"Internet of Things" as a capstone project: reflections on an educational initiative

Adon Christian Michael Moskal
Otago Polytechnic
adon.moskal@op.ac.nz

Thomas Laurenson
Otago Polytechnic
thomas.laurenson@op.ac.nz

Nathan Rountree
Otago Polytechnic
nathan.rountree@op.ac.nz

ABSTRACT

In this paper, we describe an educational initiative incorporating the "Internet of Things" (IoT) paradigm into an undergraduate Information Technology course. As IoT technology is becoming increasingly ubiquitous, it is imperative that computing students remain up-to-date with developments in this space. To this end, we guided a group of third year IT students to develop and deploy an IoT network as their final year capstone project. We report and reflect on the opportunities and challenges this presented as an educational undertaking, and conclude that the wide range of IT-related subjects encompassed in the IoT paradigm means such a project is well-suited to the capstone curriculum. We offer recommendations to others grappling with the integration of IoT into computing education.

Keywords: Internet of Things; computing education; capstone projects; LoRaWAN

1. INTRODUCTION

There is growing interest in the Internet of Things (IoT) in computing education. The "Internet of Things" paradigm generally refers to the connection of everyday objects to the Internet (for instance, refrigerators, coffee machines, or heating systems), utilising sensors to automatically capture and transmit data about the everyday world (e.g. Ashton, 2009).

For higher education, as a hybrid subject, IoT incorporates concepts from across the computing spectrum: e.g. networking, hardware and embedded systems, programming, security, and data management, analysis and visualisation. There are also various theoretical and philosophical issues around IoT that are pertinent to computing education, such as exploring issues around automation and removing humans from decision-making processes; surveillance and data privacy; and Big Data storage and processing challenges.

While the concept of IoT is of great relevance to present computing students, it remains a difficult subject to actually teach, mostly due to the infancy of the field. For instance, Burd, et al. (2018) identify a number of challenges for incorporating IoT into computing courses, ranging from rapidly-changing standards and technologies, to the need for a breadth of domain knowledge (e.g. from both hardware and software subjects) to effectively teach IoT concepts.

In this paper, we reflect on an educational initiative carried out at a New Zealand polytechnic, where IoT was 'taught' as a capstone project in a final-year Information Technology course. We consider the benefits of teaching IoT to students, report on some of the challenges faced in incorporating IoT into our programme, and offer recommendations to others grappling with the integration of IoT into computing curricula. Considering the wide range of conceptions of what IoT actually is (Atzori, Iera, & Morabito, 2010), we hope that reporting on the idiosyncrasies of a specific implementation may prove valuable to others working in this space.

This quality assured paper appeared at the 9th annual conference of Computing and Information Technology Research and Education New Zealand (CITRENZ2018) and the 31st Annual Conference of the National Advisory Committee on Computing Qualifications, Wellington, NZ, July 11-13, 2018 as part of ITx 2018.

2. CONTEXT

This project was carried out at Otago Polytechnic in Dunedin, New Zealand. The project was conducted within the Bachelor of Information Technology (BIT), a three year computing degree. Students undertake compulsory first year papers, and then select elective second year papers based on their interests; these elective papers are structured into loose threads, allowing students to follow a recommended path through the degree (for example, there is a programming thread, a web programming thread, a hardware thread, etc.). In the third year, the students undertake advanced study in their chosen thread, and also participate in a capstone 'project' paper, which allows them to apply the skills they have developed throughout the course in IT projects for real-world clients.

The capstone project paper is a year-long paper spread over two semesters where students work in groups on IT projects. Typically, students meet with potential clients, elicit requirements, and then develop software over the course of the year, aiming for production-ready releases by the end of the paper. Projects are able to be 'rolled over' into subsequent years where: (a) the students were not able to meet all client requirements in a single year timeframe, or (b) new features or functionality are introduced to essentially substantiate a new year-long project.

Occasionally, as was the case here, research-focussed projects will be put forth by BIT staff in cutting-edge areas of computing (see for example, Rozado & Haden, 2017). Such projects are designed to allow students to participate in emerging IT trends where there may be no real-world client projects currently available. In these cases, BIT lecturers play the role as both client and supervisor.

