International Journal of Mobile and Blended Learning
Volume 14 • Issue 4

Investigating the Classroom Environment With Physical Computing

David Parsons, The Mind Lab, New Zealand*
https://orcid.org/0000-0002-9815-036X

Kathryn MacCallum, University of Canterbury, New Zealand
https://orcid.org/0000-0003-3844-7628

ABSTRACT

To integrate digital technologies into the curriculum, teachers must support learners to use digital tools in authentic contexts. Physical computing, which involves the use of small portable electronic devices, provides an opportunity to achieve these goals. This article reports on the initial stages of a design-based research (DBR) project that will enable students to monitor and investigate their own learning spaces, with a focus on the impacts on their own well-being, and to propose solutions to any issues that they identify. The study focuses on a series of workshops, run with staff from an educational organisation, designed to explore environmental monitoring in the classroom and identify opportunities to apply the theory of situated cognition to authentic learning in context. The article reports on the first two phases of the DBR approach, defining the project focus and understanding the problem, to propose and refine a set of five design principles. The insights gained will be used in the subsequent phases of the DBR process.

KEYWORDS

Critical Incident, Design-Based Research, Environmental Monitoring, micro:bit, Sensor, Situated Cognition, Well-Being

INTRODUCTION

Small portable electronic devices such as the micro:bit, Arduino, and Raspberry Pi, are now available to students in many classrooms around the world. These devices have been adopted in schools to teach programming in a more hands-on manner in learning contexts that are more engaging and inclusive (Hodges et al., 2020; Nikou et al., 2020). The challenge for educators is, however, to achieve authenticity when using this type of electronic device. Using electronics in authentic ways in the classroom means the learning must be meaningfully connected to different subjects or domains of knowledge. So, while these tools are becoming more popular in schools, teachers still need support

DOI: 10.4018/IJMBL.315627
*Corresponding Author

to identify meaningful learning activities in which electronics can be integrated - activities where the use of these tools enable, rather than dominate, the learning. The concept of physical computing provides a lens through which we can investigate this challenge.

Physical Computing

Physical computing is an emerging area of research where students are engaged with the process of "creatively designing tangible interactive objects or systems using programmable hardware" (Przybylla & Romeike, 2017, p. 352). The integration of small electronic devices not only supports the development of critical thinking but also fosters collaborative and interpersonal skills (Psycharis et al., 2018). These devices offer significant opportunities for rich learning. While they have been primarily adopted to teach programming and computational skills (Papavlasopoulou et al., 2019) the inclusion of sensors (such as temperature, light, sound, etc.) in, or attached to, these devices provides for rich experiences where learners can engage with real-world environments, such as their own learning spaces.

Physical computing, therefore, supports rich transdisciplinary learning (Psycharis et al., 2018), for example by enabling students to apply physical computing to address environmental factors that impact their own well-being. Physical computing also provides new approaches for problem-based learning, where students can address problem-solving in a hands-on manner. It supports student-centred classrooms and small group work activities with limited teacher involvement and a focus on allowing students to teach each other and progress together. The combination of sensors and communication channels provides students with many opportunities for scientific discovery and related mathematical skills. Examples from the literature include using an accelerometer to gather data from model rocket cars and gathering soil moisture data in environment projects (Austin et al., 2020), and measuring Carbon Dioxide (CO2) in different environments (Henry, 2022). However, despite its clear potential in the curriculum (Przybylla & Romeike, 2017) there is limited research into how physical computing can best be integrated into learning experiences. The question addressed in this article is therfore: How can physical computing best be used to support authentic, student-led learning about the classroom environment and its impacts on well-being or other factors important to students?

Adopting a DBR Approach

One way to better understand how to design learning that addresses the aspects addressed above is to adopt a design-based approach. Design-based research (DBR) is a sub-area of design science specifically adopted in education to bridge the gap between research and practice in formal education (Anderson & Shattuck, 2012). DBR evolves through a series of iterations designed to test and evaluate interventions. Each iteration is designed to refine and evolve the design of the initiative. The testing of the iteration is done in authentic practice, with different methods generally adopted in each iteration to evaluate the design from different perspectives. The purpose of this approach is to generate new theories and frameworks for conceptualising learning. The design evolves from, and leads to, the development of practical design principles, patterns, and research-grounded approaches.

The DBR process consists of six iterative phases in which designers focus on the problem, understand the problem, define goals, conceive the outline of a solution, build the solution, and test the solution (Easterday et al., 2014). The scope of the first iteration of the study reported this article is phases one (focus on the problem) and two (understand the problem) of the DBR approach. The outcome of this iteration is then able to inform the next phases.

The next section addresses the "focus" phase of the study, specifying its audience, topic, and scope (Easterday et al., 2014) and defining the general problem and goals. The following sections will then address the "understand" phase of the project. According to Easterday et al. (2014), the "understand" phase investigates the problem through empirical methods and secondary sources, and synthesises that knowledge into a form that can be easily used later in the process. Therefore, in this article, "understanding" is split into two parts. The first part explores issues around well-being in the classroom environment related to environmental factors, then reviews some of the previous literature that explores the monitoring of classroom environment variables with digital tools. The main features of the specific hardware used in this study (the micro:bit and associated sensors) are also explained. The second part of the "understand" phase then discusses the empirical methods used to better understand the problem and test the proposed approach. This phase involved working with staff members of a tertiary institution to test the proposed design in a series of workshops to better understand, from an educator's perspective, how effective this approach would be when working with students.

