare them for the challenges of today's technology-driven industries.

1.1. Literature review

In the dynamic landscape of contemporary employment and academia, possessing a robust foundation in essential skills transcends mere advantage; it has become an indispensable prerequisite for success. Employers and industry now place heightened emphasis on candidates who not only exhibit academic proficiency but also demonstrate strong communication, knowledge, hands-on skills, and critical thinking abilities. These foundational competencies serve as the bedrock for effective collaboration, problem-solving, and innovation across a myriad of industries. Moreover, individuals are expected to showcase a nuanced understanding of global issues pertinent to their field, alongside a genuine commitment to continuous learning and personal development (Copple et al., 2020; Murphy and Kelp, 2023).

Alboaouh (2018), Wilson and Marnewick (2018), Quintero et al. (2023) illuminate a concerning gap between the skillsets cultivated in higher education institutions and the competencies sought after by employers. This gap is further underscored by reports from the United Nations Development Program (UNDP), which highlight pervasive concerns about the sustainability of knowledge societies in the face of widening knowledge disparities and a burgeoning youth population (UNDP, 2014). Similarly, insights from the UAE report reveal a significant mismatch between the skills possessed by incoming employees and those required for entry-level positions, indicating a systemic issue that warrants urgent attention (UNDP, 2014).

To effectively address this disparity, collaborative efforts between educational institutions and employers are imperative. A paradigm shift is needed in educational approaches, one that goes beyond traditional classroom instruction to prioritize the cultivation of practical skills essential for real-world application. This paper advocates for an integrated educational model that seamlessly blends academic learning with experiential opportunities, industry partnerships, and community engagement initiatives. By immersing students in authentic learning experiences, such as internships, research projects, and service-learning endeavors, educational institutions can empower students to develop the adaptive competencies and resilience needed to thrive in dynamic professional environments (Borrageiro and Mennega, 2023; Colleagues and Desjardins, 2012).

Research findings and numerous studies have underscored the critical importance of hands-on and practical skills in shaping individuals' success trajectories within various industries. For instance, research by Mtshali and Ramaligela (2022) emphasizes how individuals with strong hands-on skills are better positioned to secure stable employment and command higher wages compared to those lacking such proficiency. Furthermore, studies conducted by Volansky (2020), Urban (2023), reveal a strong correlation between hands-on skills and increased job satisfaction and retention rates, highlighting the multifaceted impact of practical proficiency on workplace dynamics.

Moreover, beyond its immediate implications for employment, literacy proficiency plays a crucial role in fostering broader societal inclusion and civic engagement. As emphasized by Lewis-Spector (2016) individuals with strong literacy skills are better equipped to participate meaningfully in civic activities, exercise their rights, and engage in informed decision-making processes. Additionally, literacy proficiency serves as a cornerstone for lifelong learning, enabling individuals to adapt to evolving job requirements, pursue further education, and navigate complex information landscapes in an increasingly digital world.

Overall, the significance of literacy proficiency extends far beyond its direct implications for employment, encompassing broader dimensions of social inclusion, civic participation, and lifelong learning. Recognizing the pivotal role of foundational skills like literacy is paramount for fostering inclusive societies and empowering individuals to thrive in an ever-changing global landscape.

1.2. Industrial applications

The applied model aims to increase its students' practical skills and knowledge through the development of hands-on, industry-based projects and mentoring undergraduate students to implement industry-based projects. Undergraduate students are chosen to become peer mentors and teach hands-on industry-based projects to pre-college students. The selected hands-on projects cover high-tech applications such as the Internet of Things (IoT), robotics, homeland security, smart cities, artificial intelligence (AI), and many other modern industry-based applications. Training undergraduate students in the EE Department to implement such projects and applications gave the students valuable knowledge and skills. The IoT is recognized as one of the most important areas of future technologies and is gaining vast recognition in a wide range of applications. It creates a global network of machines and devices that can communicate with each other. Security cameras, sensors, vehicles, buildings, and software are examples of things that can exchange data with each other.

The IoT is used in many applications such as healthcare, transportation, agriculture, and automated shopping. Remote healthcare has become a vital service with the growing rate of senior citizens. IoT platforms offer promising technology for health monitoring, rehabilitation, and assisted living for elderly and medically challenged humans (Ismail et al., 2021; Mahmud et al., 2017; Opeyemi Peter et al., 2020). Using the IoT infrastructure in the medical field requires affordable, low-power, reliable, and wearable devices that will improve the quality of life for many elderly and physically challenged people (Raad et al., 2021; Verma and Prabhu, 2023). In transportation applications, the IoT can be used to count the number of cyclists and pedestrians on roads and highways. Understanding the travel behavior of pedestrians and cyclists on roadways is critical in evaluating safety outcomes relative to rates of exposure, identifying appropriate, context-sensitive complete street infrastructure interventions, and understanding overall state-wide and location-specific transportation trends (Bertolusso et al., 2022).

In agricultural applications, the IoT can be used to connect video surveillance systems to monitor and collect large volumes of data remotely and analyze them in near real-time. This helps farmers optimize their operations through site-specific or variable rate applications targeted for a variety of crops, nutrients, herbicide and water needs, post-harvest handling, and transportation (Khaleefah et al., 2023; Konain et al., 2023; Sharma et al., 2023). An intelligent shopping system is another application that uses the IoT. As an example, the IoT is used for monitoring specific users' purchasing habits in a store by tracking their specific mobile phones. Later, in conjunction with AI algorithms, collected data could provide users with special offers on their favorite products or even the location of items that they need (Ismail et al., 2016; Jayaprakash and Fancy, 2017; Khaleefah et al., 2023).

