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TEACHING INTERNET OF THINGS (IoT) THROUGH SOFTWARE SIMULATIONS WITH PACKET TRACER

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ABSTRACT

The Internet of Things (IoT) has been a fast-growing trend in computer networking as more and more physical and digital objects and devices in life and at work are connected. Education and training in computer networking and IoT should enable learners to reach both cognitive and hands-on outcomes. Software simulations may bring innovative and cost-effective benefits in technology education. This research shares pedagogical designs and instructional experience in teaching IoT topics with a software simulation approach using Cisco Packet Tracer in an undergraduate networking and data communication course at a U.S. university. This study presents empirical findings and observations on the teaching process and learning outcomes. The research paper concludes with discussions of the benefits and implications of the simulation approach used in the study.

Keywords: Internet of Things, IoT, networking, hands-on learning, simulation, Packet Tracer

INTRODUCTION

The Internet of Things (IoT) has been a rapidly growing computer networking technology that enables smart interconnections and data communication among physical and digital objects and devices. IoT-enabled objects, devices and applications have become increasingly important in our modern life and various work domains, such as smart cities, smart homes, smart offices, smart college campuses, smart manufacturing, smart security, and smart healthcare devices, etc. IoT is an emerging trend in the field of computer networking that makes innovative use of radio frequency identification (RFID) and wireless sensor network technologies for internetworking, data collection, and data communication. Given the continued growth and demand for computer networks and IoT applications, it is important for college education to provide adequate and effective teaching and learning in networking education (Alsukayti, 2019; Flifel, 2019; Marquardson & Gomillion, 2019).

However, pedagogical challenges remain in teaching networking. Computer networking is highly technical and involves abstract and complex concepts such as TCP/IP layers, protocols, and configurations, which pose challenges for teaching and learning (Rashid, Othman, Johan, & Sidek, 2019; Zhang, Liang, & Ma, 2012). Therefore, it is significant to research into effective pedagogy and instructional strategies to develop and enhance students' knowledge and skills in networking areas including IoT.

Software simulations can be used in designing and implementing complex computer networks and IoT network applications such as smart homes (Alfarsi et al., 2019; Kumar, Krishna, & Ramprakash,2019). Software simulations may also be used in training and education of computer networks and IoT to enhance the learning environment (Marquardson & Gomillion, 2019; Flifel, 2019). If designed and implemented properly, software simulations may be an effective approach to teaching fundamental concepts of IoT networking and data communication as well as practical and interactive hands-on skills of using and configuring IoT systems and applications (Alsukayti, 2019).

Packet Tracer from Cisco is one of the software simulation tools used for simulating computer and IoT networks and for teaching computer networking and IoT application design. The software simulation provides a graphical user interface and visual objects for students to design, build, configure, and test computer networks with add-on objects, such as switches, routers, servers, and various connection media including wireless connections. The software also allows students to create and design IoT objects and networks such as a smart home with interconnected home appliances. There is evidence that Packet Tracer can be an effective simulation tool in teaching wireless network concepts and practical skills (Muniasamy, Eljailani, & Anandhavalli, 2019).

This research is to focus on the study of teaching IoT concepts and skills through a software simulation approach using Packet Tracer. The goal of the study is to contribute a pedagogical approach to teaching IoT topics with empirical findings and discussions on the benefits and implications of the approach.

BACKGROUND

As an emerging and significant trend in internetworking, IoT is a complex, dynamic, and technically challenging area involving various network technologies, layers, and devices. The interconnections of physical and digital IoT objects are commonly based on RFID and wireless sensor network technologies for data communication and delivery of smart services. In a typical IoT architecture, RFID readers are used to collect sensory data from tagged objects and send the data to a cloud server for processing, whereas wireless sensors are deployed to sense events and send data back to a gateway for monitoring and analysis in a wireless sensor network. The most basic IoT system architecture consists of the following three functional layers (Bayani, Segura, Saenz, & Mora, 2017; Sethi & Sarangi, 2017):

1. The perception layer is the physical layer that includes the physical event sensors for information gathering and identifying smart objects, along with local data storage and controllers.
2. The network layer handles connection and communication between various network devices, smart objects, media, servers, and transmission and processing of sensor data.
3. The application layer for defining and delivering smart application services to end users via an interface, such as smart homes, smart cities, and smart healthcare.

