Engaging Science and Engineering Students in Computing Education through Learner-Created Videos and Physical Computing Tools

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ABSTRACT
The wide availability and accessibility of personal digital technologies offers students in schools and universities the opportunity to learn through the creation of their own digital artefacts. Also, the uptake of peer-learning is continuing to grow and transform in the classroom. This paper presents an innovative pedagogical approach underpinned by the learning-by-making, peer-learning and flipped classroom pedagologies. It reports on a collaboration between two university departments, involving computing undergraduate students creating sets of instructional video materials as part of their regular learning, that were then reused to teach programming skills to engineering students in the flipped classroom format. The paper addresses such outcomes for students as increased motivation and engagement, improved learning experiences, and better content understanding - both by those who created and those who reused the teaching materials. It also shows how this approach could help flipped classroom instructors to alleviate the initial burden of creating multimedia materials from scratch. Thus, the paper contributes a report on the new pedagogical approach effectiveness from three perspectives: 1) students who create teaching materials, 2) students who learn from those materials, and 3) flipped classroom instructors.

CCS CONCEPTS
• Social and professional topics ~ Computing education

KEYWORDS
Physical computing, learning-by-making, student-generated content, peer-learning, flipped classroom, higher education, video making.

ACM Reference format:

1 INTRODUCTION
An evaluation of introductory programming courses for non-computing students in Higher Education (HE) highlighted the struggle of non-specialists in engaging with complex computing concepts, often leading them to feel overwhelmed and frustrated when engaging in introductory programming education [1]. Rizvi et al. [12] suggest this frustration was exacerbated by i) a high number of complex concepts to learn in limited time, ii) lack of interactive media with instant feedback, and iii) lack of mathematical background.

Physical computing devices such as Raspberry Pis, and 3D printing are ideally positioned to support HE students in the development of their computational and engineering knowledge, as they have the ability to transpose abstract algorithms and computing knowledge into the real world. Additionally, 3D printing is a vital prototyping technology in science, technology, engineering and mathematics (STEM) disciplines. However, opportunities to experience physical computing in HE are limited, particularly in subjects outside of fields of computing or electrical/electronic engineering, such as chemical and civil engineering, chemistry and biology.

On the other hand, two modern pedagogical trends - flipped classroom and learning-by-making – have seen a wide uptake for teaching various STEM subjects in HE [2, 8]. A key advantage of the flipped classroom is an increased opportunity to learn through hands-on and interactive exercises. While learning-by-making is positioned as an effective way to expand subject understanding, develop lifelong learning skills and improve overall learning experience. Hence, both of these approaches are ideally placed to support the introduction of physical computing education.

This paper presents the use of the self-flipped classroom pedagogical approach to support the teaching of physical computing to STEM students in HE. This study is an inter-university project aiming at developing a Physical Computing Learning & Teaching Toolkit and supporting cross-disciplinary collaboration between the Schools of Computing, Engineering, and Natural & Environmental Sciences at Newcastle University, UK. It was designed to benefit students at undergraduate and postgraduate levels, and to provide them with the opportunity to access physical computing workshops, regardless of their programme of study, experience or skill.
2 BACKGROUND

The self-flipped classroom (SFC) approach involves reuse of learner-generated materials (self-part of the name) in the flipped classroom pedagogical model (flip part of the name). In our earlier trials of this approach we discussed its benefits to students’ skills such as collaboration, communication, and life-long learning [16].

In its essence, self-flipped classroom is a blend of contributing student pedagogy (CSP) and flipped classroom (FC) approaches. The foundation of CSP is learning through engaging students as co-creators of learning resources. This pedagogy was first presented by Collis and Moonen [3] and has been further investigated by Hamer et al. [6, 7], specifically emphasising benefits of the pedagogy for computer science education.