The implemented model further offers students robotics-based projects to be implemented in the CERL. Robotics are used in many fields such as health care, agriculture, food preparation, manufacturing, and the military. In healthcare applications (Sai et al., 2023), robotics can be used to control tiny, precise instruments inside the patient's body. This allows for minimally invasive procedures in surgeries such as cardiac, colorectal, gynecologic, head and neck, thoracic, and urologic. In agriculture applications, autonomous robotic systems that automate operations like pruning, thinning, mowing, spraying, and weed removal, can be used (Khalid et al., 2023). Sensor technology can be utilized with robotic systems to manage pests and diseases that affect crops. Robotic chefs (Sochacki et al., 2023) can also be used to prepare and cook hundreds of meals in a home kitchen. This robotic chef can be controlled via a smartphone, and once the controller chooses a recipe and arranges pre-packaged containers of cut and prepared ingredients, the robot will be able to cook the predetermined meal quickly and efficiently. Also, in manufacturing applications, robots are being used to help increase productivity and efficiency while lowering production costs (Jimenez et al., 2022). Many robots in manufacturing collaborate with workers to perform repetitive, monotonous, or intricate tasks under the worker's guidance and control. Whereas in the military (Gnanaprakasam et al., 2023), robotic technology is being applied in many areas. One highly visible area involves unmanned drones. These machines can be used for surveillance and support operations on the battlefield. It is worth mentioning that the model offers many other projects based on the student's needs, to be implemented in the CERL. The research team offers tools, knowledge, lectures, and mentoring to students to be able to implement these projects in the CERL.

1.3. Main contribution

Industry-based applications need highly qualified students who have practical skills and solid knowledge. The implemented model provided undergraduate STEM students with practical skills through the implementation of industry-based projects in the computer engineering research lab (CERL). All supplies and software needed to implement the industry-based projects are available in the CERL. The learning resources of industry-based projects are available in the CERL-Web database. All industry-based learning resources and projects available in the CERL-Web are provided by the project team who have been in consultation with industry partners. Both CERL and CERL-Web empower students to engage in practice sessions at their convenience, regardless of location or time constraints. Building rich industry-based learning resources for undergraduate students gives the students the theoretical foundation that is required to implement projects in the CERL.

The CERL-Web database incorporates the most recent learning resources and the latest updates to keep pace with changing technology. CERL-Web has a superior advantage over modules suggested by other researchers (Gopu, 2015; Habib, 2011), in that they not only provide undergraduate students with fundamental knowledge but also provide them with up-to-date industry-based learning resources and tools. CERL and CERL-Web are complementary to each other at which CERL-Web database provides all the industry-based learning resources that are needed for students to implement their projects in the CERL. In this paper, we will call both CERL and CERL-Web as CERL model.

2. Materials and methods

The objective of the CERL model was to implement skill sets that align with the mission of the EE Department at HBCU. The mission of the EE department is to prepare and enhance the theoretical knowledge and practical skills of students so that they are better qualified to work in industry or pursue their graduate studies in industry-based fields. To achieve this mission, the model accomplished five objectives: (1) establish the computer engineering research lab (CERL) at the Electrical Engineering Department. Industrial-related projects were offered to STEM students to be implemented in the CERL. The research team gave lectures, mentored students, and supervised the execution and implementation of the projects in the CERL; (2) implement and develop the CERL-Web module, to provide STEM students with the learning resources needed to implement projects for select courses in the CERL; (3) develop research programs that give more attention to college students to implement industry-related projects in the CERL; (4) publicize the CERL model (CERL and CERL-Web) through organizing workshops for different disciplines; and (5) evaluate the learning outcomes of the CERL model. The success of the CERL model increases the participation of HBCU graduates in technology and industry-based workforce.

It is worth mentioning that the CERL and CERL-Web allow undergraduate students in the EE Department to have more hands-on industry-based learning resources, tools, and practical skills. The students who used the CERL model gained knowledge and skills that qualified them to join the workforce or pursue their graduate studies.

2.1. Theoretical framework

The implemented model agrees with John Dewey's philosophy of progressivism which assumes that education should create a relationship between the student and society. The model suggested in this paper required engineering students to visit high schools and middle schools so that they could successfully act as leaders in the outside environment. This allowed students to focus on the democratic process and learn as exploration (Dewey, 1934, 1963, 1998, 2005). Piaget's philosophy also follows progressive views on education but allows for constructivist activities that help students gain a more complete understanding of the world and the cultures around them. Dewey's and Piaget's philosophies support models that allow for constructivist activities that help students gain a more complete understanding of the world and the cultures around them. However, these philosophies have yet to be tested on EE students (especially at an HBCU) utilizing the CERL model. Using the industry-based knowledge, skills, and resources provided by the CERL model, the constructs of Dewey and Piaget's theories can be tested, and the project team will be able to build a new teaching research lab model for STEM student success in the EE Department. The new teaching research lab model can be replicable in other disciplines and other universities.

The philosophy of the CERL teaching model is that undergraduate students gain inherent knowledge and useful skills from outside practical experience. When these are shared with professors, industry mentors, and peers, it results in a model of enhanced learning and increases student success in the classroom. Faculty and students participate in the learning process and, as a result, students obtain practical skills that are required for student success in a technologically based workforce. Student success is defined by (1) accumulated GPA; (2) student retention; (3) graduation rates; (4) student placement in a STEM-related workplace; and (5) student pursuit of graduate studies in STEM-based disciplines.

Table 1. Learning environment theory of the CERL model.