The technical complexity of IoT networks presents challenges for IoT teaching and learning in computer network education. For network education in general, students often need to experience with hands-on activities with costly network equipment and infrastructure to understand the complex and abstract concepts of network payers, protocols, addressing format and configurations (Rashid, Othman, Johan, & Sidek, 2019). The traditional mainstream teaching method of lecturing is found to be inadequate in motivating students in network and IoT education (Zhamanov, Yoo, Sakhyeva, & Zhaparov, 2018). The major challenge in teaching computer networking is that it is difficult for students to understand the technical concepts and to visualize the various network protocols and their roles and functions in data communication (Noor, Yayao, & Sulaiman, 2018). Additionally, even with the help of visual tools for hands-on practice, students may mechanically follow lab instructions to complete the task and lack the ability to use higher order thinking skills for troubleshooting and creative problem solving (Elias & Ali, 2013).

Software simulations have been used widely and effectively in industrial design and visualized training, such as pilot training. It is also often used in computer network design and may be effective for networking and IoT training and education. Software simulations with Cisco Packet Tracer can be used to create a wireless IoT network for a smart home to add gadgets and monitor and control these gadgets remotely (Kumar, Krishna, & Ramprakash,2019). Software simulations with Packet Tracer can be used in smart home implementation to improve security and automate smart devices and activities for efficiency and living comfort (Ashok, Akram, Neelima, Nagasaikumar, & Vamshi, 2020). Software simulations can be used for implementing a safe smart home system including remotely monitored devices like air conditioning, security alarm, lighting, garage, and doors, and simulated IoT network technology may be applied to many other scenarios such as smart healthcare, smart campus, and smart offices (Alfarsi et al., 2019). A smart college may be implemented using a software simulator to monitor college resources, create smarter lesson plans, and enhance campus security and information access (Tabeidi, Masasd, & Elshaikh, 2019).

Software simulations may provide cost-effective visualization and interactive hands-on experience for students in network and IoT education. Complex network and IoT layers, protocols, addressing schemes, and other concepts are abstract and difficult for students to visualize and understand. Hardware network equipment such as routers, switches, servers are quite expensive to purchase and maintain for educational purposes. Software simulators such as Packet Tracer are capable of simulating an entire network model with a graphical user interface, easy to control, and save time and cost (Bakni, Cardinale, & Moreno, 2018). The study by Bakni, Cardinale, and Moreno (2018) also identified major measurable criteria for evaluating software simulators which include the following that are most relevant to networking and IoT education:

- License: The software is legal for users to obtain and use.
- User Interface: Graphical user interface (GUI) and supported programming languages for users to interact with the simulator.
- Supported Platforms: Usability of the software source code on different platforms and operating systems.
- Heterogeneity: The capability to simulate network types and equipment from different vendors.
- Level of Details: The level of algorithms, protocols and hardware simulated.
- Supported Technology and Protocols: The network protocols, features, services supported in a typical TCP/IP 4-layer model.
- Performance: Effectiveness and efficiency of the simulator such as CPU usage, execution time, and memory usage.

Packet Tracer is a propriety software simulator provided by Cisco Systems that allows students to create and simulate computer networks and IoT systems without the need of hardware equipment or existing networks (Finardi, 2018). Table 1 below summarizes some important features of Cisco Packet Tracer based on the criteria and evaluation by Bakni, Cardinale, and Moreno (2018):

Table 1. Qualitative Evaluation of Packet Tracer

Criteria	Packet Tracer Features
License	Proprietary, but an End User License Agreement (EULA) exists.
User Interface	A built-in GUI is supported and can trace and store all events. Different languages are supported including English, Russian, German, Spanish and French. No programing language is supported but scripting is allowed using the Cisco IOS Syntax.
Platform	Linux, Android 4.1+, iOS 8+ and Microsoft Windows.
Heterogeneity	Support different types of real routers, such as: Cisco 1941, Cisco 2901, Cisco 2911, and others are supported, as well as different types of real switches like: Cisco Catalyst 2950, Cisco Catalyst 2960, Cisco Catalyst 3560-24PS are supported. In addition to that, Linksys WRT300N wireless router, Cisco 2504 wireless controller, and Cisco Aironet 3700 access point are supported. Cisco ASA 5505 firewall is supported as well. Variety of IoT devices are supported.
Level of Detail	Packet Level.
Supported Protocols and Technology	Application Layer: DHCP, DHCPv6, FTP, HTTP, HTTPS, RADIUS, POP3, SMTP, SNMP, SSH, Telnet, TACACS; Access Lists, DNS, IoT, IoT TCP, SYSLOG. Transport Layer: SCCP, TCP, UDP. Network Layer: ARP, CAPWAP, HSRP, HSRPv6, ICMP, ICMPv6, IP, IPv6, NDP. Link Layer: Bluetooth, CDP, CTP, H.323, LACP, LLDP, PagP, STP, USB, VTP. Routing Protocols: BGP, EIGRP, EIGRPv6, OSPF, OSPFv6, RIP, RIPng, Technology: IPSec, Cisco NetFlow.
Performance	Windows is more suitable for the simulator as CPU utilization performs better on Windows than on Linux. Memory consumption is comparable on both systems.

