Architecture Design and Application of a Compound Robot Control System with Movement–Process Collaboration

Mentore Vaccari

***Abstract*—This paper presents a basic laboratory training module aimed at helping undergraduate students understand the interfacing and connectivity issues involved in the Internet of things (IoT). The training module uses a sequential teaching approach to draft quasi-experiments for teaching basic IoT concepts. Interfacing includes identification, embedded sensing and embedded actuating while connectivity includes wireless connectivity and web/ mobile services. An IoT function (control and/or measurement) is first selected by users based on the physical variable of interest and the action to be carried out. The user will also select a connectivity option based on network types and transmission technologies available for communication between a sensor and/or an actuator and a gateway. The available connectivity options in this work are Bluetooth and RF. An interface is then setup based on the choices made using Arduino Pro Mini as microcontroller. Arduino Yun and a smartphone are the available gateway options depending on the connectivity option of the interface. When Bluetooth is the connectivity type on the interface, the smartphone is used as gateway while Arduino Yun serves as the gateway when RF is the connectivity option on the interface. The training module is accompanied with an instruction manual which contains instructions on the set ups and short notes on signals and systems, Analog to Digital Converters (ADC), Digital to Analog Converters (DAC), Wireless Sensor Networks (WSN), etc. The training module was tested with 100 randomly selected students. A few students had problems setting up the interface correctly. Coding the Arduino boards was a challenge for some of the students while a few others had challenges with creating sensor nodes. Choosing the correct connectivity type to match a gateway was the most challenging for the students.**

***Index Terms*—sensors, actuators, interface, Internet of Things**

I. Introduction

THE Internet of Things (IoT) may be defined as the network of physical objects or "things" that are embedded with electronics, software, sensors and connectivity so that the object can have better value or provide better services by sharing resources with other objects and by exchanging data with the manufacturer, operator and/or other connected devices. A simple IoT building block is shown in Fig. 1. Each object within the network is uniquely identifiable, can be accessed through a network and can be controlled using lightweight software. Though IoT is still emerging, there have been such projections that as many as 100 billion IoT devices would be interconnected by 2025 with a global economic impact of more than $11 trillion [1]. This is largely due to the anticipated IoT impact on agriculture, healthcare, energy management, security, etc.

Fig. 1. A simple IoT building block

A number of IoT research directions have been identified [2] and there have been a lot of interests in IoT research from both the industries and the academia. It is therefore important that academic and research institutes should at least teach the basics of IoT in order to prepare undergraduate students for the emerging IoT world. In this work, a basic laboratory module aimed at helping undergraduates understand the interfacing and connectivity issues involved in IoT is presented. Interfacing includes identification, embedded sensing and embedded actuating while connectivity includes wireless connectivity and web/ mobile services [3]. A sensor node is created using Arduino Pro Mini, temperature and humidity sensors, a relay switch actuator and LEDs, RF transceiver and a Bluetooth module. An Arduino Yun serves as the base station for the sensor nodes and also provides internet connectivity (gateway). A smart phone (running Android OS) is also used as a gateway. Web app and Android app are also created for internet and mobile connectivity respectively. Other features of the lab module include story boards as a guide for all experiments, as well as drag and drop concept for the setup when using the web app. A typical setup is shown in Fig. 2.

It is expected that at the end of the experiments, students will have a clear understanding of the operation of selected sensors and actuators, interfacing issues, data presentation and connectivity types.

II. Review

Increase in the number of potential internet connected objects has exposed problems, which cut across interfacing, connectivity, security and also optimization of connected

nodes of objects. Also, in teaching IoT, apart from vendor based kits there is scarcity of educational IoT modules adapted to class lectures. The main challenge with interfacing is to make objects that have been in the past unintelligent to now become intelligent (or smart). Smart objects are the building blocks for the Internet of Things [4]. Capabilities of smart objects include embedded sensing, embedded actuating, embedded processing, communication and addressability, identification and localization [5]. Connectivity addresses how IoT devices connect and communicate. The Internet Architecture Board (IAB) in March 2015 released an architectural document that guides the networking of smart objects. The document presents a framework for the following four common communication models used by IoT devices [1].

i) Device-to-Device Communication Model
ii) Device-to-Cloud Communication Model
iii) Device-to-Gateway Communication Model
iv) Back-End Data-Sharing Communication Model

This work uses the third communication model, that is, Device-to-Gateway communication model as shown in Fig. 3.

