Tangible Teaching Tools: The Use of Physical Computing Hardware in Schools

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SESSION

C1: Integration of theory and practice in the learning and teaching process

CONTEXT

With the push for STEM education in recent years there has been significant growth in the popularity of "physical computing and robotics devices in educational settings" (Blikstein, 2013). With the introduction of the "digital technologies curriculum" (DTC) (Australian Curriculum and Assessment Reporting Authority [ACARA], 2015) there is a larger incentive for schools to consider the use of these tools. There are very few studies that examine the general usability of such programmable hardware devices from the perspective of non-expert users. This leaves teachers with little indication about the effectiveness of such hardware, with many relying on "word of mouth" when choosing between options in a crowded market.

PURPOSE

This study seeks to understand the experience of teachers who use physical computing hardware.

APPROACH

A qualitative approach is used to collect the data through a survey open to all teachers in Australia. The survey collects data on the subjects that are being taught, the year level and the programming experience of the teachers as well as the type of hardware that they use.

RESULTS

Physical computing hardware is an attractive option due to its perceived benefits for students and the digital technologies curriculum. There are many hardware options on the market, with a majority of teachers using more than one. However, there are many challenges associated with the use of physical computing. Teachers expressed issues such as time to learn, cost, curriculum development and technical issues.

CONCLUSIONS

For the digital technologies curriculum to be effective, the teachers must be at a suitable standard to teach it. This paper shows that the curriculum is likely to increase the number of teachers using physical computing hardware as part of the DTC. This is in part due to the perceived benefit to the students that this hardware has. This paper presents several issues that must be addressed for the curriculum to achieve its full scope such as the large number of hardware devices on the market, and the issues that teachers have expressed with the hardware.

KEYWORDS

STEM, Digital Curriculum, Schools

Introduction

The number of physical computing devices being used in schools has increased in the last few years. This has been aided by programs in other countries such as the UK's decision to lead the development of the BBC Micro:Bit which produced "1 million devices, enough for every 11-12 year old in the country" (Sentance, Waite, Hodges, MacLeod, & Yeomans, 2017). Australia is following this lead by implementing a nationwide "digital technologies curriculum" (DTC). The DTC was deployed in February of 2017 (Australian Curriculum and Assessment Reporting Authority [ACARA], 2015) and begins at the foundation level. It therefore introduces computer science concepts to many teachers who have not previously encountered them.

A popular method for teaching novice programming is to take a contextualized approach. "Contextualized computing education" is defined as the use of a consistent application or domain area which effectively covers the core areas of a computer science course (Rubio, Romero-Zaliz, Mañoso, & Angel, 2014). This is an attractive idea in computer science education because instead of writing an abstract program, students can learn programming concepts through making a game or animating a story. Increasing the relevance of computer science education to students lives has been suggested as an effective strategy for making students more interested in computing (Black et al., 2013).

'Physical computing' is a specific subset of this contextualised approach to computing education. Instead of programming concepts existing only within the confines of the computer, robots or other programmable hardware are used to bring these ideas into the real world. There are many physical computing devices designed for education. Blikstein (2013) conducted a meta-analysis of the history and current market of physical computing hardware. He showed that although physical computing hardware has been developed since the 1980's there exists little consensus about the best tools to be used for computer science education.

Physical computing hardware is not required by the DTC. However, there are a large number of devices on the market that advertise themselves as an "easy to use introduction to programming". These include hardware such as Arduino ("Arduino Education," 2017) and Bee-Bot ("Bee-Bot," 2016). Physical computing hardware is also prevalent in the supporting documentation for the DTC. There are three case studies for digital technologies in primary school on the Victorian government's "DigiPubs" website (Department of Education and Training, 2017). All three case-studies feature students interacting with physical computing devices.

It is likely that the advertising of physical computing hardware in the materials supporting the DTC will encourage teachers to use physical computing hardware. This will have an impact on the teachers implementing the curriculum who have never taught digital technology related subjects before.

This paper gives an overview of the state of the physical computing hardware market in Australia and discusses the challenges that teachers have faced when implementing physical computing classrooms. It also suggests some areas in which support can be provided to teachers without the skills needed to teach this curriculum.

