Digital Makers: Ownership, Personalisation and Purpose

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Abstract
This paper describes research into supporting the creation of engaging learning experiences with programming. It describes a fieldwork study conducted to explore the framing of learning programming in tasks that motivate and are of value to the learner. The findings – that ownership, personalisation and purpose can support learning whilst providing considerable motivation - should provide educators with insights to support key design decisions for the creation of engaging programming learning experiences. They support the assertion that factors outwith programming content can significantly affect success in programming. The complex interplay between different skills associated with computer programming will remain a challenge to learners. When placed in a rich context that fits the learner well and supports the learning aims, many of these difficulties can be overcome. The work described here suggests it should be possible to compile positive features of a learning experience to enable learners have the best possible opportunity to engage with and succeed with computer programming.

1. Introduction
This work describes an investigation into the value of learner ownership, personalisation and purpose for learners of programming. It rests upon the findings of previous studies (Martin and Hughes, 2011; Martin et al., 2017a; Martin et al., 2017b) in which learners were constrained to solve a puzzle devised by the educator. In contrast, in this Digital Makers study, design decisions were intended to make the product less constrained for the learners. This made it possible for learners to apply their newly acquired programming skills to solve a problem of their own.

In the first work (Martin and Hughes, 2011), a Robot Dance investigation demonstrated that a tight cycle of content delivery and learner consolidation was effective for a wide range of learners. The second study (Martin et al., 2017a), known as Whack a Mole, attempted to mimic this but increased the learners' control over the pace by using video tutorial, with mixed results. The subject of this paper, Digital Makers, is a study built upon the Robot Dance approach with a gradual loosening of the cycle as the session progressed. In a 'Robot Dance in the Community' study (Martin et al., 2017b), it was shown that if given choice, learners would form different learning groups. This freedom was given in the Digital Makers study for the second part of the workshop. In contrast to the two previous studies, Digital Makers was a day-long event, giving much more space for learners to acquire skills and then apply them. It aimed to address the research question:

How do personalisation, ownership and purpose in an activity affect introductory programming learning?

2. Background
The Digital Makers study was part of One Day Digital, a series of digital making events organised by Nesta Scotland (2014). The aim of the Nesta event was to give 400 young people a taste of digital making. A range of five workshops was assembled, with topics including programming, stop motion animation, web making and games programming. The events ran on four consecutive weekends in Dundee, Aberdeen, Glasgow and Edinburgh respectively. Each event had five one-day workshops on offer to young people, starting at 10:00 a.m. and concluding at 5:00 pm. The events were advertised widely and participants had to register for the workshops in advance. Digital Makers was one of the five workshops delivered at each venue.

2.1. Physical Computing
Physical Computing is the construction of a digital device that uses a range of physical input and output components. The Arduino has emerged as the dominant microcontroller in the field of physical

computing (Arduino, n.d.). Originally, the Arduino was developed to assist interaction design learners to build prototypes with digital functionality. From this beginning, Arduino has grown to be a very powerful and accessible physical computing board to work with. One of the strengths of Arduino is the fact that the project has both open source software and hardware. This has resulted in a vast and varied community of learners, makers and professionals building a wide array of things (Banzi, 2012).

Building physical computing projects requires a range of interrelated core skills including electronics, craft and computer programming. Each of the core skills share some common features. They all have elements of design, creativity and problem solving and they often have a specific notation to support needed specification of designs and code. These shared features offer some interesting opportunities for cross-domain learning. For example, if the project is an alarm clock, there is a need to specify the electrical components to be used and their relation to each other: buttons, display and audio output. There are formal notations for this task and at some point there must be a transition from a circuit diagram to a physical layout such as a printed circuit board. In terms of the software, there is a need to specify the various functions of the alarm clock the end user can perform: set an alarm time, turn an alarm on and off, and so on. Various notations support the transition of a software design task from conceptual design through to the final notation of source code. The same is true for the physical product: the materials used, the form and the sequence of interaction all add to its design language, which can be captured in various notations, such as sketching, storyboards and mood boards. Each of these elements must come together for the alarm clock to function and fit the needs of the intended user.

This range of desirable competencies affords a degree of flexibility to the individual learner's experience. Some projects may have very well established design features that demonstrate good understanding of the problem and the user who will engage in the technology. Other projects may be light on design and user consideration, but may be technically sophisticated with extensive electrical or computational ability demonstrated. When a group forms containing individuals with a range of such skills, there is a good opportunity for the learners to see the value of collaboration and varied contributions to a project.

