Adopting Backward Design into a Constructionist Curriculum Design for IoT Skill Development in High Schoolers

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ABSTRACT

Despite the growing demand for experienced Internet of Things (IoT) professionals across industrial establishments, most secondary education institutions do not offer a curriculum to empower students' knowledge and skills in IoT. Enrichment programs and vocational workshops can be considered as potential solutions to equip students with necessary IoT-related skills and assist them in planning and making conscious career choices. Through this research, we aim to utilize the principles of Backward Design and constructionism in designing an IoT curriculum for enrichment programs for high school students, while incorporating electro-mechanical concepts from electronics, programming, connectivity, and design. The curriculum was used to teach IoT concepts to 28 high school students during two enrichment programs. It was found that students with hardly any prior knowledge in IoT could acquire the necessary skills to design and prototype IoT applications.

CCS CONCEPTS

• **Computer systems organization → Robotic components**; • **Applied computing → Computer-assisted instruction**.

KEYWORDS

Learning Theories, Backward design, Constructionism, Internet of Things, Curriculum design, Vocational education;

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1 INTRODUCTION

Over the past few decades, the Internet of Things (IoT) has been steadily growing its roots into many important facets of our life [38]. With the advent of Industry 4.0, major transformations have been noticed in the industrial sector, wherein the workplace and processes have been revolutionized by IoT through enabling connectivity between man and machine [15]. This rapidly growing technological transformation in workplace environments is placing new demands on employees' know-how, which apparently is resulting in a skills-gap in the industrial sector that requires immediate attention [39]. To address this concern, IoT-based solutions must be integrated into education and training curricula to prepare students and future employees for the evolving IoT skill requirements in the job market [14, 28].

Prior research has highlighted the mental preparedness of high school students for introducing IoT-related concepts, and the benefits that come along with this exposure [29, 42]. However, it is often the case that the majority of secondary schools do not provide a curriculum to advance students' IoT knowledge and abilities [45]. Moreover, the current STEM curricula in these education establishments do not have enough room to introduce IoT-related courses [20]. This encourages educators and experts to provide part-time training in IoT technology in the form of vocational courses and enrichment programs to better prepare their students for the future [14]. In order to target competence-oriented skilling during such short-term training programs, the Backward design method has proven to be an effective approach in creating instructional curricula and assessments based on the desired learning outcomes [30, 33, 48]. With this instructional design, the desired learning outcomes are firstly identified, followed by the learning activities that can be guided toward those outcomes. Additionally, allowing students to actively construct knowledge through maker activities using constructionist practices such as scaffolding, learning-by-doing and collaborative experiences can enhance their motivation, while developing a passion for exploration and learning [19, 40]. Keeping this in consideration, we designed an IoT curriculum utilizing the principles from Backward Design and constructionism, to be used in an enrichment program for high school students. The curriculum was developed with an aim to equip the learners with skills required to design and implement simple IoT applications.

Smart products are usually based on combinations of electromechanical designs with advanced sensors, on-board intelligence and connectivity [4]. By facilitating the interconnection of devices using multidisciplinary concepts from electronics, software, and the internet, the IoT technology is thus evolving into a standard for the design and creation of smart products. These multidisciplinary concepts originate from the STEM-based curriculum and thus, can be

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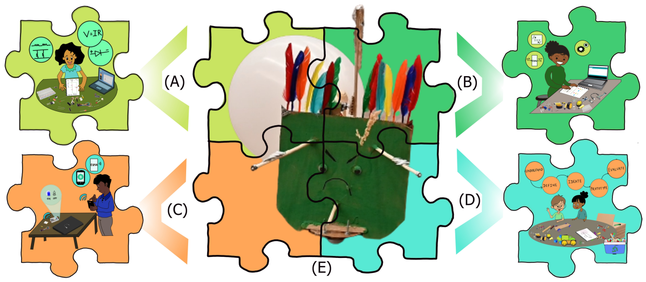

Figure 1: The curriculum for teaching IoT to high schoolers was designed using Backward design model, while incorporating constructionism in instruction activities. Using scaffolding and learning by doing approach, the learning modules (A) Basic Electronic Components and Wiring, (B) Basics of Microcontroller Programming, (C) Connecting Devices to the Internet, and (D) Design of Physical Things and Interfaces, can provide necessary skills to E) design and implement Smart Toys and Robots.

adopted easily into the learning methodologies for young novices in the field of IoT education [15]. Considering the ease of integrating the multidisciplinary concepts, our curriculum was targeted towards systematic learning of the following 4 IoT modules by providing a progressive scaffolding of concepts for a novice learner: (A) Basic Electronic Components and Wiring, (B) Basics of Microcontroller Programming, (C) Connecting Devices to the Internet, and (D) Design of Physical Things and Interfaces. Additionally, these concepts have been widely explored in MAKER-based education enabling students to build computational thinking and problem-solving skills while applying the concepts to real-world problems [23]. Being able to relate the concepts in real-world can help to enhance analytical thinking abilities and encourage lifelong learning. Therefore, our approach towards building a MAKER-based learning curriculum was aimed towards the development of smart tangible products through providing a foundation in electro-mechanical Interconnected Systems.