The core element of CSP is the explicit creation of tangible, identifiable artefacts by one or more students, for the purpose of being used by other students in their own learning. We argue that, such creation of teaching materials is underpinned by the theory of constructionism, pioneered by Papert [10] and developed to extend the constructivist learning by adding physicality to the knowledge construction. Papert led the initial efforts to explore how children experiment, design, create, and explore the world around them through the use of technology. He proposed that ideal learning occurs through the creation of tangible and shareable artefacts. The creation of such artefacts largely occurs with the support of a technological tool or media, such as video.

The second principle of the SFC - Flipped Classroom - is a form of learning where course material is delivered to students in form of audio-video recordings and reading materials via digital and online media [2]. This has been broadly reported as beneficial for teaching STEM subjects by demonstrating such advantages as a) students learning at their own pace; b) increased classroom time, providing students opportunities for creativity; c) instructors spending more time with students on solving problems [5].

These two principles position SFC as an ideal pedagogy to help establish the teaching of physical computing, a subject that inherently involves the study and creation of tangible artefacts. In our previous study we observed that some students may lack motivation to learn in an unconventional format (e.g. through learning-by-making), resulting in an inconsistent level of quality of the produced materials [16]. In the following study, this was mitigated by the instructor’s selection of videos made in previous years, such that it could be ensured that they were of high quality.

3 MOTIVATION

Programming skills are vital for professional and scientific development of students in STEM subjects, and is largely taught through traditional, didactic approaches. This leads many non-computing students to frustration when learning to code, particularly as it will be necessary to process the mathematical aspects of the problem, in addition to the abstract and logic aspects of the algorithms and coding syntax [1]. Physical computing has been shown to be an effective and affordable tool to teach physical computing to children and teenage students, as algorithm structures can be easily visualised and interacted with in the physical world (e.g. through lights, sounds, moving parts and sensors), reducing learning barriers, increasing motivation, engagement, and reasoning skills, and widening students’ adoption of coding [11, 13]. Therefore, it is pertinent to test the impact of physical computing tools for coding in an HE context.

The fact that physical computing deeply aligns with constructionist theory, allows this approach to be combined with SFC techniques. The following two factors influenced our choice of self-flipped classrooms for this project.

Firstly, we wanted to understand how students learn through the creation of videos, as literature strongly suggests improved learning outcomes [6, 9]. Conversely, we wanted to explore how students would learn from student-generated videos, particularly in an inter-disciplinary exchange of skills and knowledge, which has limited reporting in previous studies.

Secondly, we wanted to improve student learning and engagement by asking them to learn key concepts from the videos before attending the teaching sessions. This allowed students more time for hands-on activities in the class, having access to the physical tools and advice from the instructors. Furthermore, this also minimised time spent by the instructor creating resources, as existing reports on FC suggest a significant investment for the instructors who flip their classes from scratch [4].

Through our investigation of these issues, we aim to provide an approach for integrating physical computing and 3D printing into the HE curricula.

4 PRACTICE AND CONTEXT

The practice described in this paper involves two phases, with each of them occurring in an individual setting.

Phase 1: Between 2015 and 2017, all computing students who elected to study a third-year undergraduate module on Ubiquitous computing were required to generate three assessed video tutorials explaining programming and peripherals for a Raspberry Pi. The module aimed to introduce students to the field of ubiquitous computing, while allowing them to develop practical physical computing skills using tangible computing devices, such as a Raspberry Pi. The module was delivered in a flipped classroom format and comprised 35 to 50 students per year. For instance, cohort 2016-17 had 48 students, who created 144 videos on 10 different topics, eg. “getting started with Raspberry Pi” (Figure 1), “what is input & output”, “processing digital data”, etc.

Figure 1: A screenshot from a student-created video tutorial “Getting started with Raspberry Pi”.

