# How Well do Students Understand the All-Encompassing, Ubiquitous, and Interconnected Nature of IoT? Evaluating Student Capstone Projects

Timo Hynninen and Antti Knutas



April 1, 2024

# How Well do Students Understand the All-Encompassing, Ubiquitous, and Interconnected Nature of IoT? Evaluating Student Capstone Projects

Timo Hynninen
South-Eastern Finland University of Applied Sciences
Mikkeli, Finland
timo.hynninen@xamk.fi

Antti Knutas
LUT University
Lappeenranta, Finland
antti.knutas@lut.fi

## ABSTRACT

The Internet of Things (IoT) content and curricula is a recently emerged trend for computer science and software engineering educators. IoT as a paradigm is often described as an all-encompassing new phenomenon covering homes, industries, governments, and the environment. For that reason, IoT topics have become a part of computer science and software engineering programs. Existing research has been conducted on the development of IoT curricula but as this work is fairly recent the evaluation of those approaches requires further work. This paper presents a case study from a capstone course within a three-course IoT specialization. We evaluate student capstone projects using the thematic analysis method in order to assess our IoT specialization studies. As a result, we present an overview of how the students see the IoT, and what kind of IoT projects they design and implement. Most often the student projects implemented home automation projects. Often these prototypes lacked connectivity and communication capabilities to other systems. An IoT characteristic that is most rarely seen in student projects is 'physical actions in the environment.'

## CCS CONCEPTS

• **Social and professional topics → Computing education**.

## KEYWORDS

Internet of things, capstone, case study

## 1 INTRODUCTION

The internet of things (IoT) is a fast-growing phenomenon in the computer and information technology field. Many of the large technology companies, along with experts, believe that the IoT will have a role in the next technological evolution [24]. Yet, in a recent ITiCSE working group report Burd et al. state that education and training for "developing and securing of IoT lags behind the demand" [6], although many approaches to teaching IoT already exist in the literature [5, 6]. Hence, teaching the IoT is a relatively new trend that requires further investigation, particularly in the evaluation of different approaches to the IoT curricula.

In this paper, we present a breakdown of the capstone projects students submitted during the last course of a three-course-long IoT specialization. We assess how the students perceive the IoT through the projects they designed and implemented around the theme. The objective is to evaluate how well the content and focus of our IoT specialization courses reflect the interconnected, ubiquitous nature of IoT. We used the thematic analysis method [4] to systematically go through the projects and their distinct features. Projects from two courses between two academic years (2019 and 2020) were analyzed. We used three dimensions of the IoT, as distinguished in the article by Förster [13], as the theoretical framework guiding the thematic analysis.

Specifically, our research questions are:

- What dimensions of the IoT do the projects cover?
- Do the projects depict the all-encompassing nature of IoT and provide solutions for a variety of domains?
- Should we change or emphasize something differently within our IoT curriculum?

The rest of the paper is structured as follows. Section 2 discusses the scope and prior work of the IoT. Additionally, the research gap is stated. Section 3 describes our course and curriculum design along with the data analysis methods. Section 4 presents the main findings from the data. Section 5 contains answers to the research questions and discusses the validity and limitations of the study.

## 2 RELATED WORK

### 2.1 IoT and its dimensions

The ITU's 2004 publication "Overview of the Internet of things" gives one of the first, comprehensive definitions of IoT as a "global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies" [26]. The paper by Förster et al. defines the key characteristics of IoT as (1) the ability to sense the environment, (2) the ability to communicate the data, and (3) taking actions in the environment [13].

The working group of Burd et al. lists IoT dimensions as knowledge units. The core IoT content in this taxonomy are listed as *Concepts of Things (Hardware)*, *Connectivity, the Cloud, and Data*, and *Human-Computer Interaction*. In addition to the core content, specialized knowledge, such as platform-specific development, security issues, and machine learning, are also included in the model. [5].

The Internet of Things is an umbrella term for the presence of all the everyday objects that have communications and computing capabilities [2]. Already in 2010 Atzori et al. stated in their IoT survey that the "IoT should be considered as part of the overall Internet of the future, which is likely to be dramatically different from the Internet we use today" [2]. Technologies such as 5G are the major drivers for the growth of IoT applications [18].