The remainder of the article explains the methods, including the teaching approach used and the data gathered, followed by the results. The final section of this paper then looks forward to the next phase of the project and explains how the insights gained will contribute to future iterations.

Phase 1: Project focus

The focus of this project is to explore how micro:bits can be authentically integrated into a classroom. The project aims to investigate practice that focuses on student learning happening in authentic social activities, where digital skills are integrated and built through the development of solutions using electronic devices, sensors, and the data that they gather.

To further scope this broad context, the study focuses on how micro:bits can be adopted into project-based learning to investigate environmental factors in the classroom that can impact the well-being of students. The focus of this approach is to get students to develop strategies around improving the micro-climates in their learning environments, taking account of a range of environmental variables.

The learning activity to be designed is intended to be suitable for any classroom that has access to micro:bits (or similar devices) and additional sensors. The most important aspect of this learning activity is that it is embedded in problem-based inquiry into student well-being in their own classroom environments and is intended to help them understand what kinds of environmental measures can be made, and what the impacts of environmental variables might be on their own well-being.

Phase 2a: Understanding the Literature

Relevant literature was identified to better understand the contexts in which the micro:bits could be adopted, and the ways that they could be used, The aim of this phase was to better understand the problem, through an examination of the problem context, analysis of current solutions to similar or related problems, and the proposed solution and models of learning (Easterday et al., 2014). An outcome of this phase was the identification of design principles that will then be used to help support the analysis of phase two.

The Context: The Classroom Environment and Well-Being

One topic that impacts all students is well-being, and a major factor in well-being at school is the physical learning environment. The New Zealand Ministry of Education has adopted a model that presents well-being as comprising four dimensions: Physical well-being, mental and emotional well-being, social well-being, and spiritual well-being (MoE, 1999). There is a clear link between the physical well-being provided by the environment and the mental and emotional well-being of students (e.g., Gaihre et al., 2014), with a probable impact on social and spiritual well-being.

Although many aspects of the learning environment are embedded into the design and build of the structure and are difficult for students to change, there are some parameters that can be addressed in the individual classroom, including light, sound, temperature, and air quality (Barrett et al., 2013). Some of the adjustments that can be made to these parameters include such simple things as changing window shades and adjusting ventilation. Even individual actions can make a difference, one example being moving a noisy fish tank from a classroom to a public space (Woolner & Hall, 2010). Issues related to the physical classroom environment, such as ventilation, have been brought to the fore in recent discussions about the safety of students at school during the COVID-19 pandemic. Ventilation levels can be measured by monitoring CO2 concentrations, which can also have a direct impact on student well-being, as can a range of other factors, outlined in the next section.

Current Approaches: Monitoring Classroom Environment Variables

There are many previous studies that have explored the impact of different environmental factors in the classroom. Several studies have used sensors to monitor and control temperature and lighting (e.g., Runathong et al., 2017; Yin et al., 2021). Lakshaga et al. (2021) proposed an Internet of Things-based smart classroom environment that would include monitoring light, temperature, and humidity. A key question is what the impact on students of such factors might be, if any. For example, Gaihre et al. (2014) noted that neither temperature nor humidity impacted attendance, one of the commonly used measures of the impact of the classroom environment. However, there are other measures of impact that can be considered such as task performance, as in Dockrell and Shield's (2006) study on the impacts of high levels of noise in a primary classroom. The recommended mean noise level inside a classroom should be between 35 and 45 decibels (dB) (Dreossi & Momensohn-Santos, 2005). Dockrell and Shield found that background speech of 65 dB, and other environmental noise of 58 dB, showed small negative impacts on both students' verbal and non-verbal learning tasks.

Several studies have monitored levels of CO2 in classrooms and their potential impacts. Measuring CO2 in the classroom is particularly important because it can be used as a proxy for the risk of virus infection (Dey et al., 2021). Levels of CO2 can be very high relative to the guideline value of 1,000 parts per million (ppm). The normal background concentration outdoors is 250-400 ppm, while well-ventilated indoor spaces are between 400 and 1,000 ppm. Values increasing above 1,000 ppm can lead to drowsiness, headaches, and loss of concentration, with 5,000 ppm being a common workplace exposure limit (Kane International, 2022). One study in the UK measured CO2 in seven classrooms across four schools. The average concentration was around 2,000 ppm, and in some classrooms exceeded 4,000 ppm (Coley & Beisteiner, 2002). A recent study at a school in New Zealand, using one of the CO2 monitors that had been distributed to 2,500 schools, tested the impact of ventilation in classrooms as part of a COVID-19 related learning activity. Data gathered showed that well-ventilated classrooms had low levels of CO2, but a crowded office showed levels over 1,000ppm, indicating that well-being in schools is not limited to classroom spaces (Henry, 2022). Such levels can have a negative impact on both student attendance and learning. CO2 concentrations above the guideline level have been linked to a relative 10% to 20% increase in student absence (Shendell et al., 2004). Another study indicated that even small increases of 100 ppm over the guideline correlated with small reductions in student attendance, though not attainment (Gaihre et al., 2014). However, a different study indicated that high levels of CO2 in the classroom led to a drop of approximately 5% in students' power of attention (Coley et al., 2007). It should be noted that there are many factors that can influence CO2 levels in different areas of the classroom and at different heights, so multiple sensors are needed to gain an accurate picture of a given classroom, along with multiple measures over time that capture different types of room usage and student activity (Mahyuddin et al., 2014). There are also several other environmental factors that can be monitored in the classroom, In the UK, the 'Learnometer' (Gratnells, n.d.) can also be used to measure dust particles and chemicals.