3. OUR IOT PROJECT

Our IoT project started in early 2016, centred on the development and deployment of an Internet of Things network to be released as an open resource for the local community. We planned to:

- establish a central gateway device that would facilitate the connection of various node devices to the network;
- develop the necessary infrastructure to send and receive, store, and display data on the network; and

- establish a community engagement process to help the public to be able to utilise the network.

We adopted the LoRaWAN specification (LoRa Alliance, 2015), an open, standardised protocol for IoT communication, because the specification is well-documented and widely used. LoRaWAN is a low power, wide area wireless network designed to send small packets of data (e.g. a few bytes) infrequently over long distances (e.g. up to ten kilometres). Eleven students worked over the course of two years to research IoT technologies, acquire and configure necessary hardware, and deploy the network with a collection of working node devices.

By the end of 2017, our students had successfully configured and deployed an IoT network based on the LoRaWAN specification, consisting of:

- a variety of LoRaWAN sensor nodes, including temperature, humidity, motion detection, and soil moisture sensors;
- a gateway device installed on the roof of the main Otago Polytechnic building to provide long-range wireless connectivity to sensor nodes;
- a network server hosting a messaging queue service for real-time access to network data, as well as a Mongo database to receive and persistently store node data; and
- a front-end web application to display raw and visualized data from LoRaWAN sensor nodes.

The sensor nodes send data to the gateway device, which relays the data to the main network server. The data is stored in databases on this server. End-user applications can then query this server, requesting data and displaying it as needed to users. The network architecture is shown in Figure 1.

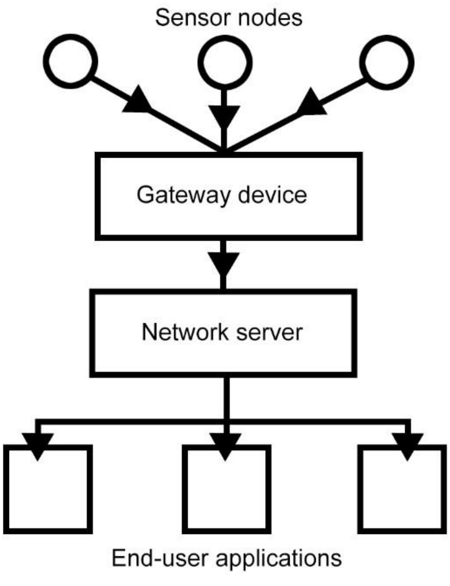

Figure 1. Network architecture of the IoT network, showing the relationship between sensor nodes, the gateway device, the backend servers, and end-user applications.

As part of our IoT initiative, we also established a series of regular meetups with members of the local community interested in the Internet of Things; these included members of industry, scholars and enthusiasts. The purpose of the meetups was threefold: first, to establish connections with like-minded people from the Dunedin area; second, to canvass the local community for IoT projects suitable for use on our network; and third, to give the students opportunities to present their work for critique in a public forum.

4. REFLECTIONS ON IOT AS AN EDUCATIONAL INITIATIVE

A primary goal of our undergraduate BIT degree is experiential learning, and the capstone project paper is designed to provide a realistic learning environment where students can apply their emerging knowledge in new and unfamiliar situations. We routinely partner with industry so students can experience working with ‘real clients’. Attempting to incorporate the IoT paradigm into our capstone paper presented a number of benefits in terms of experiential learning opportunities, but also a number of challenges that needed to be addressed.

4.1 Opportunities

Gorka, Miller and Howe (2007, p30) write that capstone IT projects should be:

- “sufficient in complexity to pique student interest”;
- “of sufficient scope to provide students with the opportunity to integrate and apply the knowledge and skills they have developed throughout the curriculum”; and
- “sufficiently open-ended to allow students to develop their own solutions to the problem.”

We believe the IoT paradigm offers opportunities in all three of the above areas to constitute a suitable capstone project.