Phase 2: Starting in 2018, two Raspberry Pi physical computing workshops were offered to all undergraduate and
postgraduate students studying computing, natural and environmental sciences or engineering. The first workshop focused on the use of digital sensors to build a burglar alarm and a digital thermometer, while the second covered the programming of a bionic hand (Figure 2). Registration was required due to limitations of teaching space and resources, with a typical intake of 30 students per workshop, with the places being allocated on a first-come, first-served basis from over 200 registrations received per workshop. These each ran for four continuous hours, on two distinct days.

Making use of the video tutorials created in Phase 1 (cohort 2016-17), seven high quality video tutorials were selected to introduce engineering and science students to key concepts needed for the two physical computing workshops. The tutorials were uploaded to a private YouTube channel, and a playlist link was sent to registered students two weeks before the workshop. Two further reminders were sent to inform students of the videos: a week, and then, two days before the workshop. This was to encourage students to make use of the prepared materials.

5 EVALUATION
The effectiveness of this practice is evaluated from three perspectives: 1) the students who created the video tutorial materials, 2) the students who learnt from those materials, and 3) the instructors who facilitated the learning process through the application of the Self-Flipped Classroom pedagogy. In order to understand these perspectives, the following methods of data collection were employed:

• 30-minute semi-structured interviews with eight ubiquitous computing students, focusing on their experiences of video coursework creation.
• Voluntary pre-workshop surveys with 18 students, asking them to self-report existing level of programming skills and confidence, and their motivation for coming to the workshop.
• Voluntary post-workshop surveys with 18 students, exploring their experience at the workshop, their perceived improvement in understanding and implementation of computing concepts, as well as their opinions on the use of student generated videos.
• An hour-long focus-group with 9 volunteers from the workshop students focused on the student experience of learning from the video tutorials produced by other students.
• A 40-minute semi-structured interview with the workshop instructor, aimed at understanding their experience of teaching in the flipped classroom format using student-created materials.

The qualitative data was analysed using inductive thematic analysis and quantitative data was subjected to a statistical analysis to determine the means and 95% confidence intervals.

6 RESULTS
According to students’ interview results, computing students perceived the creation of video tutorials to be very beneficial, reporting an increase in motivation and the acquisition of additional skills through the process. Such skills, as collaboration, communication, information and media literacy, are listed among essential 21st Century Skills [14]. Our analysis of the students’ work shows that they not only felt but actually demonstrated the development of these skills [15]. Moreover, many students in the interviews reported that they preferred video making to traditional report writing and exams. One student stated: “Videos were good, it’s a different way. I have never done it before and it was good.” While another student added: “It [video tutorial creation] did push me to do more features with the Pi that I hadn't done in the practicals”. This was consolidated by assessment outcomes, with marks averaging in the ‘Upper Second’ category (65%). This begins to address previously reported concerns on students’ motivation and the quality of student-generated materials.

All students who attended the physical computing workshops reported that they watched videos relevant to their prior level of knowledge. These videos helped them to prepare for the workshops, what was especially useful for the mixed-ability group of students attending the workshops. This was highlighted by one focus group participant, who said: “It’s a good idea because we’re all going to be on different levels of knowledge. So, having the basics re-taught, you’re like ‘oh, I remember that’ or ‘oh, I haven’t covered that yet’. But you can also skip ahead if you like ‘I know this already,’ but also it’s good to get a refresher.”

Students also commented on how watching the introductory videos before applying the new concepts in practice helped them to solidify their knowledge and improve their confidence. A comparison of the pre- and post-workshops surveys demonstrated a 48% increase (P=0.05) in reported programming confidence after completing the workshop activities. Besides, non-computing students reported an interest in integrating physical computing technologies into their regular HE module content. See Table 1 for a summary of the results for some of the survey questions.