The Packet Tracer simulator has been found useful in providing visualization and interactive hands-on learning experiences for students in network and IoT education, which helps to motivate student participation and enhance their acquisition of practical skills (Bakni, Cardinale, & Moreno, 2018; Noor, Yayao, & Sulaiman, 2018; Rashid, Othman, Johan, & Sidek, 2019; Shi, Han, & Li, 2018; Zhang, Liang, & Ma, 2012). However, there are some identified limitations with the simulator in networking education such as perceived gap in skills transfer and challenges for students to develop high level critical thinking and creative problem-solving skills (Elias & Ali, 2013; Marquardson & Gomillion, 2019). Therefore, further research is needed to develop effective pedagogical and instructional strategies and designs to develop the higher order learning skills for students while retaining the software simulations for visual and interactive hands-on learning experience.

The updated Bloom's taxonomy lays out 6 levels of progressive learning objectives with specific action verbs for each level of achievement (Anderson & Krathwohl, 2001):

1. Remembering: Recall information, facts, terms, and basic concepts
2. Understanding: Demonstrate comprehension of facts and ideas through descriptions and interpretations
3. Applying: Solve problems in new situations by applying knowledge and techniques learned
4. Analyzing: Examine information to identify causes, motives, and relationships
5. Evaluating: Make judgement about information or ideas based on certain criteria
6. Creating: Propose new or alternative solutions

Reflective learning may be helpful to the development of high levels of learning and competencies such as analyzing, evaluating, and creating. Gibbs (1988) applies reflection to the learning process and develops a reflective cycle of learning that consists of six components: (1) Description – Recall and describe what happened in the learning activity or experience; (2) Feelings – Identify learner's feelings and reactions to the experience; (3) Evaluation – Make value judgements about the pros and cons of the experience; (4) Analysis – Bring outside experience and research to help understand the situation; (5) Conclusions – Draw conclusions on what has been learned from the experience and analysis; and (6) Personal Action Plans – Decide on what steps to take next time based on what has been learned. The components of Evaluation, Analysis, Conclusions and Personal Action Plans are important high-level skills and competencies.

INSTRUCTIONAL DESIGN AND METHODOLOGY

This section presents a proposed instructional design for teaching introductory IoT knowledge and skills in an undergraduate network and data communication course. The instructional design includes a series of activities and assessments for teaching, learning, and measuring student progress and outcomes. The learning activities and process incorporate the use of network software simulations and reflective learning. The overall IoT theme is on Smart Home with a series of 4 modules, and the software simulator used is Cisco Packet Tracer version 7.2.1. Each module has brief lectures, discussions, video and hands-on demonstrations, guided hands-on practice, and follow-up reflections. Necessary Packet Tracer data files, templates, and hands-on instructions are provided to students. The four modules have specific focus ed topics and progressive learning objectives. Table 2 below summarizes the four modules and their learning objectives:

Table 2. Smart Home IoT Modules and Objectives

Module	Topic	Objectives
1	Adding IoT Devices	1) Explore and understand an existing smart home network 2) Add wired IoT devices to the smart home network 3) Add wireless IoT devices to the smart home network
2	Connect and Monitor IoT Devices	1) Add a home gateway to the network 2) Connect IoT devices to the wireless network 3) Add an end user device to the network

Table 2. Smart Home IoT Modules and Objectives

Module	Topic	Objectives
3	Connect IoT Devices to a Registration Server	1) Add a registration server to the network 2) Register IoT devices to the registration server
4	Create Your Own Thing	1) Create your IoT thing, such as a security camera 2) Add your own thing to the smart home network