The use of robots is one of many approaches used in order to stimulate students' interest in studying electro-mechanical systems [18]. Bringing robots into classroom settings not only makes learning fun and exciting, but it also plays a key role in helping students learn how to solve problems and work collaboratively [13, 26]. Moreover, with increased accessibility to low cost hardware and open source software platforms such as Arduino, teaching techniques have been explored and found to be effective in enhancing students' interest in learning about electronics and computer programming to build and design robots [27]. Through our research, we present the curriculum design of ***Design and Prototyping of Smart Toys and Robots***, for teaching IoT concepts to high school students. The objective of the curriculum design is to provide students with a hands-on engineering design experience covering all aspects of IoT, from designing smart robots, to the hardware and software that allows them to connect to the Internet as shown in Figure 1. Project-based and structured tutorials are provided in the curriculum to enable students to learn and develop smart products while completing a variety of projects. A number of learning activities are designed allowing students to express their opinions and ideas while gaining more knowledge through peer interaction and discussion. Finally, a pilot-testing of the curriculum was performed on 28 high school students during two enrichment programs, and it was observed that students with minimal prior knowledge were able to design and prototype IoT applications in form of smart toys and robots. Students were able to internalize the concepts during the learning experiences and were able to use them to solve problems during their final projects.

Thus, our contributions are as follows:

(1) Development of the learning curriculum for an enrichment program to teach high school students about IoT-related concepts by using the Backward design approach from learning sciences, and
(2) Design of a MAKER-based instruction model as a part of the learning curriculum by using theories of constructionism

In order to meet the demands of a society that is constantly changing, we believe that this research will provide insights to the HCI community in building learning curricula that go beyond traditional classroom requirements.

2 RELATED WORK

Adoption of learning strategies in IoT education: With the IoT revolution, physical machines and devices are increasingly becoming connected to the digital world and the trend is expected to rise in the years to come. Using integrated sensors and Internet, information about states of machines and devices are easily collected and shared across data warehouses in cloud services. As a result of this digital transformation, the industrial revolution is seen to alter workplace conditions and employment skill requirements. Education should therefore prepare future workers for these shifts. To provide students with the necessary competencies beyond traditional classroom settings, vocational training and enrichment programs are often relied upon and built according to the concept of outcome-based education [16, 41]. This educational approach, also referred to as Backward design is flexible and can be tailored to the individual student's needs, making it efficient and attractive for students [31, 44]. According to earlier studies, this design strategy was more effective than traditional lesson plans in achieving the objectives quickly, improving student learning, and motivating students to retain the lessons they had learned [24, 37]. Considering its benefits, we utilized the Backward design model to design the curriculum for the enrichment programme to teach IoT topics to high school students.

When designing learning content for short-term vocational training courses, it is crucial to engage young students and facilitate their understanding through hands-on experiences, allowing them to construct new knowledge. Prior research emphasizes the importance of aligning instructional methods with learning theories to optimize effectiveness in IoT courses [1, 45]. Constructionism principles have been explored in several studies to develop efficient instruction models for students to comprehend and build IoT systems [1, 6, 9, 21]. Constructionism posits that learners actively construct knowledge and gain a deeper grasp of concepts and skills through hands-on experiences while creating tangible products, and using their prior knowledge as a foundation [19]. Such learning often takes place in social settings, where learners can exchange ideas and collaborate on projects. Hughes et. al. utilized a constructionist context for a week-long maker-oriented camp to teach IoT concepts to students belonging to K-12 education level [21]. Make2Learn workshop focused on IoT education by promoting free exploration and tinkering with creative materials and learning contents [9]. Constructionist-driven educational toolkits have been proposed to allow users to discover and explore IoT concepts [6, 36]. These studies demonstrated the effectiveness of constructionist learning environments in supporting students' development of IoT knowledge and skills resulting from their experiences designing and creating IoT artifacts and encouraging their interest in STEM fields. Considering its benefits, our curriculum adopts the following four principles of constructionism into the design of the IoT instruction model: (A) Scaffolding approach so as to follow a sequence in learning content while building off of prior knowledge, (B) learning by doing to explore topics, construct critical thinking and communication skills, (C) Project-based Learning using individual and group projects to develop problem-solving skills and promote life-long learning, and (D) Collaborative Learning to facilitate sharing of ideas while working in groups.

Integrating IoT education with STEM and MAKER culture and Robots: IoT, according to the IETF, is the network of physical objects embedded with electronics, software, sensors, actuators, and connectivity to exchange data [35]. To comprehend and implement IoT systems, learners need interdisciplinary skills in hardware and software [43]. Our IoT curriculum focuses on teaching concepts of electronics, programming, connectivity, and design to prototype smart devices connected to the Internet. Open-source hardware and software platforms like ESP32 and Raspberry Pi, paired with various programming tools like C, Python, MIT App Inventor, and Ardublock facilitate affordable and accessible IoT projects [10]. Instructors can use such platforms to design effective and affordable course curricula.

The introduction of IoT concepts to high school students faces challenges despite the availability of accessible resources [43]. Proper curriculum development and learning strategies are crucial to incorporate multidisciplinary IoT concepts, equipping students with the skillsets necessary for IoT projects [20]. To address this, blending STEM and MAKER-based education into IoT learning frameworks has been proposed [7, 47]. This combination fosters creativity, critical thinking, and compensates for the lack of theoretical knowledge in MAKER-based courses [47]. Chen et al. [7] proposed a teaching model by integrating STEM into IoT-MAKER courses, emphasizing complementary aspects in terms of interdisciplinary content, inquiry-based learning, iterative processes, and fostering talent.

Integrating new technologies such as computational devices (Raspberry Pis, Arduinos) and robots into MAKER-based settings have shown to have positive impact on the learning experience for learners [8, 32]. The learners have been found to engage in these high tech-oriented learning activities with high excitement and motivation [3, 13]. Therefore, robotic devices and other modular, relatively affordable technologies should be used to instruct students in STEM education (secondary, tertiary, or vocational education) [2]. In this context, extensive research has been carried out by prior work with students of primary and secondary education [49]. It has been observed that by utilization of these techniques, the participants can acquire the necessary abilities quickly while also keeping the expense of their training at a minimum. More recently, research work has explored an emerging area of IoT where toys are not only interacting with the users, but are pervasive – lending themselves to a network commonly referred to as the Internet of Toys (IoToys) [50]. By facilitating young students' understanding of IoT through enhanced and creative play, these toys have been used in designing workshops, creating curricula for creation of effective learning environments [22].