## 2.2 IoT curricula and teaching

Burd et al. [6] distinguished the different approaches recent research has described implementing IoT curricula. Currently, the four ways to add IoT content into computer science education are through 1) broad introductory courses, 2) integrating IoT into existing courses, 3) arranging focused IoT specializations, and 4) courses on specific IoT use cases.

Mäenpää et al. used a project-based learning approach to develop IoT applications for an urban greenhouse setting [20]. Based on running their project course the authors also propose assessment criteria for the student projects, which can be used in different contexts and with different technologies [21].

As for other types of IoT course implementations, Raikar et al. described an active learning approach [25], Galluzzi et al. [14] used a lean startup strategy, and de Haan [10] compared research and practice-oriented approaches for creative technologies in IoT.

According to Förster et al. [13], the challenges in teaching an IoT course module are the multitude of different tools and platforms, the complex details of communication technologies (protocols and parameters), and experience with real-world end-to-end systems. In short, the variety and complexity of the different hardware and software, together with the complexity of communications protocols make the IoT a challenging topic, as there are so many details to cover. Likewise, this complexity may distract the students from seeing the working, real-world applications, and therefore need the experience to complete projects without structured guidance.

## 2.3 Research gap

Internet of Things content and curricula have recently gained much research interest. The working group reports of Burd et al. [5, 6] provide a rough map of existing IoT literature. Different approaches to designing IoT courses or integrating IoT into existing curricula have been published, e.g. [12, 15, 16, 19].

Still, this field of research is in its infancy. The existing IoT curricula and recommendations are quite new, and assessments of their impact and pedagogic alignment require more work. Even though experience reports from running IoT courses are not hard to come by (for example [1, 17, 20]), evaluations of the different approaches are scarce in the literature. In addition, we are not aware of work that evaluates how the different IoT dimensions are addressed in the course design and achieving learning goals. The current study demonstrates one approach to assessing IoT curricula and course design, thus attempting to take concrete steps towards tackling this gap in the literature.

**Table 1: The three course IoT specialization module, individual courses and their learning objectives**

| IoT Essentials | IoT Technologies | IoT Project |
|---|---|---|
| The basics and connections that make up IoT. Microcontrollers, computers and sensors for IoT projects. Sensor / actuator systems. Building an end-to-end IoT system. | Value of data produced by IoT. Architectures and infrastructure for IoT solutions. Communication protocols and technologies. | The students apply their skills in a practical IoT project. |

# 3 METHODOLOGY

## 3.1 Course Design

The IoT Project course was designed to be a capstone course in a three-course IoT curriculum. In the curriculum design, we employed the "Focused Course(s) as part of an IoT specialization" approach [5], as the courses were intended to focus especially on the IoT concepts. The three IoT-focused courses were 5 ECTS points each in sizing. We used the Raspberry Pi as the primary platform in all courses, with an Arduino as a secondary board when a Raspberry Pi could not be used. Both platforms are well suited for IoT courses [17, 24]. The high-level content and learning objectives for the course modules are presented in Table 1.

The first course, *IoT Essentials*, was aimed at small electronics and smart device programming, using consumer electronics and the Raspberry Pi as the development platform. The course consisted of theory lectures around IoT concepts in general, homework assignments, and practical hands-on labs. The homework was based on the "Introduction to IoT" course from the Cisco Networking Academy [8]. The lab assignments focused on programming on the Raspberry Pi using different sensor devices connected to the Pi using its GPIO (general-purpose input/output) pins. This course's objective was to cover the basic "Concepts of Things" which is considered foundational, core content in an IoT specialization [5].

Another core IoT specialization course followed, under the name of *IoT Technologies*. This course's objective was to cover the "Connectivity, the Cloud, and Data" aspects, which are also recommended core IoT content [5]. The course carried on from the Essentials course with more hands-on labs and homework focusing on the IoT system architecture and communications. The homework included selected readings on IoT architectures and infrastructure, for example, the papers "The Internet of Things: A survey" by Atzori et al. [2] and "Internet of Things for Smart Cities" by Zanella et al. [28]. Additionally, the homework included examples of larger IoT systems using the Packet Tracer simulation tool [9]. These simulations included examples of a smart home system, a smart factory system, and a smart grid system.

Over the two academic years, the course content stayed mostly the same. The *IoT Essentials* course saw virtually no changes between the years. The *IoT Technologies* course module was updated between the years to contain more programming assignments. Additionally, new lecture demonstrations were added on the design of IoT, networked systems, and embedded systems. Selected sections of a supplementary course book, *Designing the Internet of Things* [23], was also added to the reading list.