Methodology

Context and participants

A wide variety of teachers were invited to complete an anonymous survey. A Facebook page was created to allow teachers to share the survey with colleagues to further extend the pool of teachers completing the questionnaire. An invitation to complete the survey was posted to five separate teacher groups. These were: Awesome Science Teachers (now Awesome

NSW Science Teachers), Australian Teachers Interested in STEM and STEAM, Australian Primary Teachers, Australian Primary Ed Teachers and Australian P-12 Teachers.

Additionally, an email list was developed based on schools who had participated in the Robocup Junior and Young ICT Explorers competitions. Public email addresses were obtained from the websites of schools who had participated. This list consists of 175 distinct email addresses.

Data collection and data analysis

The primary data consists of a survey filled out by teachers. The survey collected information about teachers who both use and don't use programming hardware. A total of 36 teachers completed the survey. 14 respondents were recruited via Facebook. Of the 171 email addresses, which were included in the mailing list, 22 completed surveys were submitted (a response rate of 12.9%). This number is possibly inflated as the email addresses used were the school administration email. This does not indicate how many teachers from each school submitted a survey response. The lack of identical responses suggests that only a single teacher from each school participated.

The survey was divided into two sections, one for background information on the teachers and the second collecting information about their experiences with physical computing hardware in the classroom.

The first section consisted of six questions collecting background information on the teacher. These questions include which state they teach in, the year level that they teach, what subjects they teach, the size of the class that they typically teach and self-assessments of their general technology usage and programming skill level.

The questions in the second section were related to the experiences that these teachers have had using the hardware. This section was only completed by teachers who use physical computing hardware in the classroom. They were asked:

- Why did you introduce educational hardware kits into your classroom?
- What hardware system(s) do you currently use?
- Why did you decide this hardware kit?
- How beneficial has it been to your students?
- How easy has it been to use?
- How well has it met your educational goals?
- What are the challenges you have faced in using this hardware?

Limitations of the study

It is important to note that the method of study could have introduced potential biases to the results. The respondents are self-selecting which could result in respondents who are the most keenly engaged. Furthermore, the selected target group was intended to be as wide as possible, however the response rate from the Facebook advertisement was low. This means that approximately two thirds of the respondents belonged to schools which were known to have technology programs due to their inclusion in either the Robocup Junior or the Young ICT Explorers competitions.

Nevertheless, the results provide an insight to these teachers experience with the hardware that they use to teach computer science skills in the classroom.

Results

A total of 36 responses to the survey were received. Of these, 23 had introduced physical computing hardware in their classrooms and 13 who do not use hardware in the classroom.