3 CURRICULUM DESIGN

Utilizing the Backward design model from learning sciences, the IoT curriculum was developed for high school students to impart IoT-related skills and knowledge. Backward design, as proposed by Wiggins and McTighe [30], involves creating instructional curriculum and assessments based on desired learning outcomes. Learning objectives are defined first, followed by the design of formative and summative assessments aligned with those objectives. The curriculum design ensures alignment between learning objectives, instruction, and assessment, leading to effective learning activities and outcomes. A MAKER-based instruction model, designed for this curriculum, was built on constructionist principles, where learners actively construct knowledge through hands-on experiences [19].

3.1 Design of the learning curriculum

The Backward design-based curriculum design was performed by 2 experts with approximately 5 years of experience in the field of IoT education and curriculum development (Table 1).

3.1.1 Identify the desired result. First learning outcomes were identified with an aim to equip high school students with the knowledge and skills to understand IoT concepts and create basic IoT systems, such as smart toys and robots. Students were expected to learn to design and troubleshoot electronic circuits, program microcontrollers, utilize sensors and actuators, connect devices to the internet, and be familiar with prototyping tools and resources. The learning concepts were subsequently worked upon by the experts by reflecting on their own understanding of the topics, and reviewing reputable resources, including peer-reviewed literature, government reports, and educational standards. These concepts were organized into four topic areas of (A) Electronics, (B) Programming, (C) Connectivity, and (D) Design to align with essential aspects of IoT technology [5]. The necessary learning objectives and skills were then determined to guide learners towards achieving the desired outcomes.

3.1.2 Determine assessment techniques. After establishing the learning objectives and skills, the subsequent step involved devising appropriate assessment strategies to effectively measure and foster the learning process at various stages. A combination of assessment of/for/as learning techniques were employed, aiming to create both formative and summative assessment methods [12]. Striking the right balance among these three types of assessments is crucial for enhancing the learning experience and overall outcomes [17].

Assessment of learning involves using evidence of students' learning to measure their performance against set outcomes and standards. For instance, in the curriculum, after completing the basic

Learning Outcomes	Learning Objectives	Skill Identification for IoT prototyping	Skill Assessment Criteria
· Build and debug electronic circuits	· Identify different types of circuit - open vs. closed, and connections - series vs. parallel · Identify and locate circuit components - Power Source, Conductors, Loads (resistors, LEDs, motors, Buzzer, and Potentiometer) and additional components (button, voltage regulators, capacitor, transistor, motor driver, breadboard) · Understand the imporatnce of circuit components - e.g. breadboard · Understand laws governing the relation between different circuit elements (Ohm's Law) and circuit fundamentals - e.g. Volatge division · Learn color coding in resistors to calculate resistance values · Follow safety practices related to wiring during prototyping basic electronics circuits · Learn about polarity and pin configuration of electronic components · Learn virtual electronic simulation and prototyping using TinkerCAD · Learn about circuit symbols and reading schematic diagrams · Learn about debugging tips and tricks in basic circuitry and wiring	· Ability to read component values directly from electronic components; e.g., color coding of resistors, capacitance values · Ability to connect components based on the pin configuration, polarity of terminals, etc. · Knowledge about the fundamental principles governing electron flow in any circuit · Ability to identify and select electronic components based on the circuit requirements · Ability to debug circuits in case the circuit does not function properly · Ability to read and draw circuit schematics diagram	· Connect electronic components correctly in the circuit while taking care of polarity, component values, pin configuration, etc. · Debug non-functioning circuits to find errors in the TinkerCAD circuits · Completing the circuit to make it work and show output to the coaches · Locate and identify the learning elements (e.g. resistors, polarity of terminals, etc.) · Read/measure/calculate the component values correctly · Duplicate schematic using virtual TinkerCAD or real breadboard prototyping
· Program logic for electromechanical devices using microcontrollers, sensors, actuators	· Understand basics about microcontrollers, sensors and actuators · Learn about Arduino - IDE, boards, basic functions · Learn about programming contructs - variables, datatypes, controls (if-else), loops (for, while), functions · Understand type of signals (analog vs. digital), logic levels (HIGH/ON/5V, LOW/OFF/0V), Analog-to-Digital Conversion (ADC)	· Knowledge about the ESP32 features, I/O pins and interfacing · Knowledge about basic Arduino functions to read/write data from/to ESP32/Serial Monitor/sensors/actuators · Knowledge about the binary system, and its relevance in digital electronics · Ability to read, process and make sense of raw sensor data · Ability to apply computational logic using programming constructs to code functions to control actuators	· Completing the script or pseudocode to get required outputs · Configure the Arduino IDE and board correctly for ESP32 · Configure the Serial Monitor correctly · Compile the code successfully without errors and upload to ESP32 board · Connect the sesors and actuators correctly to the ESP32 I/O pins
· Connect physical things over WiFi	· Control ESP32 from web interface using HTTP request and headers · Understand usage of BlynkIoT application	· Knowledge about the built-in WiFI capabilities of ESP32 · Ability to use ESP32 to connect and control devices wirelessly · Ability to use ESP32 as client using BlynkIoT	· Control the devices over WiFi as expected and show the outputs · Configuration of BlynkIoT correctly · Explain understanding of code and circuit
· Design physical things (smart toys) and UI controls	· Learn about the design thinking process · Understand the importance of prototyping · Learn about different low fidelity prototyping techniques · Learn about different methods used for rapid prototyping · Design user interfaces for IoT applications using BlynkIoT	· Knowledge about the various techniques used in rapid prototyping methods - addtive and subtractive · Ability to use the low fidelity prototyping techniques in the early design phase · Ability to design UIs using contol widgets in BlynkIoT	· Explain the design of physical structures or virtual controls when asked · Correctly assemble the components and parts to make the final design · Use sketches in the early design phase