The final course, *IoT Project*, was the capstone project in the three-course specialization. Students designed, implemented, and reported on an IoT solution of their choice. The students had free choice of what to build but we had set the following requirements for the projects:

- At the very minimum the required hardware components that should be used in the project are: Raspberry Pi which acts as the platform, 1-N sensors depending on the project and the group size, and, a web service or server which stores up-to-date sensor data or system state.
- The web service must be hosted separately (that is, you cannot install a web server on the Pi itself)

To build the prototypes in the projects the student had access to the following hardware: Two different kits of various sensors for single board computers (Kit 1[1] and Kit 2[2]) PIR (passive infrared motion) sensors[3] RFID tags and tag readers[4].

We also gave examples of suitable course project ideas, although we stressed that these were for reference only and students should come up with a system of their own. The examples we outlined were a smart home automation system, an application for traffic or environment monitoring, and an application for agriculture or a greenhouse. The students then proposed a project idea which they implemented after approval from the instructor.

## 3.2 Thematic analysis

As we analyzed projects from two course implementations in different years, we had to perform the analysis post-hoc. For this reason, we could not use other data sources such as interviews or the instructor's observations. The analyzed documents are formal student reports describing the design and implementation of the capstone projects. The reports were required to follow a set structure, and they had to describe the motivation of the project, describe the components and programming logic, and document how the system works in practice.

We analyzed the student project submissions using the thematic analysis method. Thematic analysis is a "qualitative research method for identifying, analyzing and reporting patterns (themes) within the data" [4]. In thematic analysis, we start with a systematic, iterative coding process for each row of data (student submission) and the final outcome is a set of themes that describe underlying phenomena behind the data set.

The coding process was conducted by the first author alone, as we could not share student works between authors from different institutions. Single coder approaches to thematic analysis are sufficient if the coding is binary or checklist-based [22]. In our case, a semi-structured coding process was used. We used the three IoT dimensions [13] as a guideline, and recorded observations in accordance with these dimensions.

The thematic analysis process consisted of five phases, presented as follows.

(1) *Familiarization with the data.* An overview of the student projects was formed during the project course. The instructor worked with the students throughout the course, approved project ideas before they were built, and verified that each project was a working prototype. Afterwards, we collected student-submitted reports from the course website.
(2) *Generating initial codes.* After the initial inspection, we read through each project submission and codified observations from the source code. Once an observation was noted we backtracked to go through submissions that were already codified, in case we missed something relating to the new observation.
(3) *Searching for themes.* Once the submissions were codified we examined the codes, the prevalence of each code, and grouped them to a common theme when possible.
(4) *Reviewing themes.* After establishing the initial themes we reviewed them and tried to look for factors explaining them using our experience as educators.
(5) *Defining and naming themes.* Evaluating and refining the themes, giving them succinct names, and generating clear definitions.

In the process of analyzing the data, we followed the ethical principles of research with human participants by the Finnish national board on research integrity. The ethical guidelines also affected the choice of research method; The work was (in part) limited to analyzing reports as we could not use surveys or interviews post-hoc without informed consent, and soliciting both responses and consent afterwards might prove difficult with the relatively low number of participants in our classes.

# 4 RESULTS

## 4.1 Student projects

In the 2019 implementation of the course, we had 25 students who formed 8 groups of 2-4 people to complete the projects. In addition, 5 more students had registered for the course: One more group had submitted a project plan but these students dropped out at the beginning of the course for unknown reasons.

Details of the projects are summarized in Table 2. A total of six projects presented some variant of a home automation system: In two of the projects (Home monitor, Home security & fire alarm) the students had built a home security system. One smart home system (Smart kitchen) was designed to be used in the kitchen, to monitor the kitchen temperature and detect a sudden fire. Additionally, the smart kitchen project included a sensor to detect when the fridge door is opened.