2.2. Physical Apps

A physical app is essentially a tangible equivalent of a mobile device app. It should be a simple compact physical computing object. It should solve a single well-defined problem. This naturally lends itself to educational workshop activities with a truncated time for completion. Rather than attempting a complex multifaceted project, the aim is a single purpose project that is buildable in as short a time as possible. In contrast to a vertical prototype, which is a technical demonstrator for part of a system, the physical app stands on its own. This is important so that the learner has the opportunity to experience the full development cycle from idea, design, build and test, to demonstrate.

3 Study Description

There were two parts to the study. In the morning the learners were walked through the process of wiring and programming some components with their Arduino; for this stage learners worked as individuals. In the second stage, learners were given the chance to self-select groupings and build a physical app utilising the morning's teaching. The study ended by giving all groupings an opportunity to share their idea and resultant physical app with the whole group. These stages are described next.

3.1 Morning: Laying the Foundation

The learners who attended these events came from a relatively large geographical area. There was therefore a good chance that individuals would not know each other. For this reason, the first activity was planned to 'break the ice' and set the scene for the day of making, sharing and appraising the work of their peers. A volunteer was sought from the group; the volunteer was placed at one end of an open space with his/her back to a small box. The rest of the learners gathered round. The volunteer was then instructed to throw small soft balls blindly over their head in the rough direction of the box. The rest of the group was encouraged to offer advice and direction on what the volunteer must do to get closer to getting a ball in the box. The group was coached as necessary. When a ball finally made it into the box (which on all occasions it did), a discussion was facilitated with the group. Example discussions related to how the volunteer felt when a little stressed and on the spot, and what was found to be helpful, such as general support ("you are doing well") or specific feedback ("angle is good but a little more power").

This was used to highlight that demonstrating something you have made to a group can be stressful and make you feel a little exposed. This stress can be alleviated, however, in a supportive environment. The other important aspect is that when someone suggests a change to a piece of work or action, it is not necessarily a negative thing or a criticism of what has been done. Often it indicates they have thought about the problem, reflected on your solution and have identified a possible improvement. This should be taken as positive, and a sign of respect and consideration of your work.

Following the ice-breaker, participants were given the knowledge and understanding pre-test to complete individually. This led into the taught component of the day where wiring and programming of a range of Arduino components was taught. In small sections, the wiring-up of a component was demonstrated and described, and then carried out by the learners, with individual support as required. This was very informal and small groups allowed a good degree of dialogue between tutor and learner. Following this, the programming of the component was demonstrated and then carried out by the learners. In this iteration of short demonstration followed by enactment by learners, the learners completed the following tasks: making an LED blink, using a potentiometer to control the blink rate and using a button to make the LED blink when pressed. The first set of examples took around 40 minutes to complete.

To change the activity and introduce a creative disruption to the flow of tuition, the participants were then guided through an idea-generation session. Equipped with Post-Its and marker pens, learners were asked to identify three things that make them excited and note them down concisely on the post-it wall. Learners were then encouraged to bring their Post-Its to the front and stick them on a predetermined part of the wall that was visible to the group throughout the day: the ‘wall of situations’. The ideas gathered together on the wall served as an information radiator (Sharp et al., 2009) for use later in the day. This process was repeated for things that make them cross and for things that make them stressed. The purpose of this was partly to move the learners out of their seats and force them to change where their attention was placed. The wall of situations also served to condense physical app ideas to form around later that day. Bringing all the ideas together allowed learners to react to each other’s experiences and stimulated memories and new ideas.

The learners were then guided through some additional Arduino output devices: servo, speaker and red green blue (RGB) LED. The servo and speaker both offered the opportunity to show learners the examples that are built into the Arduino IDE. In particular, the servo requires an external library; this offered the opportunity to describe how software libraries are used as structuring tools. Having been shown the Arduino examples (which are very accessible and well documented), the learners had a way to explore further capabilities of the equipment they were using after the teaching had concluded.

The final example the learners constructed was a red, green and blue colour mixer. With a single RGB LED and three potentiometers, a physical colour mixer was constructed. This task requires a relationship between the potentiometers and the intensity of the red green and blue component of the LED to be established. The potentiometer provides a value in the range 0 to 1023 and the intensity of the LED output is given a value in the range of 0 to 255. This requires various built-in functions and the use of variables and assignment. In a natural progression, the learners were shown how to group this now quite complex program into a single user defined function and how to alter this so that the colour of LED was specified by three parameters passed to the function. Extending this further and utilising the random function and bringing in some sound with loudspeakers, playing beeps of a program specified tone, the learners created a light and sound show.