Learning Modules

Lectures	Practice
· Circuit fundamentals, types of circuit (open vs. closed), connections in circuit (series vs. parallel), circuit components (power source, conductors, and loads) · Basics about the different learning elements involved in basic electronics circuitry: A) Breadboard - importance, connections, and how to connect components on a breadboard B) Resistors - sybmols, color coding, Ohm's Law, connections in series and parallel C) Potentiometer - symbols, pin configuration, working, voltage division D) LEDs - polarity, symbols, safety practices while connecting LEDs in circuit E) Motors - importance, terminals, effects of reversal of terminals connection to power source F) Switch and button - relation to binary, importance, symbols G) Transistors - types (npn vs. pnp), pin configuration, symbols, importance in digital electronics · Using TinkerCAD circuits and simulation to prototype and test circuit designs	· Locate and identify the learning elements in the component box (e.g. resistors, capacitors) · Locate and identify the polarity and pin configuration of the electronic components · Find resistance values of resistors using color coding, Ohm's Law, and in series/parallel connections · Prototype circuits using TinkerCAD and/or real breadboard: A) Turn ON an LED using battery and proctective resistor to prevent current overload through the LED B) Connect LEDs in series and parallel C) Using potentiometer to change light intensity of an LED and speed of a motor D) Change the direction of rotation of motors by reversing polarity of the terminals E) Use transistor as a switch -Tturn an LED ON and OFF using pushbutton and a transistor F) Using a switch, kill all functions of a robot · Debug electronics circuit to find errors. Fix the errors to make the circuit work
· Introduction to Arduino IDE, boards, ESP32 features - I/O pins, builtin WiFi · Arduino IDE - Configuration Settings, structure of Arduino Sketch, basic Arduino functions · Serial Monitor - Baud Rate settings and functions · Basic programming constructs - variables and data types, comments (single line vs. multi line), controls (if - else), loops (for vs. while), operators (comparators, increment, decrement) · Types of sensors (analog vs. digital), corresponding Arduino pins and functions, ADC A) Photoresistors - working and principle, Interfacing with ESP32 B) Ultrasonic Distance Sensors - working and principle, pin configuration, Interfacing with ESP32 · Actuators, their importance, commonly used actuators in hobbyist robotics: A) DC Motors, H-bridge circuits, Motor drivers (L293D), pin configuration, Interfacing with ESP32 B) Servo motor - understand the working of servo motors, pin configuration, Interfacing with ESP32	· Program and prototype electromechanical circuits using TinkerCAD and/or real breadboard: A) Blinking LEDs using ESP32 in delayed intervals and printing status to Serial Monitor B) Using if-else controls, turn a LED ON when a pushbutton is pressed C) Using loops, program a traffic light simulator, turn a buzzer ON for 10 times D) Using a photoresistor, create a mock prototype for smart lighting E) Using Ultrasonic Distance Sensors, design an electronic yardstick and print out distance ranges F) Controlling direction and speed of motors using Arduino G) Control the movement of a toy car by implementing functions - forward, backward, left, right, stop. H) Change the shaft position of a servo motor from 0 to 180 degrees, and then from 180 to 0 degrees.
· Configuring BlynkIoT to control ESP32 using smartphone over WiFi	· Wirelessly control LED, toy car by pressing buttons on the BlynkIoT application · Controlling LED pins wirelessly from a web interface using ESP32
· The various stages of design thinking process, starting from understanding the users' needs, to defining the problem statement, ideating different approaches for tackling the problem, prototyping solutions, and finally testing the prototypes to check if the design suits requirements · rapid prototyping methods used in engineering - additive, subtractive · demonstration of 3D printer, laser cutter in action, understand the working	· Assemble a toy car from scratch using components and parts. · Design UIs using control widgets in BlynkIoT application

Table 1: Design and development of the Curriculum using the backward design principles

electronic prototyping modules, students' understanding of electronic circuitry was assessed through quizzes on debugging circuits.

Assessment for learning occurs when teachers utilize inferences about students' knowledge, understanding, and skills to inform their teaching. Examples of these assessment practices used in our curriculum include using Q&A, play-based activities during the classroom sessions, where the instructor actively engages with students to augment or clarify their understanding of concepts during the teaching process.

Assessment as learning involves students being their own assessors, monitoring their learning, asking questions, and using various strategies to gauge their knowledge and progress. An example of this in our curriculum is providing programming exercises to students after teaching them basic programming constructs, microcontrollers, and sensors. The assessment requires students to critically analyze the given problem and devise creative solutions independently or with minimal assistance.

3.1.3 Design of instructional model. After determining the assessment strategies, the final step of the curriculum design was to plan learning experience and instruction using the following constructionist approaches.

Scaffolding in constructionism involves starting learning from accessible contexts and gradually progressing to more challenging ones [19]. We applied this by leveraging students' prior knowledge of basic electrical circuits asuch as power sources, conductors, and loads. Beginning with an introduction to basic electronics, we built up to complex topics like Ohm's Law. This sequential approach enables students to construct new knowledge based on their existing understanding. For example, learning electrical wiring in the first module prepares students for programming electro-mechanical circuits in the second.