It should be noted that few of these studies have attempted to integrate any pedagogy into their measurement strategies. In many cases, the work has been limited to researchers measuring environments independent of learners and, if there have been any responses, these have been researcher driven. In other studies, learners have had some involvement in taking measurements (e.g., Henry, 2022) but none of the aforementioned studies have put the learner at the centre to give them agency over processes and outcomes. The focus of the study reported in this article is therefore to foreground the pedagogy alongside the technology and environmental monitoring.

The Proposed Solution: The Micro:Bit, Sensors, and Communication Channels

So far, this article has outlined the potential impacts on student well-being of classroom environmental factors, as well as some initial ideas about how physical computing might be used to address these issues within a learning experience. This section describes how the micro:bit, and associated sensors, can be used to provide the infrastructure to support a learning experience within this domain.

The micro:bit is a small portable electronic device that is prevalent in many classrooms, particularly in the UK, where one million middle school students were given micro:bits in 2016 (Ball et al., 2016). The micro:bit itself contains some onboard sensors: light, temperature, direction (compass), acceleration and, from version 2, touch, and sound. These onboard sensors are a key component of the micro:bit's design. The intention was to enable learners to engage creatively with the device and explore a world where sensor-based devices are ubiquitous (Knowles et al., 2018). From the earliest prototype versions, there was a vision of a "gender-neutral sensing/actuation device that could support social- and discovery-based explorations of electronics and coding" (Rogers et al., 2017). In addition, there are many external sensors that can be connected to a micro:bit using various combinations of the 25 external connections (pins) on the edge connector of the board. Sensors that can be connected to these pins include air pressure, humidity, and CO2. Many of these sensors can contribute to a related data set of environmental measures that can be used by students to analyse their own learning environments and address any issues that they identify.

As well as their ability to gather sensor data, micro:bits also have the capability to share that data by means of their communication facilities, using their built-in radio or Bluetooth connections. Austin et al. (2020) suggest that, for educational contexts, the radio broadcast capabilities of micro:bits provide more opportunities for collaborative learning innovations than the device pairing mechanisms of Bluetooth. Although micro:bits were designed from the beginning as a means of learning about the Internet of Things (IoT) they cannot, on their own, be IoT devices, since they do not have on-board Internet connections, partly for ethical reasons (Knowles et al., 2018). However, they can combine to form a network of things, and it is also possible for micro:bits to be Internet-enabled by connecting them to WiFi expansion boards or linking them with internet-enabled devices such as Raspberry Pis or laptops, enabling micro:bits to become true IoT components.

Models of Learning: Learning with Electronics and Sensors

To successfully use sensors as part of the learning process it is important that students gain a proper understanding of what the sensor data means and how it is used. In one study, where school students were using micro:bits as part of the design and construction of a burglar alarm system, student feedback indicated that some of them had a poor understanding of what the measures being taken by the light sensor meant, how they were being used in the system, or how information flowed between components (Cederqvist, 2022). The study suggested that, for meaningful learning to take place, students need to be able to understand how code and components work together as a feedback system to produce the desired outcomes.

As previously mentioned, it is challenging for educators to achieve authenticity when using electronic devices across the curriculum. Integrating electronics into activities where they enable, rather than dominate, meaningful learning requires areas of investigation that are of broad interest to all students, along with a suitable pedagogical approach. The approach chosen for this project is to apply the theory of situated cognition, where the situation in which the learning takes place co-produces knowledge through the activities that happen within it (Brown et al., 1989). Situated cognition focuses on the tools that both practitioners and students use (these may be conceptual tools but equally can be physical ones). The role of the educator is to model the use of such tools in addressing authentic problems and provide authentic "cognitive apprenticeship" activities where learners can build a rich understanding of the tools and the world in which they are used. Social interaction and collaboration also play a central role in this learning theory. The workshops described in the methods section below were designed with this approach in mind.

The most important aspect of this learning activity design is that it is embedded in problem-based inquiry into student well-being in their own classroom environments and is intended to help them understand what kinds of environmental measures can be made and what the impacts of the environmental variables might be on their own well-being. Further, to give them an opportunity to strategise ways in which their learning environments could be improved to enhance health and well-being. In this sense, there is no specific learning outcome or set of knowledge that is expected to emerge from this activity. Rather, it is an opportunity for students to build knowledge in areas that they feel are important to them and their own learning. In principle, the activity can be used with students of different ages and capabilities by providing differing levels of support in the coding and use of the sensors, though the work done so far has been undertaken with adults.