Curriculum (project-based and discovery).	Engaging in learning enhancement and enhancing students' industry-based knowledge and skills.
Instructional method (Face-to-Face, Web module)	Anytime/anywhere
Physical setting (classrooms, labs, and makerspace)	Independent or collaborative

Table 1 represents the learning environment theory, a central component of the CERL teaching model. This theory delineates the learning environment into three components: (1) curriculum; (2) instructional methods; and (3) physical setting. The CERL teaching model strategically elevates the learning experience by furnishing students with the practical skills and knowledge essential for undertaking electronics-based projects, many of which are integrated as course projects in select courses. The collaborative exposure of learning resources among instructors of these courses facilitates curriculum enhancements, aligning them more closely with industry demands. Consequently, the amalgamation of learning resources and practical skills provided by the CERL teaching model cultivates deep and critical thinking among STEM students. The model employs diverse instructional methods, allowing students continuous access to learning resources, tools, and practical skills, both within the physical lab and through the web-based CERL-Web module. The project team employs face-to-face communication to announce available resources, tools, and practical skills within classrooms, elucidating their utilization through the web-based

module. Industry-based projects offered by CERL-Web are tailored to cater to all levels of undergraduate STEM students, while the cloud-based CERL-Web module enriches students with accessible learning resources stored in Makerspace. The physical setting of the learning environment accommodates independent and collaborative work, with undergraduate students, industry supervisors, and instructors serving as key participants in the dynamic activities of the CERL model.

Figure 1 below describes the project's theoretical framework. The learning resources and practical skills provided by the CERL model enhance the independent learning of undergraduate students through the construction, activity, and reflection phases of the model. Student engagement in projects was enhanced through the collaboration and evolution phases. The activities promote reflections and collaborations that are necessary for a higher level of student learning evolution. The diversity of project activities inside and outside the CERL model enhances the undergraduate students' critical thinking. The outcomes of the CERL model were tested using approximately 226 students (including all levels of EE students). More attention was given to seniors and juniors, to prepare them for the industry workforce environment as well as be peer mentors for the high school interns.

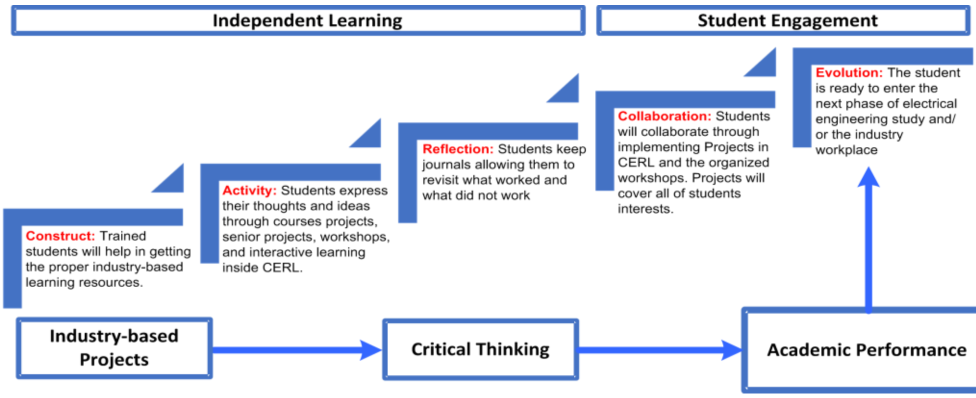

Figure 1. Detailed theoretical framework.

2.2. CERL model methodology

Figure 2 represents the flowchart of the CERL (CERL, and CERL-Web) model implementation steps. The construct phase of the theoretical framework phases will be achieved through the first and the second steps while industry-based learning resources, tools, and practical skills are provided by the CERL, and CERL-Web. These learning resources are decided based on pre-meetings with industry advisors, selected instructors, and undergraduate and graduate students who work for the industry. Based on these meetings, the project team incorporated industry-based learning resources into the CERL model. The CERL and CERL-Web are continually updated and enriched by learning resources from student feedback in selected courses as seen in step 3 of **Figure 2**. The remaining four phases of the theoretical framework (activity, reflection, collaboration, and evolution) are achieved during the execution of steps 3 and 4 in **Figure 2**.

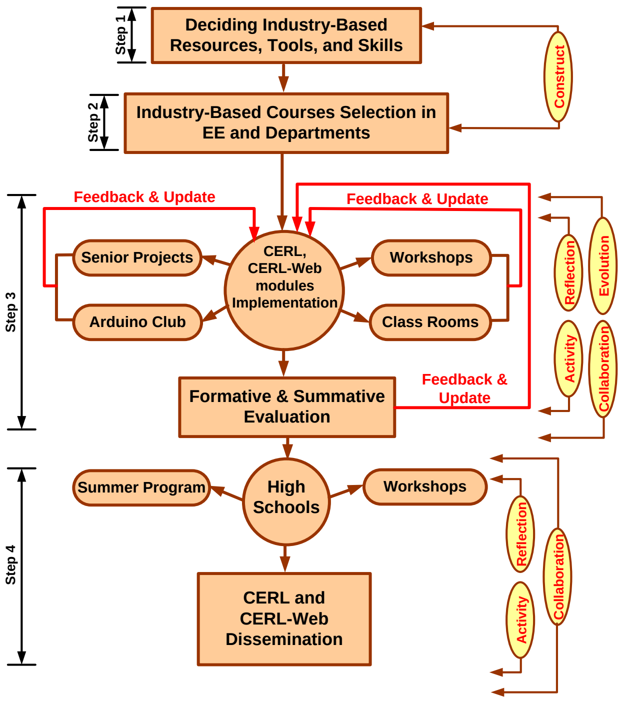

Figure 2. A flowchart of the project implementation steps and the corresponding theoretical framework phases.

Once the industry-based learning resources, tools, and practical skills are decided (steps 1 and 2), the project team will start implementing the CERL and CERL-Web (step 3). Some activities will help in the publicity and the update process of the learning resources provided by the CERL-Web module, such as (1) organizing workshops for undergraduate students and their faculty members, (2) giving short talks by the project team, inside the classrooms of selected courses to explain to undergraduate students how the CERL model can help them enhance their industry-based practical skills; and (3) offering innovative industry-based project ideas for STEM undergraduate senior students and Arduino Club. Feedback is obtained from all students who are using the CERL model and from pre-college students after participation in workshops. This was done to enable students to receive the maximum benefits from the use of our CERL and CERL-Web.