Experiential Learning: This 'learn by doing' approach involves active participation of learners in connecting theories to real-world situations. It entails a continuous cycle of inquiry, reflection, analysis, and synthesis [25]. Our instruction model offers students hands-on learning experiences through physical and logical experiments. Technology, such as simulation environments like TinkerCAD, is integrated to create authentic learning contexts, allowing students to learn, build, and debug electronic circuits.

Project-based learning: This is a learner-centered approach where students spend time investigating and solving a complex problem or challenge, in order to build knowledge and skills [34]. This method encourages students to take more ownership of their learning by giving them more authority over what they learn. Our lesson plan includes numerous project-based activities, both at individual and group level, encouraging students to provide solutions to practical problems.

Collaborative learning: Social interaction can play a central role in the cognitive development in learners, simulate brainstorming, and also improves learners' motivation [46]. Collaborative environments require strategies for group size, instructional goals, communication, assignments, and evaluation. Medium-sized groups of 3-5 students are ideal; larger groups risk unequal participation, while smaller groups may lack diversity and limit divergent thinking. Setting clear group goals before starting assignments helps maintain focus and build a shared purpose. This approach was evident during the final group project, when the goal was to create robots that could connect to the internet and carry out specific tasks.

3.2 Design of Content

The instructions consisted of 4 learning modules and a final project.

3.2.1 Learning Modules. The content design comprised four modules: (A) Basic Electronic Components and Wiring, (B) Basics of Microcontroller Programming, (C) Connecting Devices to the Internet, and (D) Design of Physical Things and Interfaces. The lesson plan included various learning activities such as lectures, guided demonstrations, hands-on practicals, and assignments.

Basic Electronic Components and Wiring: This module aimed to teach students about fundamental circuit elements, circuit connections in series and parallel, electronic components for circuit prototyping, basic circuit analysis, creating and debugging circuits using TinkerCAD and real breadboards, and the laws governing circuit parameters that guide electronics circuit design.

Basics of Microcontroller Programming: This module introduces students to Arduino and programming basics. Hands-on experience involves building circuits with ESP32 microcontrollers and coding using the Arduino programming language. Topics covered include variables, loops, conditions, and functions to enable students to implement desired functions in robot programming. Coding challenges using TinkerCAD and real breadboards allow students to perform tasks virtually and in physical setups. Microcontroller programming and interfacing with sensors and actuators are also taught. Sensors like photo resistors and ultrasonic sensors for light intensity and distance detection are included. For example, a coding challenge involves using the ultrasonic sensor to create an electronic yardstick to measure distance from an obstacle. Actuators such as DC motors and Servo motors are covered, with coding challenges to control their speed and direction using microcontrollers.

Connecting Devices to the Internet: This module provided hands-on experiences to students to connect their devices to the Internet. Some examples of learning activities include: blinking LEDs through WiFi server, controlling the robots and toys using WiFi through the Blynk application on smartphone.

Design of Physical Things and Interfaces: This module introduces the design thinking process, covering problem understanding, definition, ideation, prototyping, and testing. Students learn about rapid prototyping methods like 3D printing and LASER cutting through guided demonstrations. The module concludes with a project-based activity where students work in teams to design, build, and test their prototypes for the final project, i.e., the Battlebots challenge.

3.2.2 Final Project: The final project allows students to apply their acquired knowledge to design and construct smart toys or battlebots in groups of 3-5. The challenge is to create battlebots with the goal of eliminating the opponent's balloon located at the rear of their robot. The battlebots must adhere to certain restrictions, including the use of BlynkIoT for control, inclusion of at least one defense mechanism, and fitting within a 16 in X 16 in X 16 in cubic volume while static. The balloons should not be shielded, and each team has a license plate for identification. Specific limits are set for electronic components, like 2 ESP32 microcontrollers, 4 DC motors, and 3 Servo motors. Students can choose from materials like cardboard,

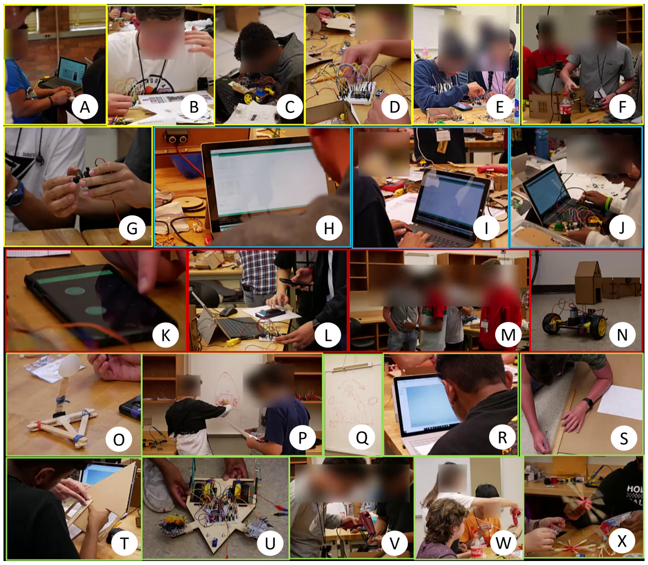

Figure 2: Snapshots showing students engaging in learning activities across four topic areas (1) Electronics (yellow borders), (2) Programming (blue), (3) Connectivity (red), and (4) Design (green). Activities include: (A) Replicating TinkerCAD circuits on real breadboards, (B) Constructing circuits based on pinout diagrams, (C) Verifying circuits on toy car assemblies, (D) Completing circuits individually, (E) Collaboratively building circuits, (F) Using ultrasonic sensors, (G) Utilizing servo motor actuators, (H) Programming obstacle-sensing code with ultrasonic sensors, (I) Working on code individually, (J) Verifying code and operation of toy car assemblies, (K) Designing user interfaces with the Blynk IoT application, (L) Testing circuit functionality via WiFi, (M) Controlling toy car assemblies using Blynk IoT, (N) Operating toy cars through the Blynk IoT application, (O) Creating a catapult from recyclable materials to launch a marshmallow projectile, (P, Q) Early design ideation and sketching for the Battlebot challenge, (R) Refining designs using digital prototyping, (S, T) Building low-fidelity prototypes, (U) Testing the final Battlebot design and (V-X) Designing and testing weapon mechanisms

hot glue guns, wooden skewers, popsicle sticks, recycled materials, and balloons to build their battlebots.