Module 1 is the beginning lesson for the IoT Smart Home theme. In this module, students are expected to open a Packet Tracer data file with an existing home network, explore the IoT devices on the network and the Packet Tracer IoT menu, and then add additional wired and wireless IoT devices. By opening the Packet Tracer data file, students have the visual experience of seeing the entire smart home network with interconnected IoT devices such as smoke detector, garage door, smart door, temperature meter, smart coffee maker, smart fan, smart solar panel, smart battery, and smart lamp as shown in Figure 1. Students also browse the network components and smart devices and see their attributes and configurations such as IP addresses as well as gateway, DNS, and security settings. The Smart Home menu at the bottom of the screen capture in Figure 1 shows the various smart devices the user may choose to use for the smart home network. The visual experience helps students to understand the IoT network and connection concepts. In addition, students have the guided practical experience of applying IoT techniques and hands-on instructions to add and configure the network settings of two new IoT devices – a lawn sprinkler and a wind detector through wired and wireless connections respectively. The hands-on experience enables students to reach a higher level of learning – applying learned knowledge and techniques for problem solving. The module ends with a reflective learning component in which the students are asked to write and recall their learning experience, reflect on and evaluate the value of the learning experience, and ask any questions or make new suggestions on the topic.

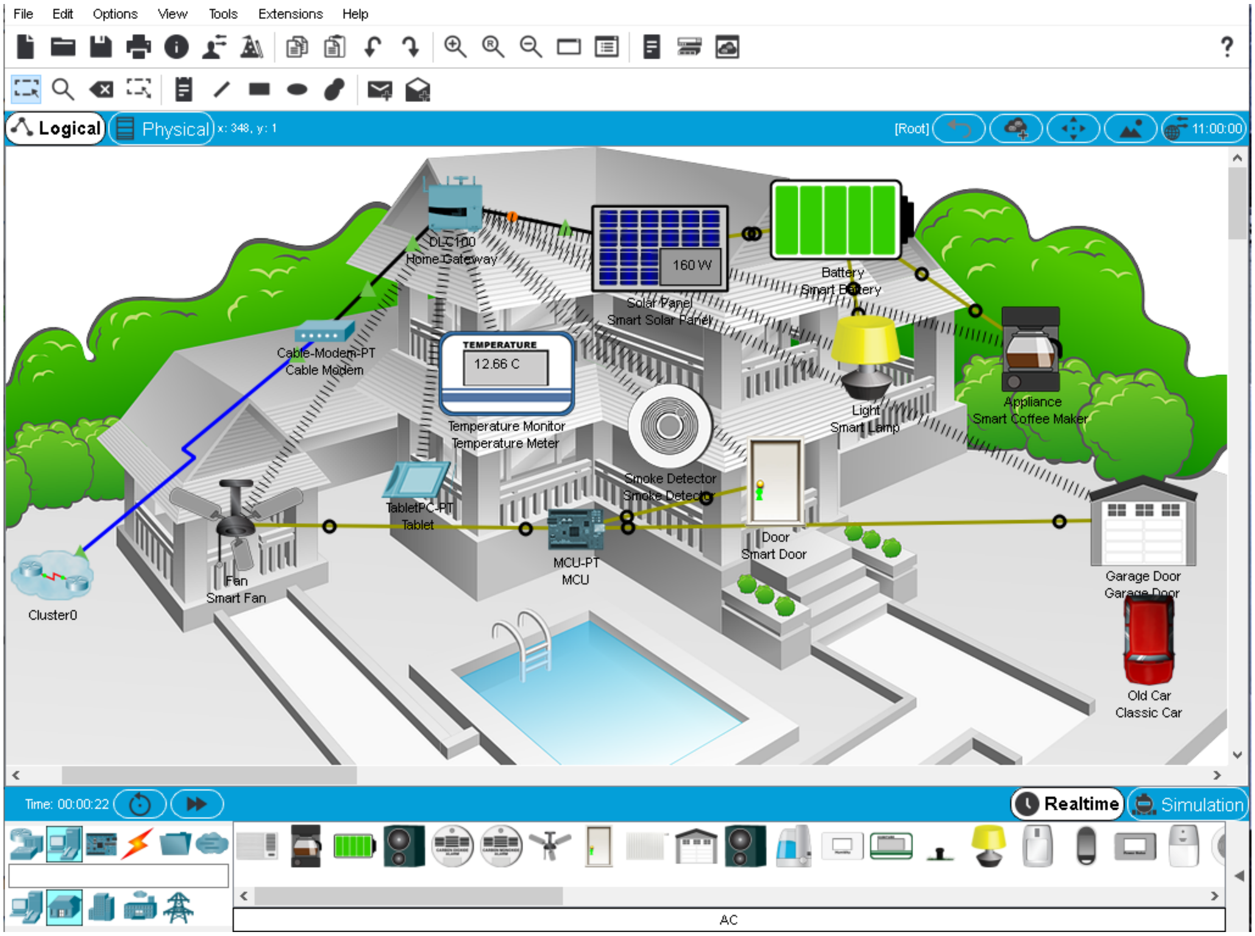

Figure 1. Smart Home Network with IoT Objects

Module 2 focuses on connecting and monitoring IoT devices. Students are expected to apply their knowledge and skills on IoT and Packet Tracer for three practical problem solving tasks: (1) Add and connect a home gateway to an existing smart home network; (2) Add three more smart IoT devices (a ceiling fan, a door, and a lamp) to the smart home wireless network, configure the connection settings of each device, and test the connections of the smart devices; (3) Add an end user wireless tablet to the home network and register the added IoT devices to the home gateway server to monitor the IoT devices. Through the discussions, demos, and hands-on learning activities in this module, students learn the new concepts, knowledge and skills on a gateway server, gateway registration, and monitoring IoT devices in a wireless network. Students also learn the conceptual knowledge of more specific and technical network connection settings for each IoT device including bandwidth, MAC address, SSID, authentication settings for security, IP configuration settings, DHCP, WPA, etc. through visual simulation and hands-on experience. More importantly, the hands-on activities enable students to acquire higher-level problem-solving skills in configuring and testing the network settings of the IoT devices in a comprehensive smart home environment at minimal cost. Figure 2 below shows a sample network setting configuration window for a smart door. Students recall, review, and evaluate their learning activities and experience in the written reflection at the end of the module.