DESIGN PRINCIPLES

The ongoing use and development of design principles (DP) is a key defining element of DBR (van den Akker et al., 2006). At every stage of the research process, initial and evolving DPs are created and tested. These DPs are used to inform and guide the direction and shape of innovation being developed as well as its implementation and testing. These DPs become a critical product of the research that may be used to guide the design of a solution created in the final phases of the project.

Based on the literature review, and guided by the pedagogical concepts of situated cognition, five design principles were identified that will guide the next part of the research, where these will be tested. These are:

DP1: The use of electronics needs to be within a problem-based inquiry
DP2: The problem should be framed in a meaningful way that is authentic
DP3: Learning should occur through the process of engaging with the problem
DP4: Learning should be collaborative and social
DP5: Learners should be guided and scaffolded in the process and tools so that they are able to lead their own learning

Phase 2b: Empirical Evaluation

In the next section, we discuss the empirical evaluation that took place during the latter part of the "understand" phase. This evaluation was designed to validate our initial understanding of the problem from a theoretical perspective, based on the above design principles, by gaining feedback on emergent aspects of the learning activity, enabling us to define our goals more clearly for the project in the subsequent stage of design-based research.

METHODS

The research methods adopted in this phase were somewhat exploratory. Before exploring the approach with students, we first wanted to test the ideas with a group that would be able to give some informed suggestions. Therefore, workshops were held with staff (educators and educational administrators) at a tertiary education provider. While these participants were not experts in coding or micro:bits they were able to provide an informed perspective on the use of the technology.

The workshop was undertaken over three sessions spread out over six weeks. The first workshop was held online, and informed participants about the impact of environmental factors on well-being in the classroom, and technologies that could enable student investigation of those factors. We then invited any staff who were interested in building on that knowledge further to engage in a second face-to-face workshop that would give us some insights into the goals and direction of the larger research project.

The first workshop was a professional development activity where the participants were introduced to many of the concepts already discussed in this paper, such as the role of CO2 and other pollutants in the classroom, ways in which various aspects of the classroom environment may be measured, and the technologies currently available within the organisation to perform such evaluations. The reason for this activity was to set the scene by providing a common level of understanding of the context of this research project and some of the details about what is possible in the classroom in terms of well-being and physical computing. This was intended to raise interest in the project and to encourage staff to engage in a follow-up research activity. 33 staff members from across the organisation nationally attended online, from a variety of roles (not all educators). The focus of this workshop was to build a basic understanding of the tools that could be used (DP5) and provide a context to frame the problem in an authentic manner (DP2).

The second workshop was a more exploratory session where staff were given the opportunity to experiment with some environmental sensors as part of a learning activity. This was run on two different dates approximately one month apart to provide options for when people could attend. The numbers who could attend this workshop were reduced by location – many of those who attended the first online sessions worked remotely and could not attend face to face. Seventeen members of staff attended this workshop over the two sessions (all had attended the first workshop). The purpose of the session was to gain some insights into how best to organise a learning activity using physical computing in this context. The session was designed around the principles of situated cognition, providing a situation that could co-produce knowledge through activity (Brown et al.,1989). By enabling participants to use these digital tools in an authentic activity, we hoped to see them build a rich understanding of both the tools and the contexts in which they may be used. In situated cognition, learners need to be exposed to practitioners using these tools in a problem space (this was covered in the first session using video of the tools in action). In addition, it is necessary to provide students with a cognitive apprenticeship, enabling them to learn in authentic domain activities that include social interaction and collaboration. Guided with appropriate scaffolding that lessens over time. The structure of the session was based on this approach, involving the following

- Beginning with some structured learning around the structure and intentions of the activity, including some theory (DP5).
- Stepping into a partially scaffolded pair activity, introducing the participants to using micro:bit sensors (DP4, DP5).
- Moving into a more exploratory activity, where the participants were expected to use provided resources to connect different sensors and explore their environment using these devices (DP5).
- Providing through these three stages an authentic activity to investigate factors impacting their own well-being in the workspace (DP1, DP2, DP3).

Therefore, the sessions together acted as a kind of miniature situated cognition experience, based on the five DPs.

Ethics approval was gained from the institutional ethics panel to gather both observational and survey data from the participants. At the end of the activity, the participants were asked to complete a survey based on the questions developed by Keefer (2009) as an updated version of the standard Critical Incident Questionnaire (CIQ) that is widely used to assess classroom experiences. This approach would provide a holistic framework to explore the approach and determine how the DP framed the experience. It was chosen for this research because its intention is to evaluate the learning experience, not the learner. Therefore, it is appropriate to apply to situations where the primary objective is to create a learning experience design. The questions in the survey (adapted slightly from Keefer's survey to fit the context) were:

1. At what moment in today's session did you feel most engaged and / or least engaged?
2. What action (if any) did anybody take that you found most affirming / helpful?
3. What action (if any) did anybody take that you found most puzzling / confusing?
4. What was the most important information you learned during today's session?
5. Do you have any questions or suggestions about today's session?