A few books on IoT [6]–[8] and several development kits that offer hardware and software for designing and building IoT devices already exist. Most of the books teach IoT in theoretical ways, while the development kits focus on vendor specific tools or other products used in creating specific IoT applications. However, there is a need to have a training module that focuses on teaching basic IoT concepts (especially to undergraduates) which has not been done or reported. This work, therefore, focuses on a teaching model that will help students experiment with IoT ideas through some laboratory sessions.

A number of learning models with corresponding teaching styles have been identified in engineering education [9]. These learning models include;

i) Sensing and intuitive learning
ii) Visual and auditory learning
iii) Inductive and deductive learning
iv) Active and reflective learning
v) Sequential and global learning

This work uses the sequential teaching approach to draft quasi-experiments for teaching basic IoT concepts. The aim is to teach IoT in a progressive pattern. The teaching trend moves from an introductory level, to an intermediate stage and then finally to an advanced level. This technique ensures that students are able to follow the gradual progress of understanding the basic concepts of IoT.

III. Understanding By Design Model

To ensure this proposed teaching model works, this research adopts a model for designing and evaluating. The Understanding by Design (UbD) Model [10], [11] is an approach which is targeted at individuals and groups who are interested in improving their skills in designing units of study. It approaches study units from a design perspective, other than as a mere pre-teaching duty. It has been proved that the model has great impact on the learners' rate of understanding [12]. The

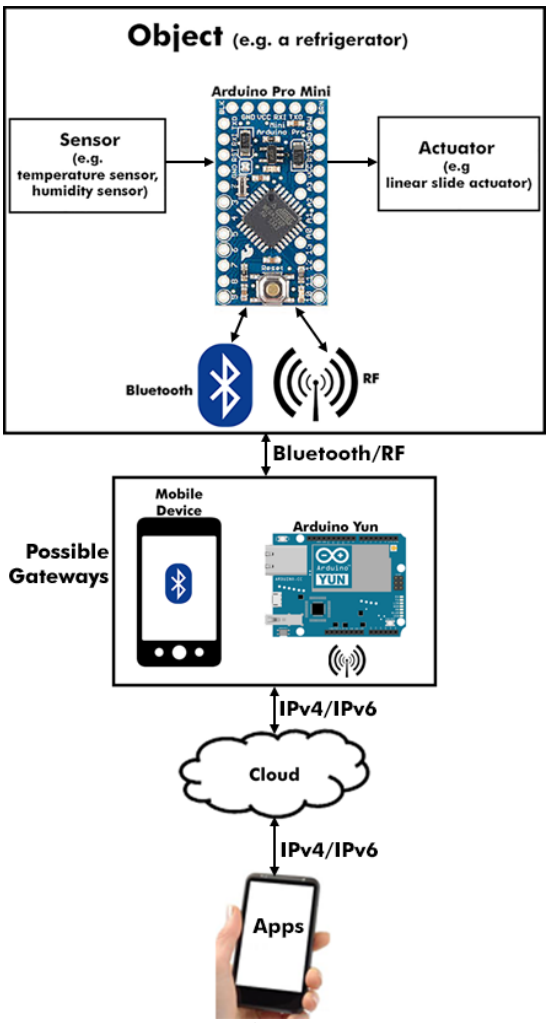


Fig. 2. Schematic diagram of the setup

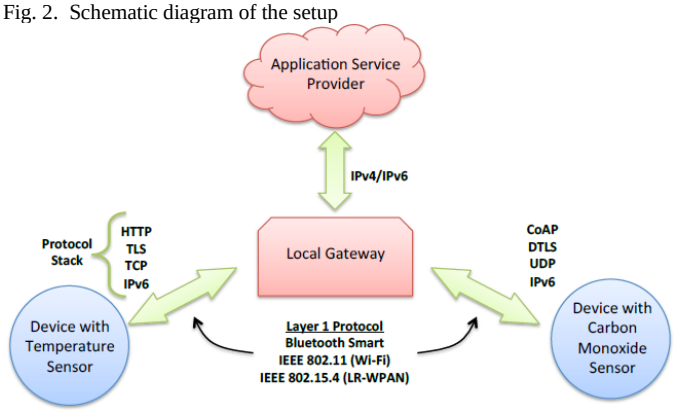


Fig. 3. Device-to-gateway communication model [1]