3.2 Afternoon: Sketch and Build

The afternoon started with the group revisiting the post-it wall of situations that excite, irritate and stress them. Learners were asked to pick several Post-Its they could relate to and expand upon them. The idea of the physical app was then described: a single-purpose object, like a kitchen appliance, which will perform one task or solve one problem well. Finally, the learners were given three hours to build a physical app based on one of the ideas from the selected Post-Its, with support available as required.

The participants were introduced to the technique of storyboarding developed by Disney in the 1930s: creating a series of linked rough sketches that communicate an interaction or chain of events. The storyboard technique was used to support their thinking and help them to articulate their physical app idea. The system they were constructing was inherently interactive and thus hard to capture in a single sketch or diagram. The advantage of storyboarding soon became clear: several designs can be explored in a short space of time without the expense of building and programming them. The act of formalising a sequence of events and interactions can also be helpful in making a learner's ideas more concrete. After some time was spent developing several storyboards, all storyboards were gathered in. At random, a storyboard was selected from the stack. The learner responsible was encouraged to share what problem s/he was solving and how the design would solve the problem. The storyboard serves as a link to the learner's description. Feedback can then be received from the rest of the learners. This further shares ideas between the group and encourages individual learners to reflect on the work of others.

At this point the learners were encouraged to form groups and attempt to build one of their physical app ideas. The group formation was left entirely in the hands of the learners. If it appeared that an individual was having difficulty getting into a group, however, they would be offered support if they desired it. Throughout the four sessions, a total of 24 physical apps were developed by ten individuals, seven pairs and seven groups. Throughout the building time, learners were left to work independently. The tutor and two additional helpers were available to offer support as groups required it. Their role was clearly defined as one of facilitation. Learners were to pursue their own ideas and facilitators were on hand to support and tune (where necessary) these ideas to fit within the confines of the workshop, the equipment available and the available time. For example, one group was keen to make a model police car as a toy for a younger brother. Initially the team hoped to make a car that could drive about. The facilitator talked through the technical challenges that this presented and re-focused the team on more achievable static model with lights and sound. The key to facilitation is including the learners in the decision-making process.

To allow participants to construct convincing prototypes, they were given access to various craft materials including balsa wood, modelling clay, foam board, hot glue, various marker pens and a selection of card. Many of the physical apps made use of these materials to embed the technology in a physical form. When the build was concluded, the learners were asked to complete the knowledge and understanding post-test.

The final activity involved getting the individuals, pairs and groups to share their physical apps. Given the time and materials, the physical apps were best described as working prototypes held together with tape, hot glue and blue tac with an Arduino at the core. Across the four sessions, the learners explained very well what they had made and why. This was well received by the other learners. Before the workshop ended, participants were asked to complete the emotional response questionnaire, making a first pass to indicate what emotions had cropped up throughout the day and then going back to offer some contextual detail.

3.3 Study Design

A combination of quantitative and qualitative methods was employed to evaluate this workshop. Questionnaires were designed to measure changes in knowledge and understanding, and emotional response. In addition to the questionnaires, digital photographs and videos of each of the completed physical apps were captured for subsequent review and analysis. The following section describes in detail the study design decisions made for each of the following parts of the study: measuring change in knowledge and understanding, measuring emotional response and understanding the sophistication of the physical apps.

As this study involved human participants, ethical approval was sought and granted by the University of Dundee's School of Computing Ethics committee. As part of the digital making initiative organised by Nesta, the study did not present any significant ethical dilemmas: it was not replacing or affecting statutory education; it involved neither working with vulnerable participants nor misleading participants. Participants were recruited by Nesta, which also enforced the only exclusion criteria, which was that participants were over 16. The study design used a variety of pre- and post-measures and participant observations that were considered appropriate and in keeping with the inquiry described to the Ethics Committee. Informed consent was obtained from all participants, as was approval for use of digital photographs and videos for research purposes.

3.3.1 Knowledge and Understanding

The basic measurement of this part of the study is to investigate if a change in knowledge and understanding (KU) has taken place in the individual learners as a direct result of taking part in the activities involved in making a physical app. A pre/post-test method was adopted to obtain a baseline of learner KU and then a post-test of KU was used at the conclusion of the study to determine any alteration from the baseline. The only inclusion criteria and prior information about the learners was their age and the fact they had self-identified an interest in the workshop, based on the event description.