Using a suitable assessment plan, data is collected and evaluated to measure the outcomes of the project. The evaluation process was used as a dynamic tool to update/enhance the learning resources of modules; thus, making them more innovative and more up-to-date (as seen in step 4).

In addition to equipping undergraduate students, the CERL model also provides services to high-school and middle-school students in part of the south-eastern area through school visits and organized workshops. These workshops spark interest in engineering and encourage high-school senior students to select engineering, especially electrical engineering when they enroll in college. Some selected high-school teachers are also selected to participate in both the summer program and the workshops for high-school students. These activities will increase the ability of teachers to conduct projects with their students throughout the school year.

2.3. Data type and collection process

Qualitative research methodologies were used to develop the theory of the CERL teaching model. To measure the effect of using the CERL model on undergraduate student learning and skill acquisition, we pursued two research questions; Q1: To what extent are the industry-based learning resources and tools offered by the CERL model suited to different undergraduate students' levels in the EE program? and Q2: Are there correlations between the use of industry-based learning resources and tools provided by the CERL model and student success? To answer the two questions, data from six (6) selected courses in the EE Department was collected for assessment. The results of the assessment are used as feedback to improve the model resources and projects for undergraduate students. The assessments of the model were done through questionnaires, CERL-organized workshops, senior projects reports, average GPA for students in the selected course, face-to-face communication with undergraduate students, reactions after the short talks given by the project team inside the selected classrooms, feedback from stakeholders (industry trained graduates, instructors, and industry advisors). All collected data were analyzed to answer the above-mentioned two questions (Q1 and Q2). From the data analysis, the industry-based learning resources and tools were modified to provide maximum enhancement of the undergraduate students' learning. The research team annually recruited seven (7) Electrical Engineering (EE) students, totaling eighteen (18) students throughout the project duration. These students underwent comprehensive training to proficiently utilize the educational resources available through the CERL database (CERL-Web) for the execution of industry-aligned projects within the CERL. Leveraging their expertise, these trained students subsequently facilitated the training of 226 undergraduate students enrolled in courses specified in **Table 2**. Moreover, they extended their instructional support to include 150 high school students and engaged eight (8) teachers from four (4) distinct high schools.

Table 2. Students' classification for the selected courses.

Course \ Student classification	Freshmen	Junior	Senior	Total # of students enrolled
ENGR 130 (freshman engineering II)	(150)			150
ELEN 304 (intro to microprocessor)		(18)		18
ELEN 493 (senior design project I)			(15)	15
ELEN 494 (senior design project II)			(10)	10
ELEN 419 (VLSI)		(4)	(8)	12
ELEN 417 (image and video processing)		(4)	(5)	9
ELEN 464 (robotics and embedded systems)		(8)	(4)	12

2.4. Industry-based learning resources and tools

The implemented model concentrates on using up-to-date industry-based learning resources and tools that were provided by the CERL-Web. The learning resources include state-of-the-art industry-based applications such as IoT infrastructures and their applications, AI, Web-based programming, mobile applications, traffic monitoring, video surveillance systems, robotics, autonomous connected cars, energy-smart grids, and patient monitoring systems. These applications are used by most industry-based leading Hi-tech companies such as AT&T, IBM, Intel, Apple, Dell, and Microsoft (AT&T, 2022; IBM, 2022; Intel, 2022; Microsoft, 2022; Verizon, 2022). Referring to **Figure 3**, the learning resources and tools provided by the CERL-Web are initially decided, once the project team interviews industry advisors, instructors of selected courses, and undergraduate and graduate students who work in the industry.

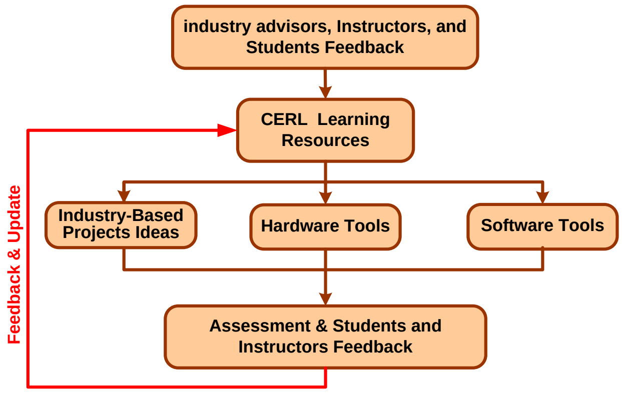

Figure 3. CERL learning resources update process procedure.

The learning resources can be generally divided into three categories: industry-based project ideas, hardware tools, and software tools. These categories should contain data that is suitable for freshmen, junior, senior undergraduate students, and high-school senior students. Arduino microcontroller, surveillance cameras, robotics, and raspberry pi are examples of the hardware that will be provided by the CERL. The software resources are expected to provide information about the programming languages used in CERL.

After the initial learning resource contents are decided, the CERL can be developed. All learning resources and software/hardware information posted on the CERL database were updated periodically, based on the feedback provided by the assessment tools, students, and faculty members. One thing that should be considered when implementing the CERL-Web module is the ease of use of all developed. All learning resources and software/hardware information posted on the CERL database were updated periodically, based on the feedback provided by the assessment tools, students, and faculty members.

One integral factor that was considered during the implementation of the CERL-Web module was its user-friendliness for all students. Implementing a well-designed module is poised to facilitate better training of undergraduate students, ultimately enhancing the practical skills of both students and instructors. All learning resources provided by the modules are free and open access for undergraduate students and their faculty. Complete details about the database of the modules can be found elsewhere (Ismail, 2019).