These were all free text responses.

The element of facilitator observation was based on the design and implementation of the workshop. The facilitator recorded any critical incidents that appeared to be either supporting or hindering learning.

RESULTS

The first session began by asking participants what they thought might be the main factors that could influence well-being in the classroom. The most popular responses were temperature, lighting, noise, and fresh air. No one mentioned the potential spread of disease, and only two mentioned CO2, suggesting that a greater awareness of environmental factors could be developed. The participants were then introduced to information about various environmental factors and their potential impact on well-being. This included the potential spread of COVID-19 in enclosed spaces, the use of CO2 monitoring as a proxy for the risk of infection, the direct impacts of high CO2 levels on learning, and the opportunity to investigate these factors using sensors. At this point, the participants were asked what kinds of environmental sensors they thought might be available for use in the classroom (i.e., low cost and usable with simple physical computing devices like the micro:bit and Arduino). Again, the responses focused on temperature, light, and noise, with some mention again of CO2 and of humidity. This suggested that a greater awareness of the potential for monitoring the local environment could be developed. The participants were then given examples of some of the many sensors that are readily available for connecting to physical computing devices, including dust concentration, oxygen, carbon monoxide, alcohol, acetone, paint thinner, formaldehyde, and various other harmful chemicals. Based on this awareness, the workshop concluded with some discussion of how micro:bits and associated sensors could potentially be used in the classroom for learning. Suggestions included taking multiple measurements and looking for correlations (e.g., light and temperature), creating visual representations (or artworks) of data being gathered over the day (e.g., using different colours), and asking students to explore how environmental considerations affected their learning, such as the ability to concentrate.

The second part of the workshop took place two weeks later (first option) or six weeks later (second option) and staff were again invited to voluntarily attend. Ten participants attended the first session and another seven attended the second. During this workshop, the participants began by familiarising themselves with the built-in sensors of the micro:bits and took measurements of light and temperature inside and outside the building. They were given some specific information before this activity such as how the temperature and light sensors work to avoid accidentally impeding the sensors while handling the devices. For example, the temperature sensor on the micro:bit is within the processor, so placing a finger on top of the processor will give a false temperature reading. Even with this knowledge in place, it was found that the temperature and light sensors within the micro:bits varied in their measurements, suggesting that they were not particularly accurate. The group was then introduced to several external sensors that were made available to them, including light, sound, temperature, pressure, humidity, and CO2 (Figure 1). For most of these measures there was more than one sensor available, so students were able to compare values for consistency.

The participants then used these external sensors to measure a wider range of factors both inside and outside the building. Among other findings, they noted significant differences in the levels of CO2 inside and outside the building even though we were in a large, air-conditioned room, though it should be noted that the internal measures were still within the acceptable range.

Figure 1. The external sensors used in the activity

Observations

The facilitator made several observations during the session about their perceptions of the student experience. The following key moments were noted:

- During the scaffolding phase, some participants seemed disinterested in gaining an understanding of how the sensors worked.
- During the partly scaffolded pair activity, there was some disenchantment by participants who found their micro:bits measured light and temperature inconsistently. One participant expressed confusion about what the micro:bit was for, in general terms. These two issues may seem separate, but both related to a lack of background scaffolding to help them to understand both the purpose of the micro:bit and exactly how to minimise differences in measurements (e.g., by being fully aware of where the processor, and therefore the temperature sensor, was located).
- During the exploratory activity, there was further concern about inaccurate devices. This seemed to stem from differences in the coding required for different sensors. Some had simple library support that enabled measurements to be made easily and accurately. However, one did not have any library code and required more complex low-level coding. This seems to have led to some errors that resulted in meaningless measurements being gathered.
- Also, during this phase, some participants found it hard to independently follow the manufacturer's instructions provided with the sensors, though other groups independently explored the options available in those instructions.

Survey Results

The results from the survey were somewhat disappointing in that only nine of the seventeen participants elected to respond. However, despite the small quantity of data, it was quite revealing in terms of the critical incident questions that were asked. The first critical incident question, which related to the moment where participants felt most engaged, revealed that even within the small sample there was an interesting range of responses, including two favouring the initial scaffolding section, three the partially scaffolded initial pair activity, and the others the more independent pair activity. In responding to when they were least engaged, of the two who responded to this prompt, one stated it was when they "were trying to choose as a group which one to do" and the other "when playing with the micro-bit and wires and downloads". This range of responses seemed quite revealing about the extent to which people enjoy (a) group work and (b) hands-on practical work.

For the critical incident question that asked about actions that the participants found most affirming, again there was an interesting range, which covered working in a team, independently gaining an individual insight into the technology, being able to follow the instructions themselves, having “one-on-one interaction” with the facilitator, but also, from others, having group interactions both with and without the facilitator - “team problem-solving”.