The questionnaire designed contained eight multiple-choice questions: four were knowledge-related and four pertained to understanding. The learner was presented with a statement demonstrating an element of programming knowledge or understanding, and given the opportunity to indicate whether it is true or false. In addition, the opportunity to indicate they do not know was also given as a strategy to reduce guessing by learners when knowledge is not present. When scoring answers, a learner received a point for a correct answer, lost a point for an incorrect answer and received no point for selecting not sure. This was to disambiguate between misplaced knowledge and absent knowledge (Perkins and Martin, 1986). This also offers the ability to see where a learner has transitioned from no knowledge to correct knowledge and when a learner has transitioned from incorrect knowledge to correct knowledge.

3.3.2 Emotional Response

Learners' emotional response was measured using the Reflective Emotional Index described in (Martin et al., 2017a). Based on the HUMAINE project work (Petta et al., 2011), it encourages learners at the conclusion of a learning experience to reflect and identify emotions they may have experienced and the intensity of each of these experienced emotions. In addition, space for free text response is given to offer insight as to why and when a particular emotion was felt by the learner. This is an important part of the study as it offers an insight into the learner's response to the activity in the circumstances of a reasonable degree of freedom in what they are building and working towards. The learner's emotional response to the activity is a good indicator of the value of this freedom.

3.3.3 Review of the Physical App

At the conclusion of each session, each group presented its completed physical app, describing what it was, whom it was for and what problem it aimed to solve. These presentations were videoed to provide a persistent record of each of the physical apps created. Videos then were reviewed and a qualitative analysis performed to derive an understanding of the sophistication of the different builds using a card sort system. The previous measures (knowledge and understanding and emotional response) related to the learner's internal experience of the activities associated with creating a physical app. A further measure, 'sophistication', scrutinises the product of the learner's efforts with awareness of the context for which the learners are creating the app. In many ways, 'sophistication' captures the extent to which learners have embraced learning to program in a rich context as well as being able to use the taught skills successfully. As a measure, it considers three elements: (i) does the idea consider the context and for whom the app was being built, (ii) does the build have a strong aesthetic and (iii) is the physical app technically complex.

4. Results

The physical apps study engaged 48 young learners, with a range of experience and different backgrounds from across Scotland. There was a substantial gender bias, with the majority (83%) of the participants being male. The following sections present the findings from the three areas of inquiry described in the study design: measuring change in knowledge and understanding, measuring emotional response and judging the sophistication of the physical app. Finally, the composition of groups will be considered with respect to the sophistication of the physical app.

4.1 Knowledge and Understanding

Knowledge and understanding are perhaps the most measured outputs from a learning experience, and for good reasons. In the simplest sense, the purpose of creating and engaging in a learning experience is to increase knowledge and understanding of a given topic. Thus, the success of a given learning experience is reflected well by an improvement in the learner's knowledge and understanding. In the physical apps study, change in knowledge and understanding was measured by administering the same eight question multiple choice paper test at both the beginning and the end of the study.

Mean knowledge scores improved by 26% and mean understanding test scores improved by 9% (Table 1). The mean post-test score (knowledge and understanding combined) showed an improvement of 17% as a result of the activities undertaken. This is evidence that programming knowledge and understanding has increased significantly as a result of the physical apps study.

	Pre-test		Post-test		n	t	Df	Sig. (2-tailed)
	Mean	Std. Deviation	Mean	Std. Deviation				
Whole sample	39.52	25.09	56.73	21.24	39	-5.05	38	< 0.05
Knowledge	46.79	34.97	72.79	25.12	39	-4.89	38	< 0.05
Understanding	32.05	22.90	41.47	26.49	39	-2.65	38	< 0.05

Table 1: Digital Makers Results

4.2 Emotional Response

Emotional response was captured with the Reflective Emotional Inventory, with responses being grouped via ten high level headings. The first five are negative emotions and the second five are positive emotions. The responses were collated and normalised to an intensity range from 0 (emotion not felt) to 2 (emotion felt intensely). The most striking result was that positive emotions were reported as being far more intensely experienced than negative emotions (Figure 1).