2.5. Selected CERL courses

The proposed CERL model was implemented on selected EE courses that are related to industry projects (Ismail, 2019). To present the model to students; three steps were implemented inside the classrooms of those courses: (1) the research team met with the instructors of such courses to get feedback from them about the industry-based course projects that could be offered for the students in these courses; (2) the research team gives a short talk in the classrooms of these courses to introduce the CERL and to introduce students to all facilities, tools, lectures that will be provided by the CERL model; and (3) teach students of the selected classes how to use the web-based database (i.e., CERL-Web module) to get access to all available resources. **Table 2** illustrates the student classification and enrolment numbers for the selected courses. The selection of such courses is based on achieving the maximum industry-based knowledge and practical skills for freshmen, junior, and senior students.

CERL modules provide students with the learning resources and software/hardware to perform industry-based projects for the following selected course.

ENGR 130 (freshman engineering II). C++ programming language is taught in these courses. A project was suggested for those courses that use microcontroller devices. This allows new students to pursue projects related to smart cities which use industry-based infrastructure such as the Internet of Things structure (IoT). The ENGR course is a general course that is taught for all engineering departments (electrical, mechanical, and civil). It is selected to help transfer high-tech skills and knowledge to students of different departments. This will help in the project publicity process.

ELEN 304 (intro to microprocessor). Robotic-based projects were offered for this course by the CERL-Web module. Students get all the required tools and equipment to implement their projects in the CERL. The project team implements and monitors the execution phases of the robotics-based projects in the CERL.

ELEN 493 (senior design project I) and ELEN 494 (senior design project II). Because students are responsible for selecting their capstone projects, the project team contacts the course instructors to encourage them to suggest industry-based related projects for students. Many advanced industry-based projects are offered by the CERL-Web module and students will have access to the CERL and its tools to implement these projects.

ELEN 419 (very large-scale integration—VLSI). This course is very important for students who plan to work in the hi-tech industry. Connecting several video surveillance systems using the Internet of Things (IoT) infrastructure is one of the suggested projects for this course. This course helps students understand the principles and design of the IoT infrastructure.

ELEN 417 (advanced topic—image and video processing). In this course, students gain experience in the field of image processing. This is used in many applications related to object detection and tracking algorithms and video processing algorithms. Counting pedestrians and cyclists is one of the main offered projects for this course. Understanding concepts from this project is required in new smart cities while designing the infrastructure of new streets and traffic signals. Field programmable gate array (FPGA) tools and IoT infrastructure is widely used in such projects to connect several different entities.

ELEN 464 (mechatronics—robotics and embedded systems). Using microcontrollers (e.g., Arduino and Raspberry pi) and understanding the principle of using robotics in real life is an important topic covered in this course. This class offers many practical projects that are used in applications such as military, and smart cities. The CERL-Web module offers learning resources to get the practical skills of using microcontrollers.

It is worth mentioning that implementing industry-based projects in the CERL for students allows them to collaborate and share their ideas and practical skills. These skills are very important for industrial projects since those projects are multidisciplinary and require teamwork.

3. Results and discussion

In the inaugural phase of model implementation, the project team embarked on a collaborative journey with industry partners and esteemed course instructors to construct a dynamic database brimming with hands-on projects tailored to meet the diverse needs of students, industry supervisors, and graduate professionals actively immersed in the industry. Drawing upon a wealth of collective expertise, the team conceived an array of project ideas meticulously curated to cater to students at varying levels of proficiency and experience. A cornerstone of this endeavor was the meticulous selection of equipment, tools, and kits, each meticulously chosen to align seamlessly with the unique requirements of the envisioned projects. By ensuring the availability of specialized resources tailored to the specific demands of each project, the team laid a robust foundation for an immersive and enriching learning experience. Furthermore, the iterative refinement of the CERL-Web module stood as a testament to the project team's unwavering commitment to excellence and adaptability. Periodic updates to the module, informed by invaluable feedback solicited from students actively utilizing the CERL, served to enhance its functionality and relevance, ensuring that it remained a dynamic and indispensable resource for all stakeholders involved. This collaborative effort exemplified the fusion of academic rigor with real-world applicability, as industry insights were seamlessly integrated into the educational framework, bridging the gap between theory and practice. The resulting database not only provided a wealth of opportunities for experiential learning but also served as a catalyst for innovation and interdisciplinary collaboration, fostering a vibrant ecosystem of exploration and discovery within the academic community.

The integration of the CERL model across diverse courses has yielded profound benefits, notably enhancing students' practical skill sets by infusing class projects into the curriculum. By incorporating hands-on projects from the extensive CERL-Web database, students are empowered to engage with projects aligned with their interests and proficiency levels, thereby fostering a personalized and immersive learning experience. The breadth and depth of projects available within the CERL module afford students the opportunity to cultivate a diverse array of practical skills and knowledge domains, transcending traditional classroom boundaries. This multifaceted approach not only augments students' understanding of the foundational concepts underlying their chosen courses but also nurtures a spirit of exploration and innovation.

The tangible impact of this pedagogical approach is evidenced by the high retention rates observed in classes adopting the CERL model. **Figure 4**, depicting exemplary student grades across select courses, attests to the efficacy of this methodology in facilitating academic excellence. Such outcomes underscore the transformative potential of the CERL model, signaling its capacity to elevate retention and graduation rates across a broader spectrum of courses within the EE Department and beyond. The scalability and versatility of the CERL model position it as a potent tool for enhancing academic outcomes and fostering student success. By extending its application to a wider range of courses within the engineering discipline, institutions stand to reap the benefits of heightened engagement, retention, and ultimately, elevated graduation rates. As a catalyst for academic excellence and student empowerment, the CERL model represents a paradigm shift in engineering education, heralding a future where hands-on learning and real-world application converge to shape the engineers of tomorrow.