The project that took home automation the furthest was the Smart home & remote control. The students implemented a web-service-based remote control application for turning electrical appliances on or off by controlling the AC sockets. Another project (Leak detector) was based on the idea of preventing water damage

[1]https://www.instructables.com/id/Arduino-37-in-1-Sensors-Kit-Explained
[2]https://www.sunfounder.com/learn/category/Sensor-Kit-v2-0-for-Arduino.html
[3]https://learn.adafruit.com/pir-passive-infrared-proximity-motion-sensor/overview
[4]https://www.instructables.com/id/RFID-RC522-Raspberry-Pi/

**Table 2: Project descriptions from 2019**

| Project name, context, and description | Data communications | Future development ideas |
|---|---|---|
| Smart kitchen (home): Temperature and flame sensors monitor the kitchen for safety. A magnetic hall sensor detects when the fridge door is open | No connectivity | Adding more electronics to enable more more functionality. |
| Smart home (home): Smart AC sockets built using relays allow them to be turned off and on by using a web application & remote control system | Used with electrical appliances | Improving the form factor (custom electronics). Improving the UI for performance and usability. |
| Home (security) monitor (home): Motion sensors trigger a camera to take a picture when someone approaches the front door at the house | No connectivity | No plan |
| Home security & fire alarm (home): The system detects when a user's mobile phone is connected to home wifi. When the mobile phone leaves home, the alarm systems are activated. A fire alarm (flame sensor) sends a warning message in case of a fire. A motion detector sends a warning notice when an intruder is in the house. | Mobile notifications (with IFTT) | No plan |
| Leak detector (home): Water, humidity and temperature sensors form a warning system for water leaks in the home | No connectivity | Better code implementation to improve the system accuracy |
| RFID attendance system (school): Students coming to class register attendance using an RFID card | No connectivity | Better code implementation to improve the system accuracy |
| People counter (business): The system consists of two motion detection sensors. Based on the sensors reading the system detects whether people are coming or going, and keeps a count of how many people have entered the space. | No connectivity | Making the system portable by using wireless communications. Business ideas expressed. |
| Pet monitoring system (home): Motion sensor placed near a balcony door triggers push notifications on a mobile application. An owner gets notified when their pet goes outside. | Mobile notifications (with IFTT) | Better code implementation to improve the system accuracy |

in the home. The last home automation-themed project was a pet monitoring system (the Pet monitor), inspired by one student's feline family member.

Two projects were based outside the context of a home. The RFID attendance system was placed in a classroom, where students would register their attendance by showing an NFC smart tag to a reader. The people counter project, on the other hand, was aimed at any business with customers coming in and out to keep an up-to-date count of the patrons.

In 2020 there were 15 students taking the capstone course. The students worked either alone or in groups of two people, amidst the Covid-19 pandemic. The 2020 projects are summarized in Table 3.

Two similar projects implemented an RFID lecture attendance system, using smart card readers and NFC tags. Three projects implemented a system in which home security, home remote observation, or remote control were the main feature. Three more projects were in the domain of the home (Smart trash bin, Temperature and humidity data, and Smart sleeping monitor). One project aimed at improving the security of airports by using movement and proximity sensors. Finally, one project designed a prototype for controlling the customer flow of a business by combining an online booking system with an RFID-operated turnstile at the doorway.

## 4.2 Summary of the projects

After formulating the descriptions for the student projects we proceeded with the thematic analysis. The purpose of this was to uncover possible recurring themes within the projects and relate them to the IoT dimensions. Table 4 summarises the IoT dimensions which were descriptive of the projects.

Overall we saw one major theme covering all of the IoT projects: Monitoring the home or environment. Another common theme was movement detection-based systems. In addition, we noticed that the student teams concentrated on gathering data instead of making interactive systems. In cases where data was provided, it was usually provided to a third party monitoring the area, such as home security alerts or pet monitoring. The monitoring applications can be roughly divided into three major subcategories: 1) Home security, 2) safety systems, and 3) people monitoring.

# 5 DISCUSSION AND IMPLICATIONS

## 5.1 Findings and implications

All in all, at the end of the three IoT specialization courses our students were able to build interesting prototypes. The IoT specialization followed the roadmap set by Burd et al. [5, 6], focusing on the core IoT content (hardware, connectivity, and human-computer interaction). The first course, *IoT Essentials*, focused on the hardware (sensors and hardware platforms) and different enabling technologies (such as networking protocols). The second course, *IoT Technologies* consisted of hands-on design and implementation of connected devices. The final course, *IoT Project*, was designed to