For instance, in terms of sufficient complexity, as IoT is still an emerging technology the task of establishing a functional network, even using off-the-shelf devices, was non-trivial for students. Particularly, configuring and deploying devices for use in the New Zealand market provided both technical (in terms of adjusting hardware parameters) and non-technical (in terms of considering the legal implications of not adhering to broadcast regulations) learning opportunities for students.

As the IoT paradigm incorporates aspects of various IT fields (e.g., programming, networking, embedded systems, security, and more), it provides ample opportunities for students to integrate and apply a wide range of skills developed over their degree. Traditionally, the organisation of our degree into various ‘threads’ of IT (e.g. programming, hardware, etc.) usually sees students ‘specialising’ in their third year, and undertaking capstone projects focussed on a particular skill or field (e.g. mobile development). The IoT project, however, better caters to the development of students as ‘versatilists’ or people who possess a diverse set of skills and can apply them to a range of situations (Morello, 2005).

Since the IoT project was initiated by BIT staff, the scope was able to be sufficiently open to allow students to explore and propose their own solutions to the problem at hand (simply, to establish an open IoT network in Dunedin). For instance, when first proposed, it was not known that the LoRaWAN specification would be adopted; initially, students consulted with industry experts working in this space, and debated a number of available technologies (including the possibility of utilising none of the existing options and developing their own networking infrastructure from scratch).

4.2 Challenges

As well as a number of benefits, the IoT project also presented various challenges from both technical and educational perspectives.

4.2.1 Technical challenges

While the focus of this paper is on the educational aspects of our IoT implementation (and not specifically on technical issues), the technical challenges we faced directly impacted on how we administered the IoT project. These challenges were related to:

- the infancy of IoT specifications at the inception of our project;
- the availability of IoT devices for the New Zealand market; and
- the lack of detailed documentation and vendor support for customising IoT devices.

The primary technical issue we faced was the infancy of the technology. For example, the LoRaWAN regional specification for New Zealand was only standardised in late 2016, several months after the initiation of our project. The broadcast frequency ranges available for public use vary from region to region, and the initial specifications did not accommodate the New Zealand context. Our initial project group spent a lot of time exploring (ultimately) unviable solutions, before the specification became stable enough to indicate a clear path forward.

Also related to the infancy of the IoT technology was the availability of devices for the New Zealand market, which was extremely limited when compared with North American, European or Asian counterparts. We trialed a variety of devices from overseas manufacturers before finding an option that could be suitably configured for use in New Zealand—to legally operate our network in New Zealand airspace we had to adjust the default device parameters.

Finally, although LoRaWAN is an open specification, a number of vendor devices we trialed did not readily accommodate customisation or configuration of default settings. Documentation around how to 'hack' the devices was lacking, and in an emerging context where a level of hacking is essentially required, this proved frustrating for the students.

4.2.2 Educational challenges

First, while providing opportunities for exploration and research, not having an explicit, pre-defined goal proved challenging for students at times. While some 'mental discomfort' is desirable for developing student problem-solving abilities (Fee & Holland-Minkley, 2010), capstone projects which are too complex can quickly leave students feeling as if they are not making progress, resulting in disengagement (e.g. Schwering, 2015; Lopez & Lee, 2005). The role of the supervisor is crucial in these moments to clarify expectations, and provide guidance on ways forward when there is an obvious lack of direction (Ravalli & Stojcevski, 2011). We tried to address this issue by introducing smaller objectives along the way (such as establishing a web presence for the project, and getting them to write business case studies for existing IoT applications) that students could work on while trying to progress the larger aspects of the project.

Second, assessing the IoT project was difficult: the diversity of roles and disciplines within the project, coupled with a lack of clearly-defined outputs, presented a challenge for fairly assessing the students' work. To address this, we emphasised *process* over *product* with our students (Goold, 2003), ensuring that even if students did not end up with a functional IoT network at the conclusion of their project, we could point to their development processes (e.g. documentation, communication, project management) and still attribute them marks accordingly. We also adopted a multi-source assessment approach (Clark, 2005), drawing evidence of student achievement from a range of sources. For example, students handed in a reflective e-portfolio, where they were required to self-select evidence of their work, including problems faced and solutions trialed; this meant that we could judge a student's overall effort on the project, regardless of their specific area of the project (e.g. hardware or software-related). We also drew on peer feedback from within the project team, as well as our own observations working alongside the students.