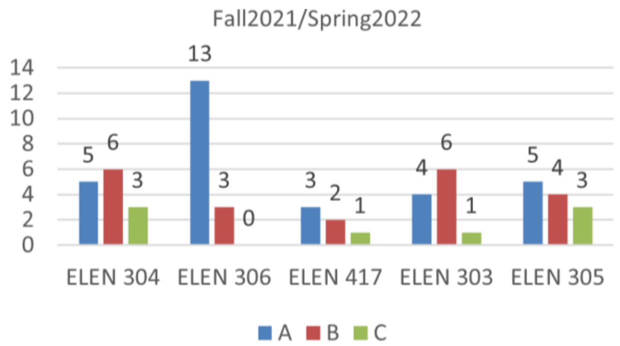

Figure 4. Grade distributions of the students in the selected courses.

Furthermore, based on observing students before and after the CERL model as well as feedback from students, incorporation of this model into a curriculum will produce strong leaders. Because of the leadership and practical skills that students learn in the CERL, students obtained industrial or corporate internships and received job offers. Thirteen (13) students of our research team received industrial internships and five (5) students received job offers from different companies.

Publicity of the CERL model occurs through organizing workshops for students. Organizing such workshops helps high school students learn about electrical and computer engineering and it helps undergraduate students (on the research team) to be leaders and gain self-confidence on how to present and organize such events.

One of the important objectives of the CERL model is to allow high school teachers to acquire practical skills in implementing robotics-based experiments so that they can teach and implement them with students in their classrooms. During the implementation of the CERL model, many teachers were trained at different schools (middle and high schools) on how to implement such projects and they also received lectures on the importance of electrical and computer engineering in real life and industry. This will help teachers and pre-college students better understand engineering, and thus help more students select engineering as their major in college.

Enrolment data from the institution (Ismail, 2019) shows that there is an increase in the number of EE students by approximately 70% in Fall 2021 compared to Fall 2020. This increase is expected after the visits to different high schools in the area. These visits to high schools were made by the research team to introduce students to the EE program through projects from the CERL-Web module. In addition to these visits, the research team organized several workshops at the CERL for high school students to implement several projects.

It is also noted that the graduation rate of EE students (Ismail, 2019) increased by approximately 20% in Fall 2021 compared to the graduation rate in Fall 2020. This increase is expected because student grades are higher in major courses since projects are related to course subjects. This graduation increase is considered a success indicator for the EE Department.

Additionally, the CERL model helped students who are classified in the disability services category and who registered for EE courses. The CERL-Web provides these students with projects that help them understand EE course materials and help them pass their courses.

A formative evaluation was completed by students in selected courses in the EE Department. After completing a project(s), students completed a questionnaire, and the results were tabulated. Moreover, a survey was also conducted with high school students after they completed projects at workshops using the same questionnaire. Based on their knowledge level, appropriate projects were selected for the high school and undergraduate students during the workshops. They were required to give a summary of what they liked and disliked in the offered projects and if there were any suggestions.

Formative highlights

In the inaugural year, undergraduate participation comprised 50% seniors, 26% juniors, 6% sophomores, and 18% freshmen. The initial questionnaire category gauged students' readiness for CERL-Web projects to fulfill academic goals, yielding overwhelmingly positive responses with 84% feeling "well prepared or prepared." Subsequently, the assessment of project team supports garnered exceptional feedback, with 98% expressing satisfaction. Transitioning into the second year, the team organized workshops for high school students, resulting in 95% feeling adequately prepared for academic pursuits and 96% satisfied with project team assistance. Despite demographic shifts, with 30% seniors, 44% juniors, 7% sophomores, and 19% freshmen, satisfaction levels remained high at 93% readiness and 95% satisfaction with project team support. Entering the third year, high school student feedback remained overwhelmingly positive, with 99% satisfied with project team support. Among undergraduates (57% seniors, 34% juniors, 9% sophomores), 100% reported feeling prepared for academic goals and 100% expressed satisfaction with project team assistance. Leveraging comprehensive survey data, an external evaluator conducted an assessment leading to CERL resource enhancements, ensuring alignment with student needs and expectations.

4. Conclusion

A research/educational CERL model has been successfully implemented in the Electrical Engineering (EE) Department. The model improves the research and practical skills of EE students. The model successfully increased enrolment in the EE Department by approximately 70% in Fall 2021 compared to Fall 2020. This increase is due to several high school visits and workshops that were organized and conducted by the research team. After implementing the proposed model in the EE Department, the graduation rate increased by approximately 20% in Fall 2021 compared to the graduation rate in Fall 2020. This is due to the extensive efforts done by the research team inside the classrooms for most of the major courses in the EE Department. The model can be implemented in any department after the projects have been designed for that department. The model proves its usefulness in High and Middle Schools. The feedback from the school students indicates that they benefit from the projects and their knowledge or understanding of engineering increased through implementing selected projects from the CERL model. Implementing this model in an engineering department will produce high-quality leaders who will be better equipped to join the work industry or pursue graduate studies.

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References

Alboaouh, K. (2018). The Gap Between Engineering Schools and Industry: A Strategic Initiative. 2018 IEEE Frontiers in Education Conference (FIE). https://doi.org/10.1109/fie.2018.8659314

AT&T. (2022). Available online: https://www.business.att.com/solutions/Portfolio/internet-of-things/?WT.srch=1&source=ECPS0000000PSM00P&wtpdsrchprg=AT%26T%20ABS&wtpdsrchgp=ABS_SEARCH&wtPaidSearchTerm=+iot&wtpdsrchpcmt=+iot&kid=kwd-52105739259&cid=783501308&schParam=1622&LNS=PS_IT_IOT_UNB_1117 (accessed on 4 March 2023).