In terms of actions that the participants found most puzzling or confusing, these were all related to technology. Whether it was understanding how the sensors worked, understanding where the sensors were positioned on the micro:bit, trying to resolve errors in the data being gathered, or “trying to attach jaw clamps to the correct pins”, these were all technical challenges.

For the fourth question, which asked about the most important information that participants had learned in the session, the responses were mainly around learning about the potential of the micro:bits, for example, “using micro:bits can be fun. There is a wide scope where it can be very simple and get very complicated. It also lets you be creative as your confidence and understanding develop”. There was also a response around trying to understand the purpose of such devices in general – “what micro:bits are and some of the things that they can be used for. This was a complete intro for me.” There were no questions or suggestions given for the final question, just some positive feedback about the value of the session.

DISCUSSION

Although the work reported so far is a very limited study, we believe it has served its purpose of helping scope out the next stage of design-based research, clearly define goals, and explore how the proposed design principles could be integrated into a learning activity. The intention of the workshops described above was to explore some different learning approaches that could then be adopted in a classroom environment. The focus of this learning activity would enable students to understand why environmental monitoring in the classroom can be of value for both well-being and learning. The trial with the educators in the workshop was undertaken to test how well the proposed activity incorporated the five proposed design principles.

From the first workshop, it was evident that the participants’ awareness of environmental variables that might impact well-being was relatively limited, and feedback from this workshop indicated that developing knowledge in this area could be of interest to learners. This indicated that the proposed approach of using micro:bits in this manner may provide a good context for meaningful engagement (DP3). It was also evident that the approach provided the participants with ideas of tools that could be engaged to monitor an environment. It was evident that although the participants had limited knowledge about environmental sensors, the initial workshop provided adequate opportunity to generate ideas that could be then integrated into a problem-based inquiry (DP1) and provide a good catalyst for supporting learners to identify and engage with a problem (DP3). However, it also highlighted that using the classroom environment meant that learners would have a similar framing of context, but it should also provide opportunities for differentiation. From the ideas shared at the end of the session, it was evident that many participants saw this as a valuable learning opportunity that would be meaningful to the learner (DP2).

From the second workshop, where some more formal data was gathered, we gained some further insights, particularly around how this activity needs to be scaffolded to support situated cognition (DP3 and DP5). We had expected that the primary interest of participants in this activity would be the hands-on collaborative work towards the end, where they were able to work independently. In fact, we found that the participants’ preferences varied, which suggests that all the different stages of a situated cognition learning journey will need to have specific values for different learners and that we should not value one aspect over another but ensure that all are given sufficient focus. It was also evident that some learners need more scaffolding than others when it comes to working with technology, and that we cannot assume that the value of a particular piece of technology is automatically understood by all (DP5). Just because an activity is expected to be authentically linked to a real-world context does not mean that learners will see this themselves without prior knowledge. As might have been expected, the things that most confused the participants were aspects of the technology. This raises an important question around to what extent an activity aims to focus on learning about technology, as opposed to learning with technology. The answer to this question will probably depend on the curricular context. For some learners, all of the technical setup should be done in advance for them, so they can simply focus on monitoring and evaluating their environments, whereas in other cases we may wish them to undertake deep learning about the technology itself, including how it works, how the connections can be set up, both wired and wirelessly, and how to develop the code for these activities. All these learnings will be taken forward into the next stage of the study.

While collaboration was only mentioned by some participants, it was clear that designing the activity to be collaborative assisted understanding (DP4). The observations showed that the participants worked well with each other and helped to build a deeper engagement with the activity. Since the activity was new for all the participants, having a buddy to help unpack and discuss ideas helped the learning. While the activity was designed to be done in pairs it was also clear that the participants worked across pairs and they helped each other. This was especially important due to the design of the activity being focused on building knowledge through hands-on experimentation with the micro:bits.

Based on this evaluation, it was clear that the proposed DPs were relevant and helped to guide the learning activity. However, it was also highlighted that differentiation was a critical part of the process. Differentiation was seen in two ways, 1) the ability to differentiate the focus where learners can explore their own interests, and 2) the ability to differentiate the learning journey. As mentioned, while not everyone may have the same interest in all parts of the learning, there should be enough to engage different learners. Therefore, we have decided to refine design principle two, where differentiation is highlighted, namely, that the problem should be framed in a meaningful way that allows for authentic integration and differentiation of application.

SUMMARY AND CONCLUSIONS

In this article, we have reported on some workshop activities based on a wish to explore the potential of using physical computing in the classroom, with a particular focus on investigating environmental impacts on well-being that can be monitored by sensors connected to small electronic devices. The workshop activities, as the first two stages of a design-based research project, were designed to help scope out the next stages of the project that will apply the principles of situated cognition to developing a series of learning experiences for school students, where they will be able to monitor and analyse their own classroom environments and propose ways of mitigating any negative environmental impacts. Our findings suggest that this is indeed a potentially engaging and authentic learning activity in which learners can extend their knowledge and apply their learning. However, it is important to take careful account of each stage in the situated cognition learning process to ensure that the needs of diverse learners are met and not to focus too early on collaborative self-directed learning without first setting the foundations in the earlier stages of cognitive apprenticeship.