model achieves this by using a backward-design unit approach which defines and considers three components when a unit is designed for study. These components include;

i) What are the desired results (the goal)?
ii) What is the evidence of achieving unit's goal?
iii) How might these results be best achieved?

With these questions, the model provides a guide to preparing an effective study unit. This paper adopts the model to evaluate the effectiveness of the proposed

teaching model. Table I shows the answers to the UbD questions for the proposed IoT teaching module.

TABLE I
DESIGNING A UNIT STUDY FOR THE PROPOSED TRAINING MODULE USING THE UBD MODELING QUESTIONS

Question	Answer
What are the desired results the training module hopes to achieve?	The goal of the training module is to expose learners to the vast applications and design of IoT systems. The students should be able to specify the interface or connectivity type to use for a defined function.
What is the evidence of achieving the desired goal?	The learner should be able to select interfaces for different functions and explain why the interface is selected. The learners should be able to apply the connectivity RULE to designing block diagrams for an IoT system. The learner should also be able to explain how the designed block diagram can serve as an IoT application in the real world.
How can the desired results be best achieved?	The learners would complete a set of experiments, which gradually brings them to the desired result. At the end of each experiment, a short quiz is given to show the evidence of achieving the unit goals.

IV. THE PROPOSED BASIC IOT MODEL

This research work focused on proposing laboratory experiments that use a generalized algorithm to determine the right interface and connectivity types when designing an IoT system because the major considerations in IoT design are interfacing and connectivity. So, students are walked through A step-by-step learning and understanding of interfacing and connectivity issues as shown in the flowchart in Fig. 4.

A student will first determine the function required of the simple IoT system. This will enable the student choose an appropriate sensor or actuator or even both depending on whether the function is measurement, control or both, respectively. Bluetooth or RF is then selected as the connectivity type. At this point, the student creates an interface using the sensor or actuator, a processor (in this case Arduino Pro Mini) and the connectivity type selected. A gateway is then selected. As a rule, the gateway must have the same connectivity type as the interface and must also be able to connect to the internet (a cloud service). The student finally tests the setup with a mobile app (on a smart phone) or a web app (on a personal computer) connected to the cloud over the internet. Table II shows examples of applying this model to IoT designs by considering the interface and connectivity of the system.

A training module and mobile/ web app is developed to conduct each of the experiments shown in Fig. 5. Experiments 1, 2 and 4 are control experiments while experiment 3 is a measurement experiment. The students are provided with all the necessary tools including circuit diagrams for connecting peripherals to an Arduino board. The mobile app runs on an Android mobile platform. The application service employed is called Blynk and is depicted in Fig. 6. A widget box is provided with all the necessary control/indicator components shown in Fig. 6b which is used in designing the interface of Fig. 6a which displays temperature and humidity on an LCD screen. Table III shows the function of each component on the interface.