4 EVALUATION

Expert Review: Before pilot testing with high school students, the curriculum underwent review by a committee of 6 experts with over 2 years of experience in electro-mechanical and IoT systems. Two experts in the committee had experience in curriculum development and teaching. The committee members were university students, recruited through word-of-mouth and recommendations. Based on the expert committee's feedback, minor edits were made to improve clarity in the lecture presentations, but no changes were made to the practice activities at this stage.

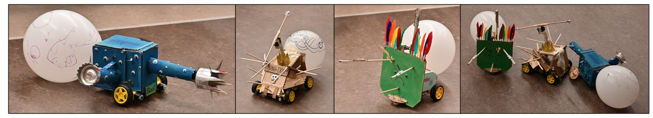

Figure 3: Battlebots from the second enrichment program

Pilot testing of the Curriculum: We conducted two 2-week enrichment programs for high school students, with 18 students in the first and 10 in second, ranging from grades 9-12. 3 students belonged to the age range of 9-14 years, while the remaining 25 belonged to the age range of 15-17 years. The workshops ran 5 days a week, with 3-hour daily sessions. Each program had a main instructor, who was also one of the curriculum designers, and 6 coaches from the expert committee who reviewed the curriculum. The first 6 days of each program included lecture sessions, guided demonstrations, and individual projects to teach various multi-disciplinary skills related to prototyping circuit hardware, programming, and connecting devices to the internet. The last four days involved students working in groups to design and build smart toys for the final Battlebots challenge. The pilot testing procedures for the curriculum were approved as exempt under the IRB protocols.

Study results: All students successfully achieved the learning objectives with evidence of their learning. The instruction modules facilitated their understanding and application of concepts to real-world problems. Collaborative work allowed them to share ideas and learn progressively, building on prior knowledge and insights. Students actively participated, presenting their thoughts, asking relevant questions, and engaging in continuous reflection and progress. Their ability to apply concepts in their final projects demonstrated the development of problem-solving skills.

As shown in Figure 2, the hands-on activities provided students with an efficient and engaging way to reinforce the understanding of the learned topics while constructing tangible artifacts. The activities ranged across the four major areas including electronics, programming, connectivity and design that constitute an IoT system. The progressive scaffolding of the learning content helped students to gradually develop the skills and knowledge during the first week of the workshop. The various assessment approaches provided the instructor with evidence on the student understanding of the concepts. For example, quizzes on debugging circuits were provided as an exercise to evaluate student understanding of the key concepts surrounding basic electronics.

The development of the final outcomes can be observed from the student performance during the final projects as shown in Figure 2P-X. Student activities ranged from design ideation to low fidelity prototyping to design refinement and iteration to final concept generation, prototyping and testing. The problem statement ensured deliverable concerning different aspects of the IoT learning module that was covered during first week. The successful execution of the final Battlebots confirms that the student groups developed a holistic understanding of the individual modules of the IoT technology. The battlebots from the second workshop are shown in Figure 3.

5 CONCLUSION

With the Internet of Things (IoT) revolutionizing the industrial sector through facilitating connectivity between man and machines, there is a need for increased awareness about the technology in the minds of young adolescents to prepare them for the changing workplace. Utilizing the principles from Backward Design and constructionism, we presented an IoT curriculum for an enrichment program to teach high school students about IoT-related concepts and skills. Upon pilot-testing the curriculum with 28 students during two enrichment programs, the results showed that the curriculum was effective in teaching the necessary knowledge and skills to design and build IoT systems.

As a scope of future work, we recommend exploring the effect of the proposed design methods on the development of Maker's mindset in learners. As shown by prior work, this mindset that encourages (A) curiosity and exploration, (B) collaboration, communication and sharing of ideas, (C) making mistakes and reflecting on them, and (D) critical thinking and problem-solving, is best developed in a learner in an interdisciplinary setting [11]. With an interplay of multidisciplinary concepts, we believe that the IoT curriculum can nurture these skills by making learners the protagonists of the learning experience. Although the results from the pilot testing indicate direct results on the skill development of novice high schoolers, we acknowledge that further analysis is required to evaluate the effect of the design methods on the development of the Maker's mindset. Nevertheless, we hope that our work provides insights to future research to explore this area in greater depth.

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REFERENCES

[1] Mariana Aki Tamashiro. 2021. How do we teach Emerging Technologies in K-9 Education? Using design fiction and constructionist approaches to support the understanding of emerging technologies' societal implications in formal K-9 education. In *Interaction Design and Children*. 637–640.

[2] Saira Anwar, Nicholas Alexander Bascou, Muhsin Menekse, and Asefeh Kardgar. 2019. A systematic review of studies on educational robotics. *Journal of Pre-College Engineering Education Research (J-PEER)* 9, 2 (2019), 2.