Limitations

The work reported in this article is based on a very small study that addresses only the initial phases of a larger design-based research project and is therefore limited in its generalisability. However, given that the study intended to inform ways in which to design physical computing experiences in a specific domain of knowledge, it nevertheless provided some insights into the learner experience that will be valuable going forward.

Next Iteration

The next iteration, which will take us through the subsequent stages of design-based research, will involve partnering with some secondary school technology teachers who have an interest in these areas of learning. Each teacher will explore different aspects of physical computing for monitoring well-being in classroom environments using various tools and learning approaches. However, there will be some consistent themes structured within the five design principles, including situated cognition as a learning approach and critical incident analysis as a way of identifying important aspects of the learner experience to enable us to identify best practices and provide reusable learning designs in this domain.

CONFLICT OF INTEREST

The authors of this publication declare there is no conflict of interest.

FUNDING AGENCY

This research was supported by funding from The Mind Lab's Research Enterprise and Ethics Working Group.

Process Dates:

Received: August 13, 2022, Revision: December 3, 2022, Accepted: December 3, 2022

Corresponding Author:

Correspondence should be addressed to David Parsons, daveparsonsnz@gmail.com

REFERENCES

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research? *Educational Researcher*, *41*(1), 16–25. doi:10.3102/0013189X11428813

Austin, J., Baker, H., Ball, T., Devine, J., Finney, J., De Halleux, P., Hodges, S., Moskal, M., & Stockdale, G. (2020). The BBC micro:bit: From the U.K. to the world. *Communications of the ACM*, *63*(3), 62–69. doi:10.1145/3368856

Ball, T., Protzenko, J., Bishop, J., Moskal, M., de Halleux, J., Braun, M., Hodges, S., & Riley, C. (2016). Microsoft touch develop and the BBC micro:bit. *Proceedings of the 38th International Conference on Software Engineering Companion*, 637–640. doi:10.1145/2889160.2889179

Barrett, P., Zhang, Y., Moffat, J., & Kobbacy, K. (2013). A holistic, multi-level analysis identifying the impact of classroom design on pupils' learning. *Building and Environment*, *59*, 678–689. doi:10.1016/j.buildenv.2012.09.016

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42. doi:10.3102/0013189X018001032

Cederqvist, A.-M. (2022). An exploratory study of technological knowledge when pupils are designing a programmed technological solution using BBC Micro:bit. *International Journal of Technology and Design Education*, *32*(1), 355–381. doi:10.1007/s10798-020-09618-6

Coley, D. A., Greeves, R., & Saxby, B. K. (2007). The Effect of Low Ventilation Rates on the Cognitive Function of a Primary School Class. *International Journal of Ventilation*, *6*(2), 107–112. doi:10.1080/14733315.2007.11683770

Coley, D., & Beisteiner, A. (2002). Carbon Dioxide Levels and Ventilation Rates in Schools. *International Journal of Ventilation*, *1*(1), 45–52. doi:10.1080/14733315.2002.11683621

Dey, T., Elsen, I., Ferrein, A., Frauenrath, T., Reke, M., & Schiffer, S. (2021). CO2 Meter: A do-it-yourself carbon dioxide measuring device for the classroom. *The 14th Pervasive Technologies Related to Assistive Environments Conference*, 292–299. doi:10.1145/3453892.3462697

Dockrell, J. E., & Shield, B. M. (2006). Acoustical barriers in classrooms: The impact of noise on performance in the classroom. *British Educational Research Journal*, *32*(3), 509–525. doi:10.1080/01411920600635494

DreossiR. C. F.Momensohn-SantosT. (2005). Noise and its interference over students in a classroom environment: Literature review. *Pró-Fono Revista de Atualização Científica, 17*(2), 251–258. <ALIGNMENT.qj></ALIGNMENT>10.1590/S0104-56872005000200014

Easterday, M. W., Lewis, D. R., & Gerber, E. M. (2014). Design-Based Research Process: Problems, Phases, and Applications. In J. Polman, E. Kyza, D. O'Neill, I. Tabak, W. Penuel, A. Jurow, K. O'Connor, T. Lee, & L. D'Amico (Eds.), *Learning and Becoming in Practice: The International Conference of the Learning Sciences (ICLS) 2014. Volume 1*. International Society of the Learning Sciences.

Gaihre, S., Semple, S., Miller, J., Fielding, S., & Turner, S. (2014). Classroom Carbon Dioxide Concentration, School Attendance, and Educational Attainment. *The Journal of School Health*, *84*(9), 569–574. doi:10.1111/josh.12183 PMID:25117890

Gratnells. (n.d.). *Learnometer*. https://gratnellslearnometer.com/

Henry, D. (2022, April 8). "Makes them feel safer": Schoolkids using CO2 monitors to fight Covid, learn science. *New Zealand Herald*. https://www.nzherald.co.nz/nz/covid-19-omicron-outbreak-students-monitor-co2-learn-science-on-the-side/5UVDZTIBC3RZ3DFLWQH2CXPG7U/

Hodges, S., Sentance, S., Finney, J., & Ball, T. (2020). Physical computing: A key element of modern computer science education. *Computer*, *53*(4), 20–30. doi:10.1109/MC.2019.2935058

Kane International. (2022). *What are safe levels of CO and CO2 in rooms?* Kane International Limited. https://www.kane.co.uk/knowledge-centre/what-are-safe-levels-of-co-and-co2-in-rooms

Keefer, J. M. (2009, May). The critical incident questionnaire (CIQ): From research to practice and back again. In *Proceedings of the 50th Annual Adult Education Research Conference* (pp. 177-180). Academic Press.