Third, although the staff involved in the project had extensive knowledge in various technical areas related to the IoT paradigm (e.g. networking, programming, hardware, etc.), we did not have anyone who had explicit experience with IoT systems. Particularly, since we were implementing a specific protocol (LoRaWAN), a considerable amount of lecturer time was invested to build up a suitable knowledge base to be able to assist students. Capstone project instruction tends to be demanding on lecturer time in general (Clear, Goldweber, Young, Ledig, & Scott, 2001), and we would add particularly when there is a gap in lecturer knowledge of the subject at hand.

Finally, there was some difficulty in coming up with real-world use cases for our network during its development. We were reluctant to open up the network for local community use while the stability and security of the infrastructure were still relatively unknown. We attempted to find suitable pilot projects from those attending the IoT meetups, but this proved equally challenging. We identified two general types of users in attendance: those with problems suited to LoRaWAN (i.e. those sending small amounts of information over long distances), and those without (i.e. those with problems better suited to, say, utilising the city's WiFi infrastructure). Those with problems suited to LoRaWAN tended to be those already working in the IoT space, and thus mostly already had solutions in place to meet their needs. Without a robust infrastructure in place to offer better return-on-investment, we were unable to convince users to pilot our system. While this wasn't a great disadvantage to our students, it did mean that those working on the IoT project had a more 'academic' experience than those working on other projects with real-life clients.

4.3 Recommendations

Ultimately, the IoT paradigm aligns well with the aims and structure of the capstone paper, offering students a project that allows them to apply their developing skills to solve new and open-ended problems. However, there are a number of challenges associated with running complex, cutting-edge projects such as IoT, and here we offer some recommendations to other educators grappling with integrating IoT into their curricula.

Undertaking a project that demands a diverse skill-set to effectively run (such as the IoT project) necessitates thorough planning and staffing ahead of time. Working in such an emerging field as IoT also makes considerable demands on staff time, and staff workloads need to be managed carefully. Recognising, also, that the IoT paradigm is more than the sum of its parts is crucial; while lecturing staff may individually contribute from the various domains comprising IoT, there is still a place for someone with explicit IoT knowledge and experience, particularly with regards to implementing specific specifications/technologies.

While the space of IoT offers a number of interesting problems for students to solve, it is imperative to ensure students do not become frustrated and disengaged from problems that are too difficult or open-ended. Constant staff support is needed to keep students motivated and on-track, arguably more so than more traditional capstone projects with clear goals and tasks defined. The creation of additional, supporting tasks that lie peripheral to the main project may be necessary to keep the project moving forward through challenging phases. It is also important to manage student expectations on the outcomes (or potential lack thereof) of such an exploratory project.

To this end, a recommendation we would make to anyone incorporating IoT into their curriculum is to plan for the uncertainty that is inherent in such an emerging technology. As educators, we are used to designing learning activities that are well-aligned to learning objectives (Biggs, 1996), and administering these activities in a coherent sequence to students. However, in a constantly evolving or shifting space such as IoT, designing logically sequenced activities can be difficult and may require adapting partway through implementation. Therefore, we suggest planning multiple, branching learning pathways that can respond to unexpected changes (e.g. in our case, the standardisation of the LoRaWAN specification midway through our project).

Equitable assessment of student work is a key concern for capstone projects in general, but particularly for those with vague or constantly-changing goals and outputs, or those that bring together students with diverse skills and roles. Having multiple assessment sources, such as lecturer observation and student peer feedback, allows triangulation of student effort. Valuing process over product also allows student learning to be assessed, even if the final output is amorphous.

Finally, the involvement of external parties or industry partners may be challenging for projects centred on new and emerging technologies. People need to be (a) interested; (b) have suitable problems to solve; and (c) not already have other solutions in place—finding external partners that meet all three criteria is difficult. Our community engagement process (via regular meetups) helped in some regards to make connections with interested parties, but we recommend having use cases or pilot projects lined up from the outset, rather than relying on 'finding' such projects during development.