**Table 3: Project descriptions from 2020**

| Project name, context, and description | Communication to systems | Future development ideas |
|---|---|---|
| RFID lecture attendance system (school / university): Students coming to class register attendance using an RFID card or mobile phone | No connectivity | Connectivity to access control systems. Research on how attendance recording affects attendance levels. |
| Airport runway intrusion detection system (airport): Movement and proximity sensors detect unauthorized access and "runaway" airplanes | No connectivity | No plan |
| Smart trash bin / laundry basket (home): Proximity sensors measure how full a basket is | Service exposes a REST API | No plan |
| Home security and automation system (home): A motion sensor, temperature sensor, and an RFID key reader are used to implement a home security system | Service exposes a REST API | More options / features for the security system |
| Smart sleeping monitor (home): Light and temperature sensors monitor the bedroom sleeping conditions | No connectivity | Better sensors |
| Temperature and humidity data collection system (home) | Service exposes a REST API | No plan |
| RFID lecture attendance system (school / university): Students coming to class register attendance using an RFID card | No connectivity | No plan |
| Automatic turnstile system (business): NFC reader and an online booking system are used for automatic, contactless (hygienic) access control system | System has a web page interface accessible online | Examining privacy aspects of the system |
| Remote home appliance control (home): Raspberry Pi as a platform for turning home appliances on and off remotely | Service exposes a REST API | Network security considerations for the system |
| Home security system (home) | No connectivity | No plan |

**Table 4: Dimensions of IoT (see Förster et al. [13]) distinguished in the analysis**

| | |
|---|---|
| Sensing | All projects were based on some measurement of the environment. All projects exhibit features in this dimension |
| Data communications | Three (out of eight) projects in 2019 were not self-contained and communicated with other systems. In 2020 half of the projects considered this dimension. |
| Actions in the environment | In 2019 only one project (Smart home & remote control) had some physical actions result from the measurements. In 2020 two projects (Smart turnstile & Remote home appliance control) implemented physical actions in their environment. This dimension was mostly not present in the projects |

be a capstone where the skills and knowledge from the previous courses should be applied.

All of the student projects were within the set requirements, and they captured the spirit of the IoT in at least some dimension. We observed in the 2019 course that connectivity - a key characteristic of the IoT - was not present in most projects. To fix this issue lecture material was re-designed in the second course to include topics covering the design and implementation of communication for devices. In the following year (2020) more projects seemed to implement some way of data communication. Still, only 5 out of the 10 projects in 2020 took the communication dimension into consideration.

The student projects were mostly situated in the context of the home. Many projects implemented a monitoring application and were designed to be security systems. Another common context of use was studying. We expected that since the students had explored IoT in other domains besides the domestic one their projects would reflect other contexts of use. More diverse framing and structuring of the problem might prompt the students to take more diverse approaches. Furthermore, it might be beneficial to place their IoT project in a wider context, to support independent problem-solving with technology, technology deployment, and orchestration.

Another interesting finding we made based on the analysis was that the students didn't seem to have a vision of how to take their prototype further. Three teams had built a system that was not only a standalone and single-purpose monitoring system but could also be connected to other systems. Furthermore, only a couple of teams had expressed plans for improving the system, even though the reporting instructions asked for a paragraph about possible future work. These teams stated in their reports that their system could be improved by making certain modifications, for example, custom hardware or using wireless technologies.

In contrast, most teams did not think of the future of their projects in terms of adding functionality. Instead, their statements for future work were either code improvements and improving the system's core functionality, or not stated at all.

Comparing the outcomes of our students' projects with other IoT-themed project courses in the literature, we can see some similarities with the results of Mäenpää et al. [20] and Raikar et al. [25]. Many of their students used similar hardware as what our students chose to use: Temperature and humidity sensors, and NFC key readers.

Based on our experiences of running the IoT Project course, we recommend using special care when formulating the problem description for the project assignment. Examples of suitable systems can be given but the examples should be from a variety of different contexts.

## 5.2 Revisiting the research questions

Next, we summarize the answers to the questions that we set out to investigate. *What does a typical student IoT project look like?* On the whole, most of the student projects aimed to solve a home automation problem, especially by passive sensing. The prototypes were mostly single-purpose monitoring applications.

*What dimensions of the IoT did the projects cover?* In the terms of the layers of the IoT as described by Burd et al. [5] building on the ITU's IoT reference model [26], the student projects covered many of the technological aspects of building IoT solutions. For example, to build the prototypes the students must be familiar with sensor-actuator systems, digital logic, device capabilities, and application programming. However, the projects turned out very technology-oriented, and we could argue that dimensions such as Human-Computer Interaction, distributed systems, or system architecture design were not very much present in the projects.