Knowles, B., Finney, J., Beck, S., & Devine, J. (2018). What Children's Imagined Uses of the BBC micro:bit Tells Us About Designing for their IoT Privacy, Security and Safety. *Living in the Internet of Things: Cybersecurity of the IoT - 2018*, *15*. 10.1049/cp.2018.0015

Lakshaga Jyothi, M., & Shanmugasundaram, R. S. (2021). Enabling Intelligence through Deep Learning using IoT in a Classroom Environment based on a multimodal approach. *Turkish Journal of Computer and Mathematics Education*, *12*(2), 381–393. doi:10.17762/turcomat.v12i2.818

Mahyuddin, N., Awbi, H. B., & Alshitawi, M. (2014). The spatial distribution of carbon dioxide in rooms with particular application to classrooms. *Indoor and Built Environment*, *23*(3), 433–448. doi:10.1177/1420326X13512142

MoE. (1999). *Well-being, hauora*. https://health.tki.org.nz/Teaching-in-Heath-and-Physical-Education-HPE/HPE-in-the-New-Zealand-curriculum/Health-and-PE-in-the-NZC-1999/Underlying-concepts/Well-being-hauora

MoE. (2018). *Progress outcomes / Technology / The New Zealand Curriculum / Kia ora—NZ Curriculum Online*. https://nzcurriculum.tki.org.nz/The-New-Zealand-Curriculum/Technology/Progress-outcomes

Papavlasopoulou, S., Giannakos, M. N., & Jaccheri, L. (2019). Exploring children's learning experience in constructionism-based coding activities through design-based research. *Computers in Human Behavior*, *99*, 415–427. doi:10.1016/j.chb.2019.01.008

Nikou, S., Collins, R., & Hendry, M. (2020, June). Engagement in physical computing for the primary classroom: the BBC Micro: bit experience. In EdMedia+ Innovate Learning (pp. 566-569). Association for the Advancement of Computing in Education (AACE).

Przybylla, M., & Romeike, R. (2017). The nature of physical computing in schools: findings from three years of practical experience. *Proceedings of the 17th Koli Calling International Conference on Computing Education Research*. doi:10.1145/3141880.3141889

Psycharis, S., Kalovrektis, K., Sakellaridi, E., Korres, K., & Mastorodimos, D. (2018). Unfolding the Curriculum: Physical Computing, Computational Thinking and Computational Experiment in STEM's Transdisciplinary Approach. *European Journal of Engineering and Technology Research*, 19–24. .10.24018/ejeng.2018.0.CIE.639

Rogers, Y., Shum, V., Marquardt, N., Lechelt, S., Johnson, R., Baker, H., & Davies, M. (2017). From the BBC Micro to micro:bit and Beyond: A British Innovation. *Interaction*, *24*(2), 74–77. doi:10.1145/3029601

Runathong, W., Wongthai, W., & Panithansuwan, S. (2017). A System for Classroom Environment Monitoring Using the Internet of Things and Cloud Computing. In K. Kim & N. Joukov (Eds.), *Information Science and Applications 2017* (pp. 732–742). Springer. doi:10.1007/978-981-10-4154-9_84

Shendell, D. G., Prill, R., Fisk, W. J., Apte, M. G., Blake, D., & Faulkner, D. (2004). Associations between classroom CO2 concentrations and student attendance in Washington and Idaho. *Indoor Air*, *14*(5), 333–341. doi:10.1111/j.1600-0668.2004.00251.x PMID:15330793

van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (Eds.). (2006). *Educational design research*. Routledge. doi:10.4324/9780203088364

Woolner, P., & Hall, E. (2010). Noise in Schools: A Holistic Approach to the Issue. *International Journal of Environmental Research and Public Health*, *7*(8), 3255–3269. doi:10.3390/ijerph7083255 PMID:20948959

Yin, S., Zhang, D., Zhang, D., Li, H., & Yu, Y. (2021). Wireless Sensors Application in Smart English Classroom Design Based on Artificial Intelligent System. *Microprocessors and Microsystems*, *81*, 103798. doi:10.1016/j.micpro.2020.103798

David Parsons is National Postgraduate Director for The Mind Lab in Auckland, New Zealand. He holds a PhD in Information Technology and a Master's degree in Computer Science, and has wide experience in both academia and the IT industry. He is the founding editor in chief of the International Journal of Mobile and Blended Learning (IJMBL) and has published widely on technology-enhanced learning, software development, and agile methods. He is President of the International Association for Mobile Learning, a member of the Australasian Society for Computers in Learning in Tertiary Education, and a certified member of the Association for Learning Technologies.