![Figure 2: Students at workshop: “Python and bionic hand”](image)

Table 1. Level of agreement† with the statement, as answered by students who attended the SFC workshops.

| Statement                                           | Mean  
|-----------------------------------------------------|-------
| It was easy to learn from the videos.               | 4.1±0.2
| The video tutorials helped more than other resources.| 3.4±0.3
| I would prefer videos made by an instructor.         | 3.3±0.2
| Video tech. flaws had negative impact on learning.  | 2.7±0.3
| I had doubts about the content covered in the videos.| 1.9±0.2

†Level of agreement was 1-5, with 1 being “Totally disagree” and 5 being “Totally agree”.

Students reported the ease and clarity of learning from the videos, also stating a slight preference for videos made by other
CEP'20, January, 2020, Durham, United Kingdom

students, rather than videos made by instructors. “Well, it sort of shows the view of the student rather than the lecturer, and there’s always a different view from a lecturer teaching something and a student actually learning it. A student will know what another student wants to know, which is better for a student to actually give it rather than a lecturer,” – said one participant.

Finally, it was reassuring that students slightly disagreed that video technical flaws (e.g. some camera shakiness or some image bluriness) would have a negative impact on learning, which indicates that students give more importance to content, message clarity and simplicity, rather than to quality of videography. For example, a focus group participant commented: “Some videos were really well done, explaining why you’re doing this, not just how to do it. It’s like you have a problem and you’re trying to solve it, walking through the problem and then the solution, rather than just jumping in, ‘what is this?’ ‘what is this used for?’”

On the other hand, students did note that some videos had less than perfect visual qualities. Although all focus group participants agreed that those technical flaws did not negatively impact on their learning, one student stated: “I think it affects reliability. I trusted the videos because you sent us the links! But if somebody else was opening it and saw quality like this, he might be kind of sceptical, he might trust more something that has better quality.”

While this has an initial outlay of instructor time, the students placed a clear emphasis on the importance of instructors screening and selecting the videos being reused, such that they could be “trusted” to contain meaningful learning content.

As for the instructors’ point of view, in addition to the learning outcomes for both the students involved in the creation and use of the video tutorials, the introduction of the video materials has led to saving time at the workshop by cutting down the introductory “lecturing” section to less than 20 min. This allows the instructors to focus available classroom time toward the practical activities. Furthermore, it catered for differentiation in the computing ability of students attending the workshops, as they could elect to watch the videos suitable for their prior understanding of the key concepts. Also, despite the time spent on the selection of the videos for reuse this load was not even close to the time the instructors would have spent on creating those videos themselves.

7 FUTURE WORK

The ongoing development of the Physical Computing Learning & Teaching Toolkit involves the integration of learner-created videos and physical computing tools within computing modules in engineering disciplines. This is to be followed by the assessment of student performance, and evaluation of the impact of physical computing and SFC approaches on student skills. We plan to develop future courses which include both phases of the SFC approach, such that the same cohort of students create multimedia learning materials and make use of previous students’ materials as part of their learning, to benefit from all the advantages of participating in the SFC approach.

Moreover, we also continue to explore how best to efficiently assess multimedia materials, as this previously involved screening hundreds of videos in order to select ones of high quality, which was a time-consuming process for the instructors.

8 CONCLUSION

In this paper we presented our experience and outcomes of introducing teaching physical computing for undergraduate and postgraduate students using the SFC approach. Previous studies of SFC reported limited findings on outcomes for students who were users of the learner-generated materials, and this constituted the main focus of this study. It was found that SFC can be beneficial both for students creating content, and for students making use of the created content. In particular, this approach contributed toward the development of digital skills, levelling students’ prior knowledge, boosting confidence levels in student programming abilities, and it also helped directing more classroom time towards practical activities. Furthermore, the SFC supported instructors who were looking to integrate multimedia materials in their module teaching, by alleviating the initial outlay involved in creating traditional flipped-classroom materials.

ACKNOWLEDGMENTS

This project was funded by the Strategic Innovation Fund 2017/18, ULTSEC, Newcastle University, UK. The authors thank Dr Madeline Balaam, the module leader for Ubicomp from 2015 to 2017, and all the students who participated in this study.

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