Bell, E., Seymore, K., Breen, S., et al. (2022). Empowering Black Scientists in STEM: Early Success of the Black Biomechanists Association. Biomedical Engineering Education, 2(2), 113–121. https://doi.org/10.1007/s43683-022-00078-z

Bertolusso, M., Spanu, M., Pettorru, G., et al. (2022). A Machine Learning-based Approach for Vehicular Tracking in Low Power Wide Area Networks. 2022 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB). https://doi.org/10.1109/bmsb55706.2022.9828755

Borrageiro, K., & Mennega, N. (2023). Essential Skills Needed in the Fourth Industrial Revolution (4IR): A Systematic Literature Review. 2023 IST-Africa Conference (IST-Africa). https://doi.org/10.23919/ist-africa60249.2023.10187815

Chang, Y. S., Wang, Y. Y., & Ku, Y. T. (2023). Influence of online STEAM hands-on learning on AI learning, creativity, and creative emotions. Interactive Learning Environments, 1–20. https://doi.org/10.1080/10494820.2023.2205898

Chng, E., Tan, A. L., & Tan, S. C. (2023). Examining the Use of Emerging Technologies in Schools: A Review of Artificial Intelligence and Immersive Technologies in STEM Education. Journal for STEM Education Research, 6(3), 385–407.

https://doi.org/10.1007/s41979-023-00092-y
Colleagues, O., Desjardins, R. (2012). Better Skills Better Jobs Better Lives: A Strategic Approach to Skills Policies.
Copple, J., Bennett, N., Dudo, A., et al. (2020). Contribution of Training to Scientists' Public Engagement Intentions: A Test of Indirect Relationships Using Parallel Multiple Mediation. Science Communication, 42(4), 508–537. https://doi.org/10.1177/1075547020943594
Dewey, J. (1934). Art as experience. New York: Perigee Books.
Dewey, J. (1963). Experience and Education. New York: Macmillan.
Dewey, J. (1998). How we think: A restatement of the relation of reflective thinking to the educative process. In: Rev. (editor). Houghton Mifflin.
Dewey, J. (2005). Democracy and education. Stilwell, KS: Digireads.com Publishing.
Gnanaprakasam, C., Swarna, M., Geetha, R., et al. (2023). A Novel Design of Smart and Intelligent Soldier Supportive Wireless Robot for Military Operations. 2023 International Conference on Advances in Computing, Communication and Applied Informatics (ACCAI). https://doi.org/10.1109/accai58221.2023.10199831
Gopu, V. (2015). Field Monitoring and Measurements Education: A Model for Civil and Environmental Engineering.
Habib, E. (2011). Collaborative Research: Development of Adaptable Web Modules to Stimulate Active Learning in Hydrology using Data and Model Simulations.
IBM. (2022). Available online: https://www.ibm.com/internet-of-things?S_PKG=-&Matchtype=b (accessed on 4 March 2023).
Intel. (2022). Available online: https://www.intel.com/content/www/us/en/internet-of-things/overview.html?cid=sem43700032463403707&intel_term=%2Bintel+%2Biot&gclid=Cj0KCQjwl7nYBRCwARIsAL7O7dH4r8VIW5CTjRPa4vRXbASxjORbQvoKZsGfizRPHKNdHkO5-FDX1j4aAndeEALw_wcB&gclsrc=aw.ds (accessed on 4 March 2023).
Ismail, Y. (2019). Computer Engineering Research Lab (CERL) model. Available online: https://www.subr.edu/page/CERL (accessed on 4 March 2024).
Ismail, Y. (2016). "6-DOF Robotic Arm Using Haptic Feedback Wired and Wireless Platforms." International Journal of Computing and Network Technology 4: 89+.
Ismail, Y., Balbis, L., Abdelgawad, A., et al. (2021). Homeland security video surveillance system utilising the internet of video things for smart cities. IET Computers & Digital Techniques, 15(4), 302–319. https://doi.org/10.1049/cdt2.12014
Jaeger, E. A., AEngerman, K., ABoncana, M., et al. (2021). Identifying Predictors of HBCU Success in Broadening Participation in STEM: A Case Study Approach. The Journal of Negro Education.
Jayaprakash, D., & Fancy, C. (2017). Using python inbuild modules for effective pharmacy billing application. 2017 International Conference on IoT and Application (ICIOT). https://doi.org/10.1109/iciota.2017.8073644
Jimenez, L. A. E., Sanderson, D., Chaplin, J. C., et al. (2022). Self-configuration of a Robotic Platform to support a self-organized Manufacturing Process. IECON 2022 – 48th Annual Conference of the IEEE Industrial Electronics Society. https://doi.org/10.1109/iecon49645.2022.9968868
Khaleefah, Raad. M., Al-isawi, N. A. M., Hussein, M. K., et al. (2023). Optimizing IoT Data Transmission in Smart Agriculture: A Comparative Study of Reduction Techniques. 2023 5th International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA). https://doi.org/10.1109/hora58378.2023.10156757
Khalid, N., Elkhiri, H., Oumaima, E., et al. (2023). Revolutionizing Weed Detection in Agriculture through the Integration of IoT, Big Data, and Deep Learning with Robotic Technology. 2023 3rd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME). https://doi.org/10.1109/iceccme57830.2023.10252598
Konain, M., Janapati, R., Ahmed, S. M., et al. (2023). IoT based Solar-Powered Mushroom Farming for Sustainable Agriculture. 2023 International Conference on Sustainable Computing and Smart Systems (ICSCSS). https://doi.org/10.1109/icscss57650.2023.10169539
Lewis-Spector, J. (2016). Building strong futures: Literacy practices for developing engaged citizenship in the 21st century. The Australian Journal of Language and Literacy, 39(1), 86–95. https://doi.org/10.1007/bf03651909
Mahmud, M. A., Abdelgawad, A., Yelamarthi, K., et al. (2017). Signal processing techniques for IoT-based structural health monitoring. 2017 29th International Conference on Microelectronics (ICM). https://doi.org/10.1109/icm.2017.8268825
Microsoft. (2022). Available online: https://azure.microsoft.com/en-us/features/iot-accelerators/?OCID=AID631184_SEM_2LXRHSHB&lnkd=Google_Azure_Nonbrand&gclid=Cj0KCQjwl7nYBRCwARIsAL7O7dGPfyLMt3vM5PzFFxQcO16Vj4Q96V_Dtr3chGDpfPbmbpaB101L9W0aApl2EALw_wcB (accessed on 4 March

2024).