In terms of the key IoT aspects by Förster et al. [13], most of our students' projects implemented the "sensing of the environment" dimension. However, most projects were standalone sensing systems, and only some of them were connected to other systems or the surrounding world. Only a couple of projects implemented the "take actions in the environment" dimension. On the whole, it could be summarized that the projects implemented only some of the key aspects an IoT system typically has. Table 4 summarises how the projects relate to the different dimensions of the IoT.

*Do the projects depict the all-encompassing nature of IoT and provide solutions for a variety of domains?* The projects produced working prototypes that could be described as smart devices with often limited communications capabilities. As these devices did not communicate (much) with other systems, we feel that even more emphasis should be put on approaches that emphasize communication and services. For example, a cloud-based approach such as one described by Bogdanović et al. [3] could be a solution.

*Should we change or emphasize something differently within our IoT curriculum?* To re-iterate the previous point, another lesson learned is that few student prototypes had interactions with the surrounding environment. It seems that to most students, the IoT is not about autonomous things that are connected but rather systems that can be used. In this sense, we feel that the communication dimensions of the IoT remain mostly unexplored in our curriculum. We encourage other IoT educators to pay special attention to this topic.

## 5.3 Validity and limitations

The selected data source - formal student reports - poses a threat to internal validity through study design. We had to analyze the student projects post-hoc, since we had projects from two consecutive years' course implementations. As the reports were required to adhere to a format and explain the motivation and use of the project, we feel that they contain a sufficient amount of information on the projects. However, we must acknowledge that a second method of data gathering, for example, interviews, could be used in the future to tackle this limitation, as this would facilitate the triangulation [11] of the results.

Additionally, the number of projects we analyzed means we can't present a quantitative analysis using statistical indicators. Therefore, we must acknowledge that our conclusions are more exploratory than confirmatory. Despite this limitation, we feel that our experiences are useful to other educators as we have presented actionable recommendations for the scope and context of IoT course projects.

In future work, we should consider further investigation into how the students achieve the learning outcomes of our IoT curriculum. As IoT is a broad field, the curriculum must reflect as many dimensions of all the interrelated topics as possible. We should also look into how to diversify the framing of our assignment criteria, and prompt the students to think about IoT solutions in the various domains that exist.

Another avenue of future research is the misconceptions related to IoT topics. The computer science education community has produced many studies addressing student misconceptions, and even lists of common misconceptions exist, most notably the curated list of programming misconceptions by Chiodini et al. [7] and the misconception catalogue in the thesis work by Sorva [27, pp. 358-368]. A similar collection of IoT-related misconceptions could be useful.

## REFERENCES


[1] Farha N Ali. 2018. Experiences in Teaching the Internet of Things Courses. In *Proceedings of the 49th ACM Technical Symposium on Computer Science Education*. 378–383.

[2] Luigi Atzori, Antonio Iera, and Giacomo Morabito. 2010. The internet of things: A survey. *Computer networks* 54, 15 (2010), 2787–2805.

[3] Zorica Bogdanovic, Konstantin Simic, Miloš Milutinovic, Božidar Radenkovic, and Marijana Despotovic-Zrakic. 2014. *A Platform for Learning Internet of Things*. ERIC.

[4] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101.

[5] Barry Burd, Lecia Barker, Monica Divitini, Felix Armando Fermin Perez, Ingrid Russell, Bill Siever, and Liviana Tudor. 2018. Courses, content, and tools for internet of things in computer science education. In *Proceedings of the 2017 ITiCSE Conference on Working Group Reports*. 125–139.

[6] 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.

[7] Luca Chiodini, Igor Moreno Santos, Andrea Gallidabino, Anya Tafliovich, André L Santos, and Matthias Hauswirth. 2021. A curated inventory of programming language misconceptions. In *Proceedings of the 26th ACM Conference on Innovation and Technology in Computer Science Education V. 1*. 380–386.

[8] Cisco. [n.d.]. *Cisco Networking Academy Builds IT Skills & Education For Future Careers*. https://www.netacad.com/

[9] Cisco. [n.d.]. *Cisco Packet Tracer*. https://www.netacad.com/courses/packet-tracer

[10] Geert de Haan. 2015. Educating creative technology for the internet of things-research and practice-oriented approaches compared. In *Proceedings of the Mulitimedia, Interaction, Design and Innnovation*. 1–7.