[3] Raidell Avello, Jari Lavonen, and Miguel Zapata-Ros. 2020. Coding and educational robotics and their relationship with computational and creative thinking. A compressive review. *Revista de Educación a Distancia (RED)* 20, 63 (2020).

[4] Ranbir Singh Batth, Anand Nayyar, and Amandeep Nagpal. 2018. Internet of robotic things: driving intelligent robotics of future-concept, architecture, applications and technologies. In *2018 4th International Conference on Computing Sciences (ICCS)*. IEEE, 151–160.

[5] Barry Burd, Lecia Barker, Félix Armando Fermín Pérez, Ingrid Russell, Bill Siever, Liviana Tudor, Michael McCarthy, and Ian Pollock. 2018. The internet of things in undergraduate computer and information science education: exploring curricula and pedagogy. In *Proceedings Companion of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education*. 200–216.

[6] Attapan Chan-In and Arnan Sipitakiat. 2020. Designing an Educational Internet of Things Toolbox: A case-study of a learner-centric tool design. In *Proceedings of the FabLearn 2020-9th Annual Conference on Maker Education*. 90–93.

[7] Rongjun Chen, Yani Zheng, Xiansheng Xu, Huimin Zhao, Jinchang Ren, and Hong-Zhou Tan. 2020. STEM teaching for the Internet of Things maker course: a teaching model based on the iterative loop. *Sustainability* 12, 14 (2020), 5758.

[8] Pao-Nan Chou. 2018. Skill development and knowledge acquisition cultivated by maker education: Evidence from Arduino-based educational robotics. *EURASIA Journal of Mathematics, Science and Technology Education* 14, 10 (2018), em1600.

[9] Monica Divitini, Michail N Giannakos, Simone Mora, Sofia Papavlasopoulou, and Ole Sejer Iversen. 2017. Make2Learn with IoT: Engaging children into joyful design and making of interactive connected objects. In *Proceedings of the 2017 Conference on Interaction Design and Children*. 757–760.

[10] Michael V Doran and George W Clark. 2018. Enhancing robotic experiences throughout the computing curriculum. In *Proceedings of the 49th ACM Technical Symposium on Computer Science Education*. 368–371.

[11] Dale Dougherty. 2013. The maker mindset. *Design, make, play: Growing the next generation of STEM innovators* (2013), 7–11.

[12] Lorna M Earl and M Steven Katz. 2006. *Rethinking classroom assessment with purpose in mind: Assessment for learning, assessment as learning, assessment of learning*. Manitoba Education, Citizenship & Youth.

[13] Amy Eguchi. 2017. Bringing robotics in classrooms. In *Robotics in STEM education*. Springer, 3–31.

[14] Hicham El Mrabet and Abdelaziz Ait Moussa. 2021. IoT-school guidance: A holistic approach to vocational self-awareness & career path. *Education and Information Technologies* 26, 5 (2021), 5439–5456.

[15] Kerem Elibal and Eren Özceylan. 2020. A Review of Logistics 4.0 Literature for Curriculum Development for Vocational High Schools. In *Proceedings of the 2nd African International Conference on Industrial Engineering and Operations Management Harare, Zimbabwe*.

[16] Jan Emory. 2014. Understanding backward design to strengthen curricular models. *Nurse Educator* 39, 3 (2014), 122–125.

[17] National Forum for the Enhancement of Teaching and Learning in Higher Education. 2017. Expanding our Understanding of Assessment and Feedback in Irish Higher Education.

[18] Mariano Garduño-Aparicio, Juvenal Rodríguez-Reséndiz, Gonzalo Macias-Bobadilla, and Suresh Thenozhi. 2017. A multidisciplinary industrial robot approach for teaching mechatronics-related courses. *IEEE Transactions on Education* 61, 1 (2017), 55–62.

[19] Idit Ed Harel and Seymour Ed Papert. 1991. *Constructionism*. Ablex Publishing.

[20] Jing He, Dan Chia-Tien Lo, Ying Xie, and Jonathan Lartigue. 2016. Integrating Internet of Things (IoT) into STEM undergraduate education: Case study of a modern technology infused courseware for embedded system course. In *2016 IEEE frontiers in education conference (FIE)*. IEEE, 1–9.

[21] Janette Hughes, Jennifer Anne Robb, and Margaret Lam. 2020. Designing and Learning with IoT in a Passion-Based Constructionist Context. Springer, 760–771.

[22] PIRITA Ihamäki and K Heljakka. 2018. Smart, skilled and connected in the 21st century: Educational promises of the Internet of Toys (IoToys). In *Proceedings of the 2018 Hawaii university international conferences, arts, humanities, social sciences & education, Prince Waikiki Hotel, Honolulu, Hawaii*. 1–19.

[23] Yu-Lin Jeng, Chin-Feng Lai, Sheng-Bo Huang, Po-Sheng Chiu, and Hua-Xu Zhong. 2020. To cultivate creativity and a maker mindset through an internet-of-things programming course. *Frontiers in Psychology* 11 (2020), 1572.

[24] Lynn Marie Kelting-Gibson. 2003. *Preservice teachers' planning and preparation practices: a comparison of lesson and unit plans developed using the backward design model and a traditional model*. Montana State University.

[25] David A Kolb. 2014. *Experiential learning: Experience as the source of learning and development*. FT press.

[26] Beng Yong Lee, Lee Hung Liew, Mohd Yazid Bin Mohd Anas Khan, and Azlina Narawi. 2020. The effectiveness of using mbot to increase the interest and basic knowledge in programming and robotic among children of age 13. In *Proceedings of the 2020 The 6th International Conference on E-Business and Applications*.