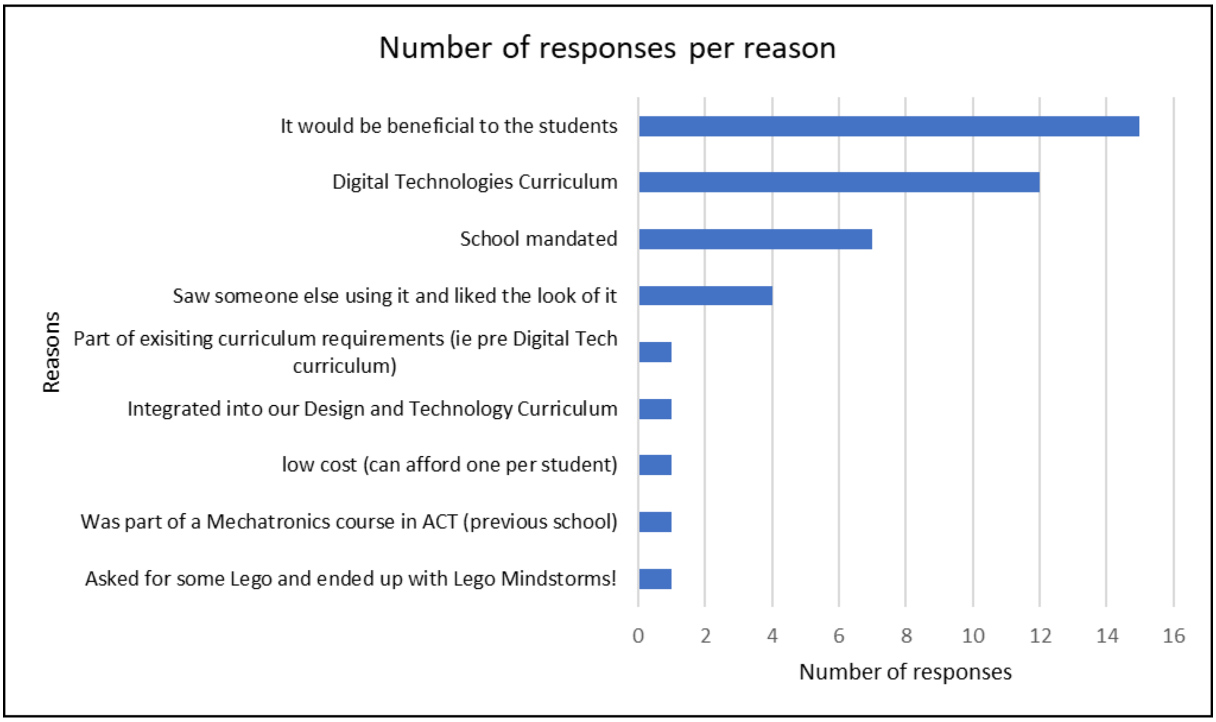

Figure 1: Reasons for the introduction of physical computing hardware

Figure 1 shows the reasons that teachers gave for deciding to introduce physical computing hardware into their classrooms. The two main reasons given were that it would be beneficial to the students and due to the DTC.

The most common reason for introducing hardware into the classroom was that it would be beneficial to the students. This was mentioned by teachers of all programming experience levels, from novice to expert. The two teachers in the sample who had never programmed before both mentioned this as their only reason for introducing hardware. This indicates that even for teachers with little programming experience, if they believe that students will benefit from the introduction of hardware they will implement it.

The second most common reason was the DTC. This shows that even in the first six months that it has been mandatory, it has factored into the decision making of teachers. The combination of the perceived benefit to students and the DTC support the assumption that the DTC will increase the demand for physical computing hardware in Australian schools.

The presence of the 7 other reasons given for the introduction of hardware show that teachers decision making is varied. The variety of reasons given provide further evidence for the assumption that the demand for physical computing in schools will continue to grow.