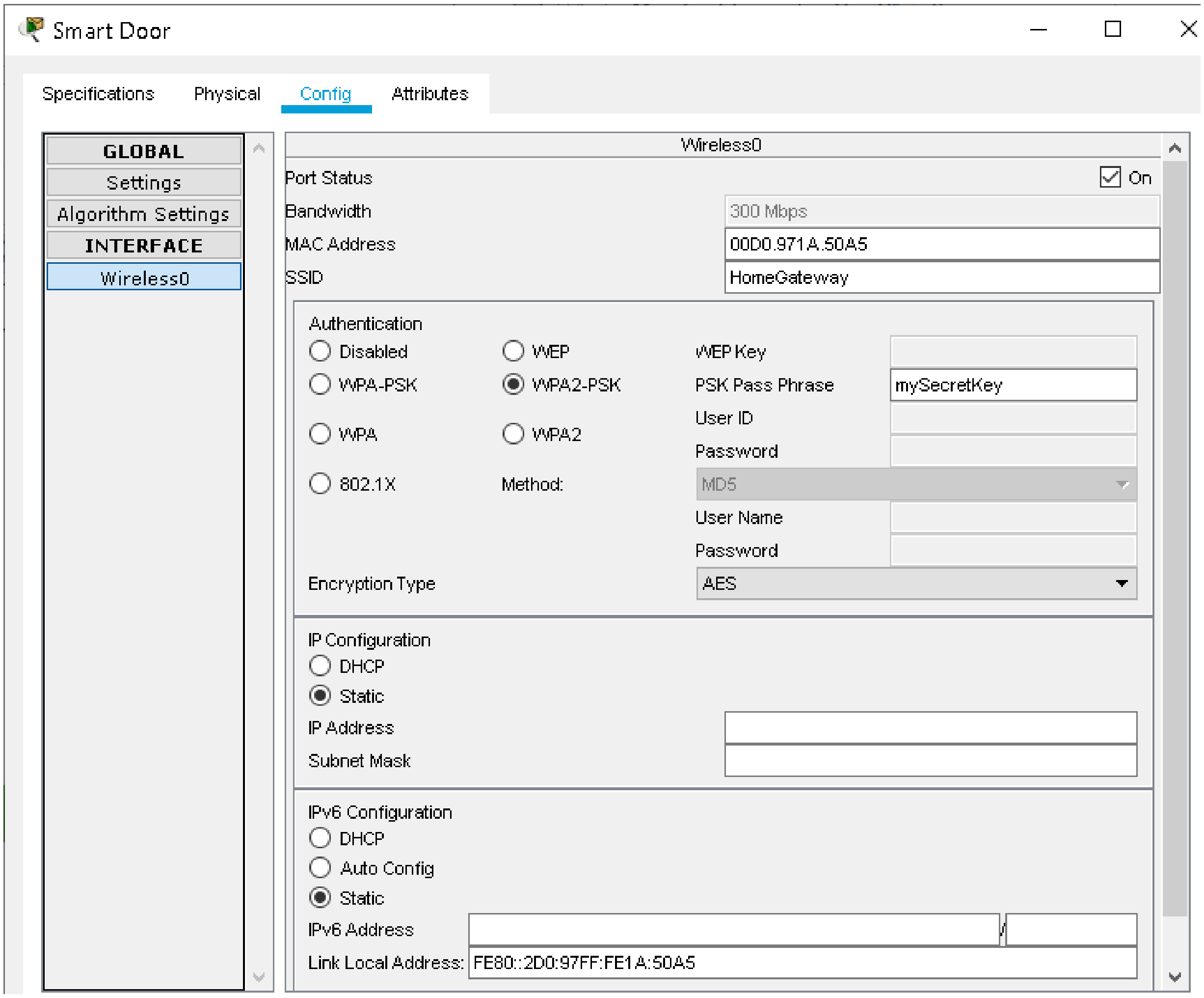

Figure 2. Smart Door Configuration Window

In Module 3, students are expected to add and configure a registration server for the smart home network, create a registration server account, and register IoT devices to the registration server to monitor the IoT devices remotely via a web URL. Through the various activities of this module, students learn the new concepts and knowledge of a remote registration server, a secure administrative server account for remote login and IoT monitoring, and various services and settings available on the registration server including IoT, HTTP, DHCP, DHCPv6, TFTP, DNS, SYSLOG, AAA, NTP, EMAIL, FTP. Students also learn higher-level problem-solving skills in configuring services and registering IoT devices to a remote server via simulation in Packet Tracer. Figure 3 below shows the configuration window for services on the registration server. Students recall, review, and evaluate their learning activities and experience related to the remote registration server for the smart home network in the written reflection at the end of the module.