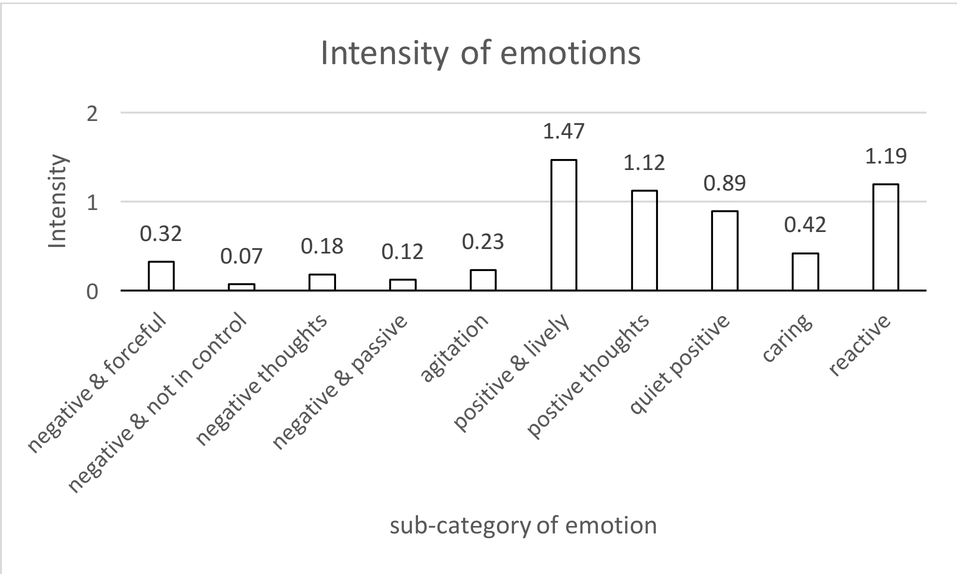
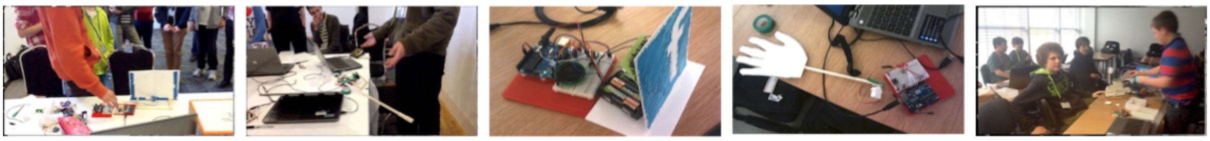


Figure 1: Strength of Emotional Responses

4.3 Review of the Physical App

Across the four sessions, 24 different physical apps were developed, responding to a wide variety of ideas. Each of the apps built was reviewed for the elements of idea, build and complexity. The elements were judged using a structured framework that involved rank ordering the apps for each element and identifying different levels in each set according to the characteristics of that category. Aspects of these elements are considered next.

Idea: this considered the quality of the physical app idea and its purpose. The top performers (Figure 2, noting the group size and gender balance) demonstrated a robust acknowledgement of the brief: to build a physical app based on one of the earlier ideas suggested by each group. They provided evidence of being derived from a problem rather than a technical capability and by being a novel idea with strong links to specific users and/or context with a resolved sequence of interactions. App 16 was a homework progress monitor with a clear consideration of user and good resonance with the brief. This also solved a problem the learners personally identify with. App 23 was a physical alarm clock that starts with a small noise that gradually increases in intensity, then progresses to a physical arm that bashes the sleepy person until s/he wakes. This was a response to the challenge of getting out of bed for school after the holidays, put on a post-it in the morning.

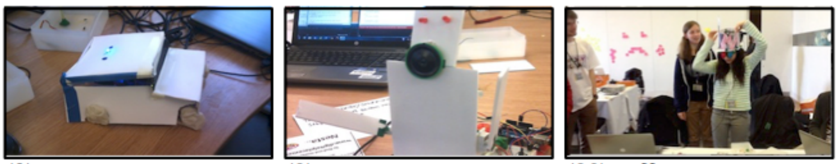


(16) mmff (23) m (4) m (1) m (9) mmm

Figure 2: Idea – Top Performers

App 4 provided a single purpose audio-visual notification of a Facebook notification. This was in keeping with what they had been asked to do and demonstrated the potential need for more eye-catching notification. App 1 provided a performance-rewarding app that quite literally gave you a pat on the back and also kept note of it with an LED bar graph. The final app in this category, App 9, was entitled the FIFA notification station. It had a moving physical arm that drew attention to new information pertinent to a computer game that was popular among the group. The learners spent a great deal of time choosing specific items of information and mocking up the visual display with marker pens on the foam core board. The common feature across all top performing apps was that they are driven by an idea rather than technology. The physical app told a story of who it was for and why it was for them. In most cases the user was the learner, which meant they were building something that related to them whilst they learn about physical computing and what it entails. The weaker apps were driven by technical expertise and were simply an assemblage of the learner's newly acquired technical skills, with little thought of purpose or for users.