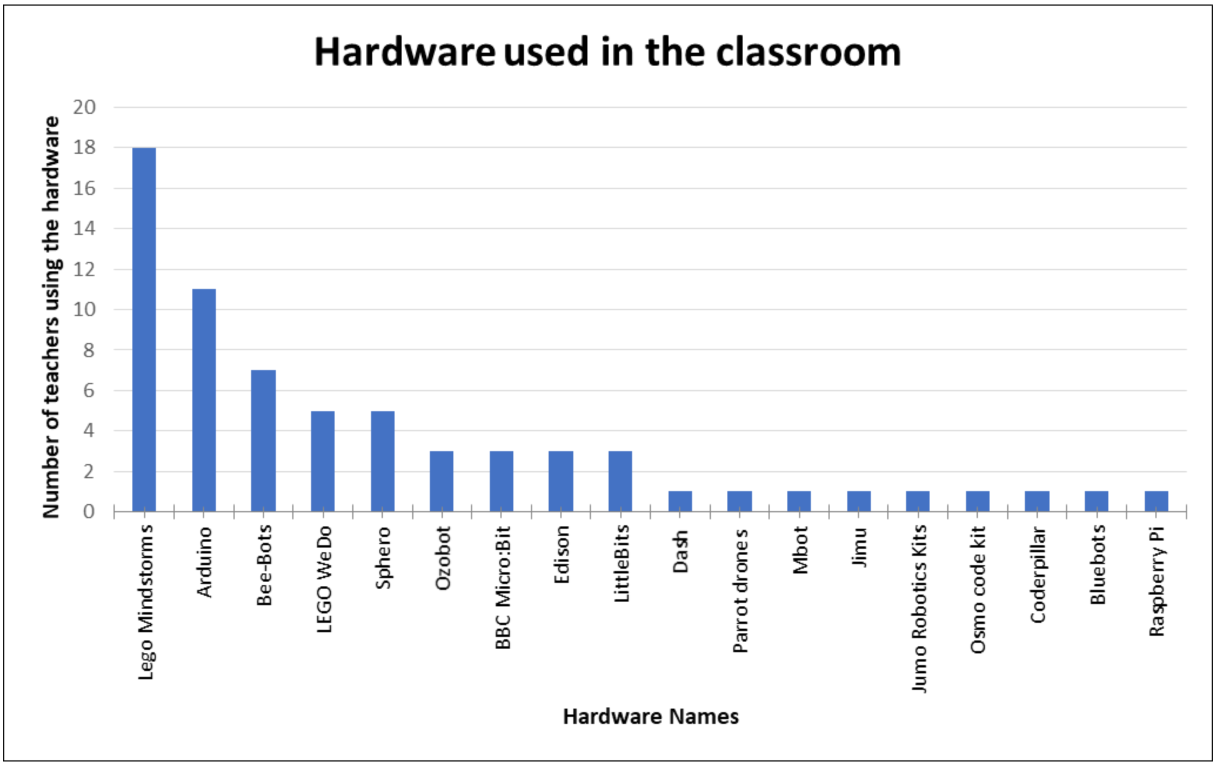

Figure 2: Physical computing hardware teachers have used in the classroom

Figure 2 shows the hardware that teachers have used in the classroom. In total, the 23 teachers have used 18 different hardware kits between them. This shows that there is a very competitive and fractured market in educational hardware. The large number of kits used by such a small group of respondents suggests that there is no real consensus on the best hardware that can be used. Lego Mindstorms was by far the most popular (but this is possibly due to the survey being sent to schools who had participated in RoboCup Jr, where it was the standardised platform). Arduino was also widely used, possibly due to its popularity amongst engineers. For many of the other kits however, there was not much overlap between the teachers. There were 9 different types of hardware that were only used by a single teacher.

The number of different hardware kits mentioned by the small sample size shows that there are many teachers using more than one type of hardware. 65% of respondents were using more than one type of hardware and 39% of all respondents were using more than 4 types of hardware. This shows that there is a lot of experimentation occurring within the market to try and find the best hardware for the classroom.

Challenges

Respondents were asked to identify the challenges that they have faced in using physical computing hardware in their classrooms. These responses were analysed and categorised to determine the themes that were present. The challenges that the teachers faced fell into four categories: cost, time, curriculum and technical.

‘Cost’ relates to the actual cost of the hardware that must be purchased. This came up several times in the responses. Interestingly, when this was mentioned as an answer to this question it was always in relation to the upgrade of hardware rather than the purchase of new hardware. Two teachers had issues with the Lego Mindstorms NXT kits because the software that was developed for this hardware no longer supports new computers and iPads.

One school was not able to afford the upgraded robots; therefore, they had to deal with the software discrepancies that exist when using new software for old hardware.

school uses NXT robots, cannot afford new ones, EV3 is not 100% backwards compatible.

A second school upgraded the hardware because the previously developed software did not support the iPads the students were using.

Lego kits needed to be updated as older kits weren't compatible with students BYOD ipads.

The cost of hardware necessitates a long upgrade cycle to ensure that schools get the most out of their purchased hardware. The presence of backwards compatibility, such as the limited compatibility included in the Mindstorms EV3 software (Lego, 2017), can help extend the useful lifespan of hardware. However, the responses indicate that this can cause more issues.

'Time' relates to the time that teachers must put into setting up the new hardware for their classroom. This is important because many teachers work long hours. In 2016, the average teacher worked 52.3 hours (Weldon & Ingvarson, 2016) so the amount of time that hardware takes to setup, learn and teach with will impact on its effectiveness. "Steep learning curve" and the time taken to learn new hardware was a common complaint. These comments show the impact that ease of use has on the usefulness of devices for education. Given teachers' time constraints, the longer it takes to learn to use hardware, the more difficult it will be to introduce it to the classroom.

For the LEGO Mindstorms, a lack of time to play and experiment with them is the major challenge. I also need an expert to help me get started.