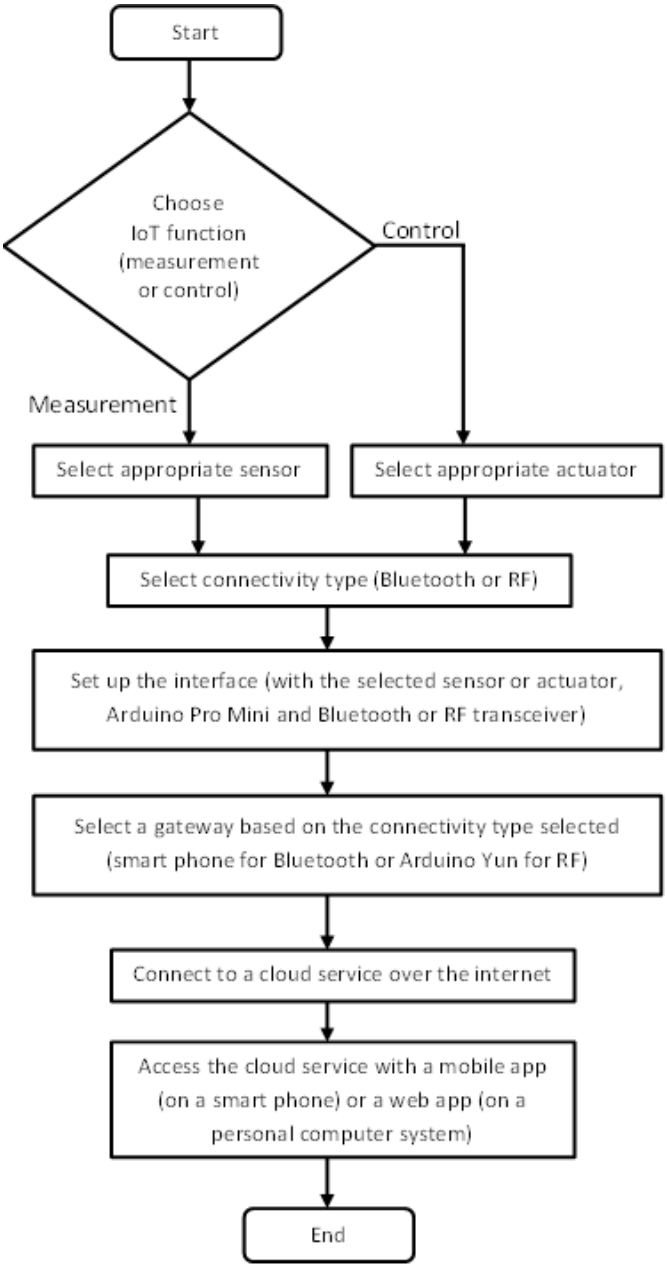


Fig. 4. Flowchart showing experimental procedure

At the end of each experiment, students take a quiz, which evaluates and gives evidence of the learning progress. This evidence corresponds to the UbD model. The web/ mobile interface for each experiment is built with a feedback indicator to ensure the control request is executed. This is required in situations where physical access to controlling device is not possible.

The experiments for the basic IoT training module are further discussed.

TABLE II
EXAMPLES OF THE APPLICATION OF THE PROPOSED BASIC IOT TEACHING MODEL

Function	Sensor	Processor	Connectivity Type	Gateway	Connectivity to Cloud Service	App
To monitor humidity in a room	Humidity sensor	Arduino Pro Mini	Bluetooth	Smart phone	Internet	Web App
To monitor soil temperature	Temperature sensor	Arduino Pro Mini	RF Transceiver	Arduino Yun	Internet	Mobile App
To ensure that a refrigerator door is not left open for more than 20 seconds	Temperature and humidity sensors, linear slide actuator	Arduino Pro Mini	Bluetooth	Smart phone	Internet	Mobile App

TABLE III
FUNCTION OF EACH COMPONENT ID

S/No	Component ID	Component Functions
1.	Relay C	Relay Control for turning on/off the A/C or LED bulb.
2.	Motion C	Motion Control for turning on/off the dc motor
3.	L D	Light Indicator for indicating the A/C or LED bulb state.
4.	A D	Actuator Indicator for indicating the motor state.