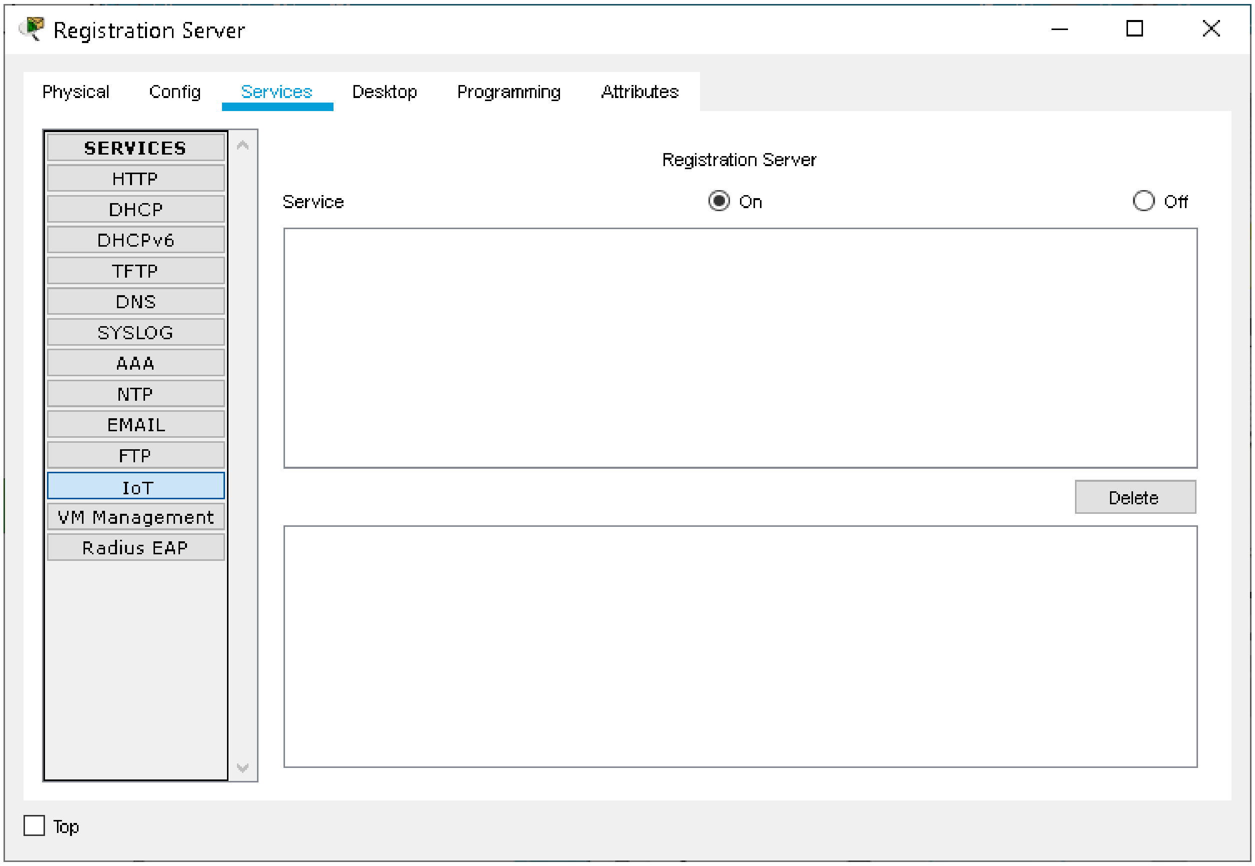

Figure 3. Registration Server Configuration Window for Services

In Module 4, students are expected to create a new IoT device, configure advanced properties, and add the new device to the smart home network. Students not only learn the new concepts and knowledge of properties and settings of an IoT object visually but also use their knowledge, techniques, and creativity to create and configure something new for the IoT network at an advanced level. Students also recall, review, and evaluate their learning activities and experience related to the new IoT object in their written reflection at the end of the module. Figure 4 below shows a sample new IoT thing (a smart vacuum cleaner) created using Packet Tracer.

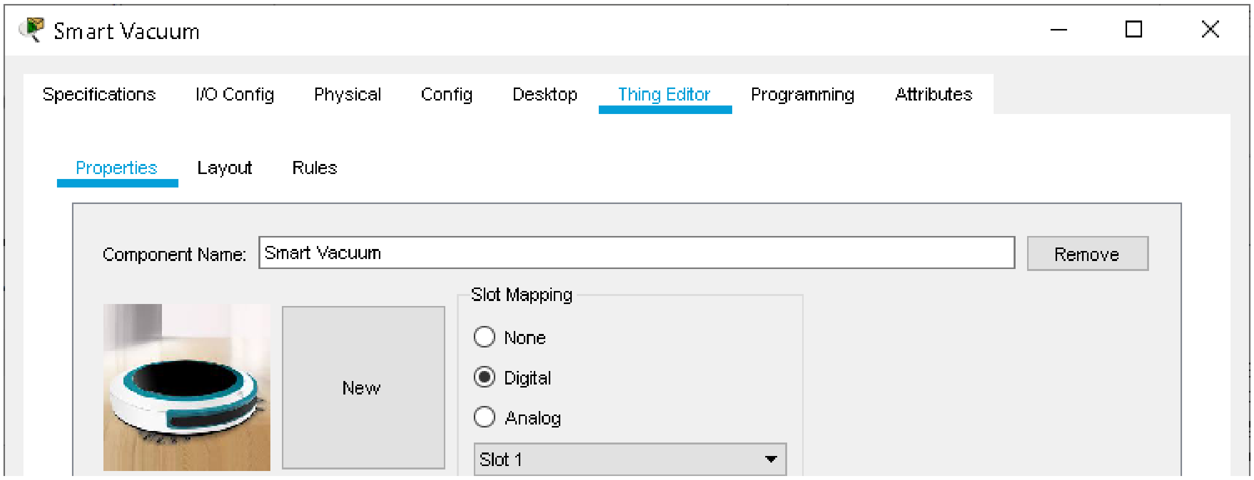

Figure 4. A New IoT Thing Created in Packet Tracer

The 4-module instructional design and learning activities were used in an undergraduate course in networks and data communication at a U.S. university in fall 2019. The total number of students in the course selected for this study was 29. The students were asked to participate in all the activities required for these 4 IoT modules, including lectures, discussions, demonstrations, hands-on practice, reflections. The student participants were assessed by two types of instruments for data collection: (1) A daily review assessment form for each student's written answers to record the hands-on work completion status and to recall, review and evaluate their learning activities and experience for each module; (2) Essay questions in the final exam to assess student knowledge and understanding of IoT in Packet Tracer simulations. The daily review assessment form was graded as Pass or Fail based on student participation, progress, and reflections. The four essay questions in the final exam make up 20 points or 20% of the final exam grade – 5 points or 5% per question for each module. The next section presents and discusses the findings.