[11] Norman K Denzin. 2017. *The research act: A theoretical introduction to sociological methods*. Routledge.

[12] Anatolij Fandrich, Tobias Stuckenberg, and Ira Diethelm. 2020. DIY Smart Home: The Development of an Exemplary Internet of Things Infrastructure for Computer Science Education. In *Proceedings of the 2020 ACM Conference on Innovation and*

*Technology in Computer Science Education*. 523–524.

[13] Anna Förster, Jens Dede, Andreas Könsgen, Asanga Udugama, and Idrees Zaman. 2017. Teaching the internet of things. *GetMobile: Mobile Computing and Communications* 20, 3 (2017), 24–28.

[14] Valerie Galluzzi, Carlotta A. Berry, and Yosi Shibberu. "2017". A Multidisciplinary Pilot Course on the Internet of Things: Curriculum Development Using Lean Startup Principles. In *"2017 ASEE Annual Conference & Exposition"*. "ASEE Conferences", "Columbus, Ohio". https://peer.asee.org/27486.

[15] Jorge Guerra Guerra and Armando Fermin Peréz. 2016. Implementation of a robotics and IoT laboratory for undergraduate research in computer science courses. In *Proceedings of the 2016 ACM Conference on Innovation and Technology in Computer Science Education*. 369–369.

[16] Jorge Guerra Guerra and Armando Fermin Perez. 2017. Alignment of Undergraduate Curriculum for Learning IoT in a Computer Science Faculty. In *Proceedings of the 2017 ACM Conference on Innovation and Technology in Computer Science Education*. 362–362.

[17] Stan Kurkovsky and Chad Williams. 2017. Raspberry Pi as a platform for the Internet of things projects: Experiences and lessons. In *Proceedings of the 2017 ACM Conference on Innovation and Technology in Computer Science Education*. 64–69.

[18] Shancang Li, Li Da Xu, and Shanshan Zhao. 2018. 5G Internet of Things: A survey. *Journal of Industrial Information Integration* 10 (2018), 1–9.

[19] Maisson Lichtenecker, Maria Cristina Carpes Marchesan, Andréia dos Santos Sachete, and Fábio Diniz Rossi. 2020. Reference Curriculum for IoT Applied to Anything: A Proposal. (2020).

[20] Hanna Mäenpää, Sasu Tarkoma, Samu Varjonen, and Arto Vihavainen. 2015. Blending problem-and project-based learning in internet of things education: Case greenhouse maintenance. In *Proceedings of the 46th ACM technical symposium on computer science education*. 398–403.

[21] Hanna Mäenpää, Samu Varjonen, Arto Hellas, Sasu Tarkoma, and Tomi Männistö. 2017. Assessing IOT projects in university education-A framework for problem-based learning. In *2017 IEEE/ACM 39th International Conference on Software Engineering: Software Engineering Education and Training Track (ICSE-SEET)*. IEEE, 37–46.

[22] Nora McDonald, Sarita Schoenebeck, and Andrea Forte. 2019. Reliability and inter-rater reliability in qualitative research: Norms and guidelines for CSCW and HCI practice. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (2019), 1–23.

[23] Adrian McEwen and Hakim Cassimally. 2013. *Designing the internet of things*. John Wiley & Sons.

[24] Gary J. Mullett. 2016. Teaching the Internet of Things (IoT) Using Universally Available Raspberry Pi and Arduino Platforms. In *2016 ASEE Annual Conference & Exposition*. ASEE Conferences, New Orleans, Louisiana. https://peer.asee.org/26053.

[25] Meenaxi M Raikar, Padmashree Desai, and Jayalakshmi G Naragund. 2016. Active learning explored in Open elective course: Internet of Things (IoT). In *2016 IEEE eighth international conference on technology for education (T4E)*. IEEE, 15–18.

[26] Y Series. 2001. Global Information Infrastructure, Internet Protocol Aspects and Next-Generation Networks. *ITU-T Recommendation Y* (2001).

[27] Juha Sorva et al. 2012. *Visual program simulation in introductory programming education*. Aalto University.

[28] Andrea Zanella, Nicola Bui, Angelo Castellani, Lorenzo Vangelista, and Michele Zorzi. 2014. Internet of things for smart cities. *IEEE Internet of Things journal* 1, 1 (2014), 22–32.