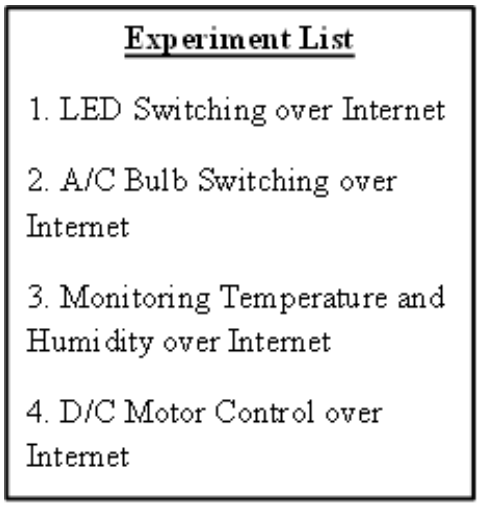
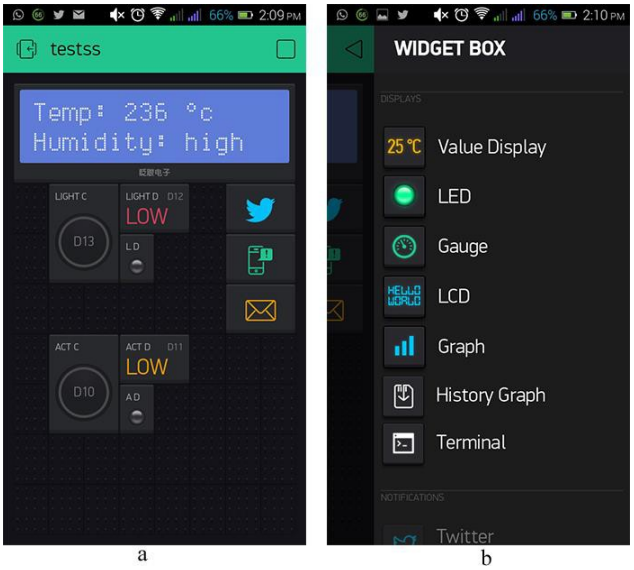


Fig. 5. List of experiments for the basic IoT training module



a b

Fig. 6. Mobile App

A. LED switching over Internet

The goal of this experiment is to introduce students to the basic concept of IoT using an LED. Although neither a sensor nor an actuator is needed for this experiment, students are expected to identify that the IoT function required is control.

For this experiment, students will be required to set up the system and independently use RF and Bluetooth as connectivity types. The students then use the mobile/ web app to test their system. They will be required to record the actual state of the LED when controlled from the app.

B. A/C bulb switching over Internet

Controlling an A/C bulb is a step ahead of controlling an LED. With this, the learner understands how to manipulate alternating current devices by controlling them remotely. It also brings students to the understanding of actuators using a relay. Students must identify the IoT function as control and select a relay as the actuator for switching the bulb on and off. Students will then be required to set up the system and independently use RF and Bluetooth as connectivity types. The students then use the mobile/ web app to test their system. They will be required to record the actual state of the bulb when controlled from the app.

C. Monitoring temperature and humidity remotely over Internet

It has been discussed earlier that sensors are key parts of an IoT system. To this end, a measurement experiment that used temperature and humidity sensors is introduced to the learner. Students must identify the IoT function as measurement and select the appropriate sensors. These sensors must be correctly connected to the processor (Arduino Pro Mini) and set up must be completed by the students. Bluetooth must be used as the connectivity type and data obtained from the mobile app recorded.

D. D/C motor control over Internet

This experiment concludes the basic understanding of IoT for the learner. The learner controls a dc motor over the internet. Students must recognize the IoT function as control and identify the actuator. They must set up the system correctly and test with the mobile/ web app. Motor speed will be varied on the app and compared to the actual speed of the motor.

Though students are not required develop the mobile or web apps they will be working with, they have to code the Arduino boards (Pro Mini and Yun). Templates and instruction manual are provided to help them come up to speed with coding the Arduino boards. The instruction manual also includes instructions on the set ups and short notes on signals and systems, Analog to Digital Converters (ADC), Digital to Analog Converters (DAC), Wireless Sensor Networks (WSN), etc.

V. Test And Results

To test the proposed teaching model, organized laboratory sessions were carried out at the authors' University using 100 Year 3 students of the Department of Electronic and Electrical Engineering. Ten groups constituting 10 students per group were used. The students used the developed lab module and apps to execute each experiment listed above. Results are presented in Figs. 7a, b and c.