5. FUTURE WORK

With the successful deployment of a functional LoRaWAN network at the end of 2017, we are currently working towards release of the network as an open resource for the local community. We have various pilot projects lined up to evaluate and extend the functionality of our IoT infrastructure, and are compiling extensive documentation specifically for the New Zealand context so users can more easily join the network in the future. We hope to offer the network to the general public in 2019 following a successful evaluation of the stability and reliability of the infrastructure.

We anticipate the continuation of the IoT project with future students to afford new educational opportunities. For instance, new students will experience what it is like to join an existing project partway through, and have to come up to speed with someone else's work and documentation. The next cohort of students will also have more experience working with real clients through our pilot projects.

6. CONCLUSION

As the IoT paradigm becomes increasingly popular, it is imperative that computing programmes keep students up-to-date with the latest developments. However, integrating IoT with traditional Informational Technology curricula is not straightforward, mostly due to rapidly-changing technology, and the breadth of domain knowledge needed by both staff and students.

Because of this complexity, we ran our IoT initiative as a capstone project for students in their final year. We hypothesised that the project would fit the capstone curriculum well because: (a) it was sufficiently complex to keep students interested; (b) was sufficiently complex to allow students to apply the skills they'd learn previously in the degree; and (c) sufficiently open-ended to encourage problem-solving from students.

Ultimately, the IoT project worked well within the capstone project paper, and provided students with a variety of learning experiences not otherwise offered within the degree. However, there were a number of challenges to be addressed as the project unfolded, specifically around managing student expectations, managing staff workload, fair and equitable student assessment, and the involvement of industry/external parties.

7. ACKNOWLEDGMENTS

We would like to thank InternetNZ for providing funding that made this project possible, and all the students for their hard work.

8. REFERENCES

Ashton, K. (2009). That 'internet of things' thing. *RFID journal, 22*(7), 97-114.

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer networks, 54*(15), 2787-2805.

Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher education, 32*(3), 347-364.

Burd, B., Barker, L., Divitini, M., Perez, F. A. F., Russell, I., Siever, B., & Tudor, L. (2018, January). Courses, Content, and Tools for Internet of Things in Computer Science Education. In *Proceedings of the 2017 ITiCSE Conference on Working Group Reports* (pp. 125-139). ACM.

Clark, N. (2005, January). Evaluating student teams developing unique industry projects. In *Proceedings of the 7th Australasian conference on Computing education-Volume 42* (pp. 21-30). Australian Computer Society, Inc..

Clear, T., Goldweber, M., Young, F. H., Leidig, P. M., & Scott, K. (2001). Resources for instructors of capstone courses in computing. *ACM SIGCSE Bulletin, 33*(4), 93-113.

Fee, S. B., & Holland-Minkley, A. M. (2010). Teaching computer science through problems, not solutions. *Computer Science Education, 20*(2), 129-144.

Goold, A. (2003, June). Providing process for projects in capstone courses. In *ACM Sigcse Bulletin* (Vol. 35, No. 3, pp. 26-29). ACM.

Gorka, S., Miller, J. R., & Howe, B. J. (2007, October). Developing realistic capstone projects in conjunction with industry. In *Proceedings of the 8th ACM SIGITE conference on Information technology education* (pp. 27-32). ACM.

Lopez, T. B., & Lee, R. G. (2005). Five principles for workable client-based projects: Lessons from the trenches. *Journal of Marketing Education, 27*(2), 172-188.

LoRa Alliance. (2015). A technical overview of LoRa and LoRaWAN. *White Paper, November*.

Morello, D. (2005). The IT professional outlook: Where will we go from here?. *Gartner Report, 14*, 84.

Ravalli, G., & Stojcevski, A. (2011). Students Perception of Capstone Projects. In *SEFI Annual Conference.*

Rozado, D., & Haden, P. (2017, November). Otago polytechnic accessibility software hub: an open source repository of accessibility software for motor impairment. In *Proceedings of the 29th Australian Conference on Computer-Human Interaction* (pp. 428-432). ACM.

Schwering, R. E. (2015). Optimizing learning in project-based capstone courses. *Academy of Educational Leadership Journal, 19*(1), 90.