Steep learning curve…

Teaching myself to use them

Time limitations, facilities and storage

Edison's have taken a little while to get to grips with more complex coding…

The third theme that emerged from the comments was 'curriculum'. A number of teachers commented on the "availability of curriculum resources" that are of a high quality and aimed at the correct level for students. Often there existed a gap for teachers between the sample tasks that are included with physical computing hardware and what the students wish to do.

Access to quality project activities to fill the gap between the sample tasks and student desires while teaching them the essential programming skills. Most activities are too low level (k-6), are plug and play without the programming, or are for proprietary gear.

Access to good quality guides for students to follow that do not propagate misconceptions related to electricity.

diverse ability of students

When teachers are in a position where they don't have access to good quality resources for the subjects that they are teaching, they are forced to create them themselves. This has two effects. Firstly, teachers without the knowledge to create these resources are likely to struggle to teach adequately. Secondly, the teachers who do have the knowledge and experience to develop their own resources must do so on their own time. We have already discussed that teachers feel as though they don't have the time to get started with the hardware; developing the resources adds extra time to this process.

One teacher raised the issue that hardware can add an extra layer of complexity to the concepts and therefore increase the difficulty of curriculum design.

Designing curriculum around the software and hardware interface - sometimes concepts required for the hardware are not easy to understand at the level where students are at, although they are still capable of using it and playing with it.

Another curriculum issue was the combination of project based learning and more traditional teaching styles. It is up to the teacher to decide how to balance these two ideas to ensure that the students get the most out of using the hardware. (Holmberg, 2017; Hussain, Fergus, Al-Jumeily, Pich, & Hind, 2015; Jin, Haynie, & Kearns, 2016)

Balancing project based learning and direct instruction

I think it's important that educational kits be more than expensive toys. Students should be able to create and solve problems with them. That's why I prefer kits like Lego over kits like Sphere.

Previous studies have shown that "young learners are often distracted by the physical hardware" (Jin et al., 2016). By increasing the number of distracting elements in the classroom, the teacher must be prepared to control the class to keep them on track.

The students seem to get sidetracked building the Lego and don't spend as much time on the coding.

The final category was 'technical issues'. This categorises issues that can only occur when using a physical piece of hardware. The other three categories can all be applied to programming applications on a computer. These are issues related to the upkeep and maintenance of the hardware. Some teachers had issues with parts continually going missing.

Losing parts, flat batteries, time taken in building robots rather than programming them (although students generally enjoy building).

Parts going missing!

Other teachers had more general technical problems with the hardware. The lack of specifics offered by the respondents suggests that a large number of problems have been encountered.

Continual technical problems

Arduinos and coding and different shields.

Troubleshooting the devices to allow them to work.

A number of teachers mentioned that they were not able to supply enough devices for every student. This is a combination between the cost and technical issues. If the cost were lower they might be able to purchase enough hardware for each individual student. As they aren't able to do this, the hardware must be used by many students.

Maintaining the equipment when it is used by multiple classes

Another teacher raised the point that when the students have to share between classes they are limited in the creativeness that they can influence on the designs.

Having to share kits between classes means students usually needed to stick to standard robots (using Mindstorms) rather than spend time building their own creations.

Having enough devices for the children to use.

The results have shown that there is a real need for tools that can help teachers choose between the available hardware options. We propose a website that hosts a survey for teachers to self evaluate the hardware devices that they use. This can provide an evolving resource for new teachers to be able to find hardware that suits their specific situation. A prototype has been developed and is available at http://jmss.it/physicalcomputing.

Conclusion

The DTC ensures that students are being equipped for a digital future. For the curriculum to be effective, the teachers must be at a suitable standard to teach it. This paper shows that the curriculum is likely to increase the number of teachers using physical computing hardware as part of the DTC. This is due to the perceived benefit to the students that this hardware has, combined with the prevalence of physical computing in the digital technology curriculum resources. This paper presents several issues that must be addressed for the curriculum to achieve its full scope. Firstly, the large number of hardware devices on the market present a challenge for teachers to be able to choose the best hardware for the job. Secondly, the teachers currently using hardware in their classrooms have described issues that they are experiencing. These issues can be categorised as time, ease of use, cost, curriculum and technical. These issues identified by the early adopters must be addressed before subsequent groups can begin to use this hardware effectively.

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