Fig. 7a shows that most students (76 out of 100) were able to select the correct IoT function (that is, measurement or control) and setup the interface correctly. A right choice of measurement or control is necessary for a successful interface setup. Therefore, all the students that got the IoT function wrong found it difficult to set up the interface correctly. Only a very few who got the IoT function right were not able to set up the interface (mainly because they could not set up the sensor nodes successfully).

Fig. 7b shows that a number of students (36 out of 100) got confused with the connectivity rule that the gateway must have the same connectivity type with the connectivity type chosen for the interface. This is because there are two possible gateways (Arduino Yun and Smart phone) available for selection depending on the connectivity type defined for the interface. If the connectivity mode of the interface is Bluetooth, then a smart phone must be the gateway. When the connectivity type defined on the interface is RF, Arduino Yun is used as gateway.

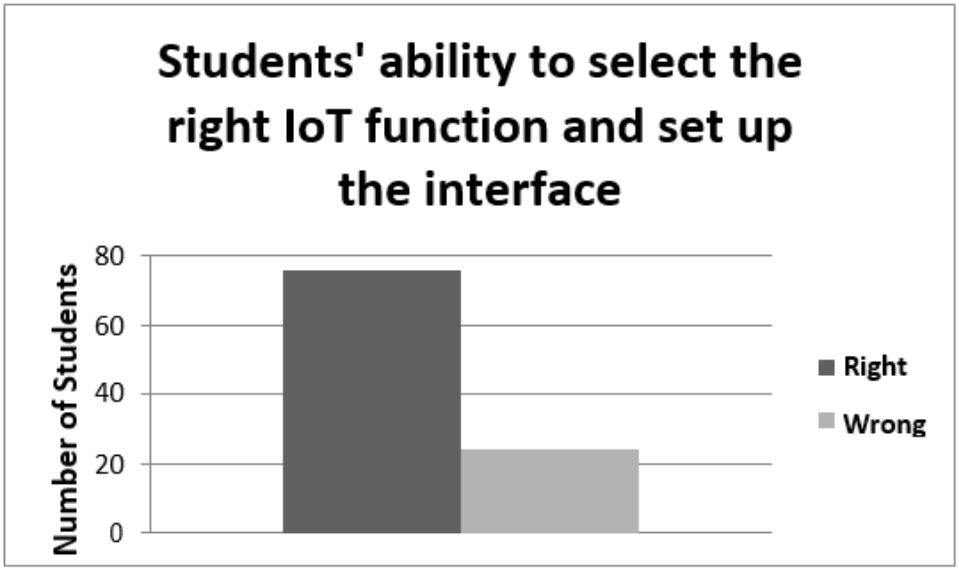
The main result is shown in Fig. 7c. It shows that only 51 out of 100 students were able to complete all the experiments successfully. This is largely due to the selection of a wrong gateway for the connectivity type selected as shown in Table II. Also, a few had problems setting up the interface correctly because of a wrong choice of IoT function. Coding the Arduino boards was a challenge for some of the students while a few others had challenges with creating sensor nodes (that is, connecting the sensors and/or actuators, RF and/or Bluetooth with the microcontroller- Arduino Pro Mini).

The graphs shown are directly related to the following steps already identified in the flowchart that is, choosing appropriate IoT function, selection of appropriate sensor or actuator, selection of connectivity type, setting up the interface, selection of appropriate gateway and connection to cloud service.