Mtshali, T. I., & Ramaligela, S. M. (2022). The Rhetoric of Hands-On Practical Skills. Research Anthology on Vocational Education and Preparing Future Workers, 624–642. https://doi.org/10.4018/978-1-6684-5696-5.ch036

Mullen, S. (2014). Study Abroad at HBCUs: Challenges, Trends, and Best Practices. Opportunities and Challenges at Historically Black Colleges and Universities. M. Gasman and F. Commodore. New York, Palgrave Macmillan US. pp. 139-164.

Murphy, K. M., & Kelp, N. C. (2023). Undergraduate STEM Students' Science Communication Skills, Science Identity, and Science Self-Efficacy Influence Their Motivations and Behaviors in STEM Community Engagement. Journal of Microbiology & Biology Education, 24(1). https://doi.org/10.1128/jmbe.00182-22

Neher-Asylbekov, S., & Wagner, I. (2022). Effects of Out-of-School STEM Learning Environments on Student Interest: a Critical Systematic Literature Review. Journal for STEM Education Research, 6(1), 1–44. https://doi.org/10.1007/s41979-022-00080-8

Njenga, J. (2023). STEM Student Engagement at Historically Black Colleges and Universities (HBCUs) and Predominantly White Institutions (PWIs): An Analysis of Differences Using National Survey of Student Engagement (NSSE) Data. Society for Information Technology & Teacher Education International Conference 2023. E. Langran, P. Christensen and J. Sanson. New Orleans, LA, United States, Association for the Advancement of Computing in Education (AACE). pp. 1760-1765.

Ojajuni, O. P., Ismail, Y., & Lawson, A. (2020). Distributed Denial-of-Service Attack Detection and Mitigation for the Internet of Things. International Journal of Technology Diffusion, 11(2), 18–32. https://doi.org/10.4018/ijtd.2020040102

Perez, R. J., Motshubi, R., & Rodriguez, S. L. (2023). (Mis)Alignment of Challenges and Strategies in Promoting Inclusive Racial Climates in STEM Graduate Departments. AERA Open, 9, 233285842311686. https://doi.org/10.1177/23328584231168639

Quintero, P., Jimenez, M., Santiago, N. G., et al. (2023). An Industry-Academy Partnership to Bridge the SES Gap in Engineering Education. 2023 IEEE Frontiers in Education Conference (FIE). https://doi.org/10.1109/fie58773.2023.10343315

Raad, H. K., Fargo, F., & Franza, O. (2021). Autonomic Architectural Framework for Internet of Brain Controlled Things (IoBCT). 2021 International Symposium on Networks, Computers and Communications (ISNCC). https://doi.org/10.1109/isncc52172.2021.9615713

Raf, F. S. (2014). Challenges Facing Student Learning at HBCUs Today: An Exploratory Investigation. International Journal of Humanities and Social Science. 6(1).

Sai, S. G., Akhil, R. V. K. Sh., Sushma, V. S., et al. (2023). A Comprehensive Study of Robotic Healthcare System. 2023 3rd International Conference on Smart Data Intelligence (ICSMDI). https://doi.org/10.1109/icsmdi57622.2023.00105

Sharma, D. R., Mishra, V., & Srivastava, S. (2023). Enhancing Crop Yields through IoT-Enabled Precision Agriculture. 2023 International Conference on Disruptive Technologies (ICDT). https://doi.org/10.1109/icdt57929.2023.10151422

Sochacki, G., Abdulali, A., Hosseini, N. K., et al. (2023). Recognition of Human Chef's Intentions for Incremental Learning of Cookbook by Robotic Salad Chef. IEEE Access, 11, 57006–57020. https://doi.org/10.1109/access.2023.3276234

Taylor, O. L., & Wynn, M. E. (2019). Leadership Dimensions for Broadening Participation in STEM: Increasing the Role of HBCUs and MSIs. ACS Symposium Series, 177–195. https://doi.org/10.1021/bk-2019-1328.ch012

UNDP. (2014). Arab Knowledge Report: Youth and Localisation of Knowledge. Available online: https://www.undp.org/arab-states/publications/arab-knowledge-report-2014 (accessed on 4 March 2023).

Urban, A. (2023). How Hands-On Assessments Can Boost Retention, Satisfaction, Skill Development, and Career Outcomes in Online Courses. AI, Computer Science and Robotics Technology, 2. https://doi.org/10.5772/acrt.23

Verizon. (2022). Available online: https://www.verizon.com/about/news/how-internet-things-can-create-congestion-free-cities?cmp=KNC-C-HQ-NON-R-AC-NONE-NONE-2K0PX0-PX-GAW-71700000029137807&cvosrc=ppc.google.iot&cvo_campaign=71700000033696684&cvo_crid=243314813161&Matchtype=p (accessed on 4 March 2023).

Verma, H., & Prabhu, S. (2023). Implementation Of IoT and Applications in Smart City in Achieving the Smart Environment. 2023 Second International Conference on Augmented Intelligence and Sustainable Systems (ICAISS). https://doi.org/10.1109/icaiss58487.2023.10250618

Volansky, K. J. (2020). What are best practices to teach "hands-on" skills in a blended environment? Journal of Applied Learning and Teaching. 3(1): 80-89.

Wilson, T. T., & Marnewick, A. L. (2018). A Comparative Study of Soft Skills Amongst the Washington Accord Engineering Degree Graduates with Industry Expectations. 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC). https://doi.org/10.1109/ice.2018.8436282

Yannier, N., Hudson, S. E., & Koedinger, K. R. (2020). Active Learning is About More Than Hands-On: A Mixed-Reality AI System to Support STEM Education. International Journal of Artificial Intelligence in Education, 30(1), 74–96. https://doi.org/10.1007/s40593-020-00194-3