FINDINGS AND DISCUSSIONS

Table 3 below presents the findings on the student participation and success rates in the in-class hands-on practice and follow-up written reflections in the daily review form regarding each of the 4 IoT modules. The findings indicate the following:

- The student participation rate was very high in all 4 modules, including 100% for Modules 1 and 3 and 96.55% for Modules 2 and 4. The high participation rate suggests that the students were highly motivated to participate in the learning activities on each module.
- The student success rate (Pass rate of scoring 80% or higher) was also very high in all 4 modules (over 96%), at the same rate as for participation rate. Unexcused absence from class was given the Fail grade according to the course policy. The high success rate indicates student achievements and competencies in understanding the fundamental concepts of IoT networks, applying their knowledge and skills to hands-on problem solving, and in analyzing and evaluating their knowledge and learning. The student success rate is well above the expected success rate of 80% for ABET accreditation assessment.
- The high rates (96.55%) of student participation and success in Module 4 indicate that the overwhelming majority of the students reached the high-level learning of creativity and creative problem solving as defined in the revised Bloom's taxonomy (Anderson & Krathwohl, 2001).

In addition, observations of student reflections, comments and questions in the daily review forms collected indicated students' consistent and high interest in the IoT topics, their comprehension of the key concepts in all 4 modules, and their strong enthusiasm about the guided hands-on practice for specific task completion or problem solving in Packet Tracer simulations.

Table 3. Participation and Success Rates in Hands-on Practice and Reflections

Module	Student Population	Participation Rate	Pass	Fail	Success Rate
1. Add IoT Devices	29	100%	29	0	100%
2. Connect & Monitor IoT Devices	29	96.55%	28	1	96.55%
3. Connect IoT Devices to Server	29	100%	29	0	100%
4. Create Your Own Thing	29	96.55%	28	1	96.55%

Table 4 below presents the findings on the essay questions about the IoT modules in the final exam. The essay questions are evenly distributed among the four IoT topics and focus on assessing student understanding of key IoT concepts and analysis and evaluation of IoT configuration tasks and software simulation solutions. The findings show 100% participation rate in the essay questions for the 4 modules among all students selected for the study. The average score is close to 90% (4.43 out of 5) for Module 2 and over 90% (over 4.5 out of 5) for Modules 1, 3, 4, which is well above the expected 80% achievement level for ABET accreditation assessment for each topic. The success rate for the study group is all above 80% or the expected class success rate on the IoT topics for ABET accreditation. The standard deviation is consistently low for all four modules, which indicates low variations and stable progress and achievements among the students in the group for the four modules.

Table 4. Participation and Success Rates in Hands-on Practice and Reflections

Module	Participants	Average Score	MAX	MIN	Standard Deviation	Success Rate
1. Add IoT Devices	29	4.64	5	3.5	0.52	89.65%
2. Connect & Monitor IoT Devices	29	4.43	5	3	0.59	86.21%
3. Connect IoT Devices to Server	29	4.53	5	3	0.55	93.10%
4. Create Your Own Thing	29	4.57	5	3.5	0.52	89.65%

CONCLUSION

IoT networks and applications are a fast-growing trend in computer networking. There have been pedagogical challenges in network and IoT education and training due to the highly technical, complex, and abstract nature of the subject. This research proposes the use of software simulations as a visual, interactive, and cost-effective approach to teaching and learning of IoT networks and applications. This study contributes an instructional design of teaching progressive smart home IoT concepts, knowledge, and skills at various levels of the Bloom's taxonomy for learning by incorporating comprehensive learning activities, including lectures, discussions, demonstrations, hands-on practice using software simulations with Cisco Packet Tracer. Students also gain higher levels of learning through regular reflections on the learning activities and experience. The main implications of this study are: (1) A software simulation approach can be innovative and cost-effective for teaching computer networking and IoT; and (2) It would be pedagogically more effective to incorporate student reflections in the teaching and learning process.

Empirical data and observations from a group of 29 undergraduate students for this study indicate effectiveness of the instructional design. However, the sample size is fairly limited in this study. Future studies may expand to a larger group of subjects. Future studies may also focus on a new domain of teaching IoT applications, such as smart campus, smart healthcare, smart security, etc. with additional or new variables and learning outcomes.

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