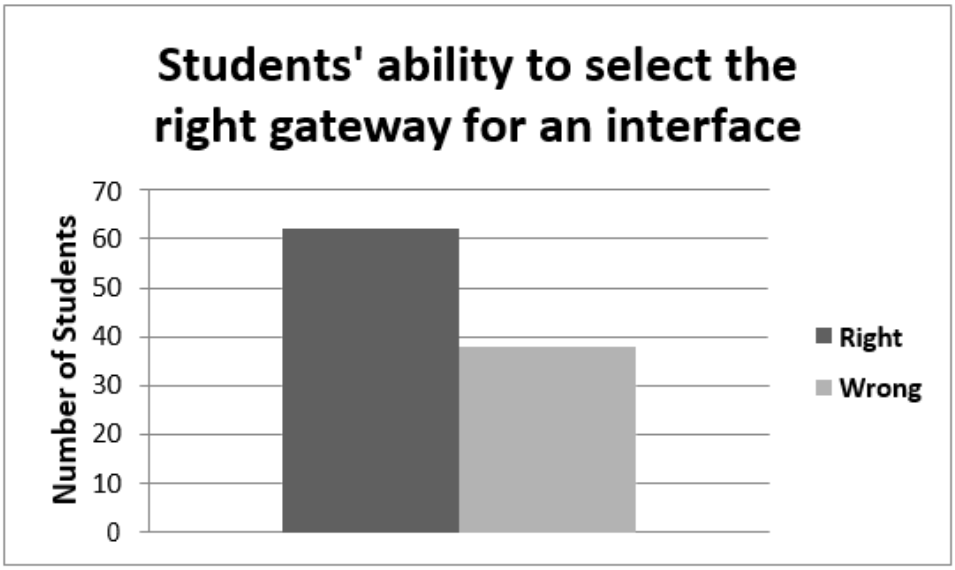
VI. Conclusion

The essence of teaching basic IoT concepts is for the ability of students to apply these concepts to real life applications (such as agriculture, medical, industrial, social etc.). This implies that an advanced study material is required to bring students to an application level. Based on the results presented in the previous section, the proposed IoT teaching model works to an extent and will definitely engender interest in developing IoT applications especially in developing countries where IoT applications are almost nonexistent. However, for further research purposes, this can only serve as a basis for introduction to IoT and will require a follow-up model for teaching real life IoT applications.

In summary this work has been able to address interfacing



(a)



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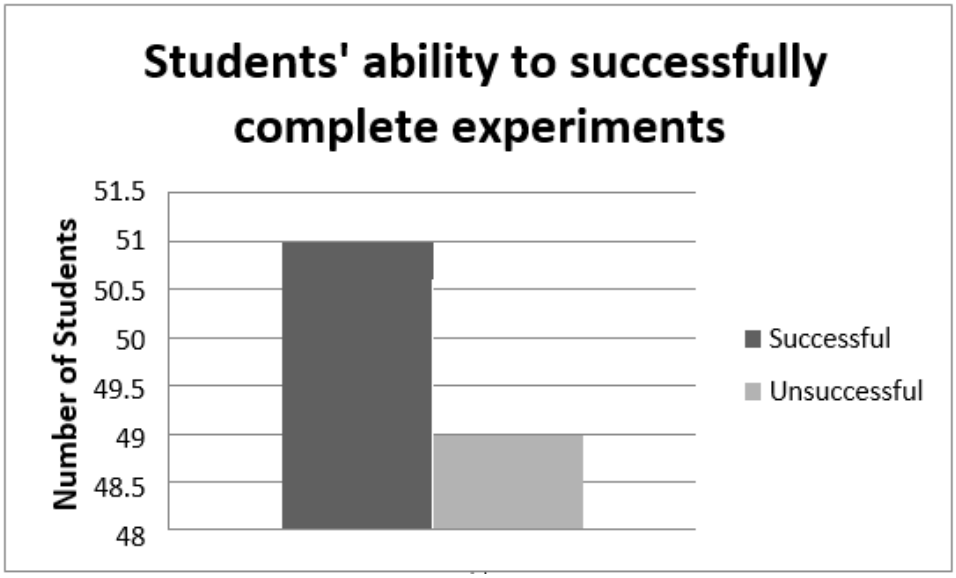

(c)

Fig. 7. Results obtained from using the training module

and connectivity issues involved in teaching IoT. A training module has been developed which utilizes temperature and humidity sensory units, LEDs, relays and radial motor as sensors and actuators. Connectivity was tested using RF transceivers and Bluetooth. Arduino Yun and a smartphone were used as gateways.

It was also obvious that some students had problems with experiment completion because of inadequate understanding of the relevant theory. This fact will assist the teachers focus on theories and adjustment of teaching methods to address students' misconceptions.

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