[27] Dimitrios Loukatos, Eleftherios Chondrogiannis, and Konstantinos G. Arvanitis. 2020. A Low-Cost Example, Combining MIT App Inventor, Arduino Specific Components and Recycled Materials to Foster Engineering Education. In *24th Pan-Hellenic Conference on Informatics*. 367–371.

[28] Petre-Daniel Mătăsaru, Luminiţa Scripcariu, and Felix Diaconu. 2018. Analysis of proposed innovative methods for training students in IoT and computer networks within the frame of current trends in technical and vocational education. In *2018 International Conference and Exposition on Electrical And Power Engineering (EPE)*.

[29] Anna Mavroudi, Monica Divitini, Francesco Gianni, Simone Mora, and Dag R Kvittem. 2018. Designing IoT applications in lower secondary schools. In *2018 IEEE Global Engineering Education Conference (EDUCON)*. IEEE, 1120–1126.

[30] Jay McTighe and Ronald S Thomas. 2003. Backward Design for Forward Action. *Educational leadership* 60, 5 (2003), 52–55.

[31] Jay McTighe and Judy Willis. 2019. *Upgrade your teaching: Understanding by design meets neuroscience*. ASCD.

[32] Aditya Mehrotra, Christian Giang, Laila El-Hamamsy, Anthony Guinchard, Amaury Dame, Géraldine Zahnd, and Francesco Mondada. 2021. Accessible Maker-Based Approaches to Educational Robotics in Online Learning. *IEEE Access* 9 (2021), 96877–96889.

[33] Anne Mette Morcke, Tim Dornan, and Berit Eika. 2013. Outcome (competency) based education: an exploration of its origins, theoretical basis, and empirical evidence. *Advances in Health Sciences Education* 18, 4 (2013), 851–863.

[34] Paniti Netinant, Punnipa Narad, and Meennapa Rukhiran. 2021. A case study of project-based learning on Internet of Things course. In *Proceedings of the 7th International Conference on Frontiers of Educational Technologies*. 126–131.

[35] The Internet of Things at the IETF. 2022. The Internet of Things at the IETF.

[36] Am-Suk Oh. 2018. A Study on Maker Kit based on Internet of Things. *International Information Institute (Tokyo). Information* 21, 1 (2018), 231–238.

[37] Mónica Ontaneda Rea and Jorge Luis Sánchez Román. 2018. Implementing backward design to improve students' academic performance in EFL classes. *Centro Sur* 2, 2 (jul. 2018), 37–49.
[38] Maria Rita Palattella, Mischa Dohler, Alfredo Grieco, Gianluca Rizzo, Johan Torsner, Thomas Engel, and Latif Ladid. 2016. Internet of things in the 5G era: Enablers, architecture, and business models. *IEEE journal on selected areas in communications* 34, 3 (2016), 510–527.
[39] Shaoping Qiu, Malini Natarajarathinam, Michael D Johnson, and Elizabeth A Roumell. 2021. The Future of Work: Identifying Future-ready Capabilities for the Industrial Distribution Workforce. In *2021 ASEE Virtual Annual Conference Content Access*.
[40] Mitchel Resnick. 2014. Give P'sa chance: Projects, peers, passion, play. In *Constructionism and creativity: Proceedings of the third international constructionism conference. Austrian computer society, Vienna*. 13–20.
[41] Heather L Reynolds and Katherine Dowell Kearns. 2017. A planning tool for incorporating backward design, active learning, and authentic assessment in the college classroom. *College Teaching* 65, 1 (2017), 17–27.
[42] Natalia Spyropoulou, Dimitrios Glaroudis, Athanasios Iossifides, and Ioannis D Zaharakis. 2020. Fostering Secondary Students' STEM Career Awareness through IoT Hands-On Educational Activities: Experiences and Lessons Learned. *IEEE Communications Magazine* 58, 2 (2020), 86–92.
[43] Ana-Maria Suduc, Mihai Bîzoi, and Gabriel Gorghiu. 2018. A Survey on IoT in Education. *Romanian Journal for Multidimensional Education/Revista Romaneasca pentru Educatie Multidimensionala* 10, 3 (2018).
[44] Carol A Tomlinson and Jay McTighe. 2006. *Integrating differentiated instruction & understanding by design: Connecting content and kids.* ASCD.
[45] Maarten Van Mechelen, Rachel Charlotte Smith, Marie-Monique Schaper, Mariana Tamashiro, Karl-Emil Bilstrup, Mille Lunding, Marianne Graves Petersen, and Ole Sejer Iversen. 2023. Emerging technologies in K–12 education: A future HCI research agenda. *ACM Transactions on Computer-Human Interaction* (2023).
[46] L Vygotsky. 2019. Collaborative learning. *Collaboration, communications, and critical thinking: A STEM-inspired path across the curriculum* 43 (2019).
[47] Xingwei Wang, Wenwen Xu, and Liang Guo. 2018. The status quo and ways of STEAM education promoting China's future social sustainable development. *Sustainability* 10, 12 (2018), 4417.
[48] Grant Wiggins and Jay McTighe. 1998. What is backward design. *Understanding by design* 1 (1998), 7–19.
[49] Ioannis D Zaharakis, Nicolas Sklavos, and Achilles Kameas. 2016. Exploiting ubiquitous computing, mobile computing and the internet of things to promote science education. In *2016 8th IFIP International Conference on New Technologies, Mobility and Security (NTMS)*. IEEE, 1–2.
[50] Bieke Zaman, Maarten Van Mechelen, and Lizzy Bleumers. 2018. When toys come to life: considering the internet of toys from an animistic design perspective. In *Proceedings of the 17th ACM Conference on Interaction Design and Children*.