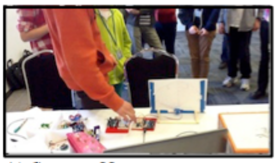
Build: this was based on the non-technical physical components of the physical app and the effort given to construction. This took into account use of materials, structures created and the aesthetics. The strongest apps had a refined and complex build and made good use of a range of materials and consideration of aesthetics. A top performing app (Figure 3) was defined as a refined and complex build that made good use of materials and had considered aesthetics. App 3 was a police car with light and sound. The learners had spent a great deal of time embedding the electronics in a model that offered a good representation of a police car. They made use of a range of appropriate building materials. App 2, the robot toy, was constructed with an array of components cleverly embedded in a convincing robot model. Where appropriate, such as with the servos, the hardware component was concealed. Where it could add to the appearance of the build, such as the speaker mouth, it had been made visible. In addition, a novel construction approach was used to create an articulated abutment join with the foam-board. By inserting straightened paper clips, the learners were able to attach appendages with some flexibility. The bottom level apps of this element failed to function or had not augmented the electronics with any modelling at all.



(3) mm (2) mm (22) mff

Figure 3: Build – Top Performers

Technical Complexity: this refers to the complexity of the build with respect to the code and hardware components used (e.g. servos, LEDs and buttons). The best in this element was expected to have a well-integrated combination of the taught examples and to contain an element of novelty or an extension of the taught concepts. The only app in this category was App 16 (Figure 4). This group identified that there were issues with using servos and pulse width modulation at the same time. To combat this, they made use of multiple Arduinos and used serial communication, a technique not taught, to allow the boards to communicate with each other. The app also included multiple components and good integration of a range of taught material all reliably functioning.



(16) mmff

Figure 4: Complexity Top Performer

Group composition: For the morning taught component of the workshop, learners worked as individuals, with a 1:1 ratio of equipment to learner. In the afternoon, when learners had the opportunity to build a physical app of their own design, they were left to form groups, pairs or work as individuals as they desired. As a result, there was a rich mix of groupings. There were eight female learners and forty male learners across the four sessions. Of those 48, ten learners opted to work as individuals (all male), seven formed pairs (one female and six male), four formed groups of three (one mixed and three male) and three formed groups of four (two mixed and one male).

To be in the top 20% of apps, the learners had to demonstrate excellence across the range of skills and notably all had identified excellent ideas. Of the four in this category, three were individual male learners with the top place going to a mixed group of four. All apps in this band were robustly demonstrable. With the exception of the top-placed group, small teams and individuals performed best overall. Further research with a greater number of learners is required to explore this finding further.

5. Discussion

5.1 Knowledge and Understanding

In addition to the high degree of engagement and the emotional response described, there was an observable learning effect. The Digital Makers study resulted in an observable increase in knowledge and understanding amongst the learners that participated. This goes some way to confirm that the additional task given to learner to flesh out the programming did not obstruct the intended aim of supporting engaging programming learning.

5.2 Emotional Response

The emotional response from learners was similar to that of Martin et al., (2017a). Learners reported negative emotions such as frustration related to bugs in code and wiring, and, the strength of the positive emotions was notably greater than that of negative emotions. It is proposed that the error-prone nature of programming will always result in frustrations. The skill in designing a learning experience is to *support* this rather than to attempt to remove it. Facilitating a learner through the resolution of a software or hardware bug sets them up with some skills of value beyond programming. It is also important to ensure learners do not reach a state in which they have invested significant effort without feedback, as this may result in wasted effort and potential damaging frustration. An example would be wiring up five identical components before confirming that the first one is wired up correctly. This is a tricky balance to achieve.

5.3 Review of the Physical Apps

Idea: there was a mix of outcomes regarding how learners engaged with placing their app in context and relating it to a real world problem. The majority of learners made a good attempt to contextualise their creation, many found resonance with the brief to a greater or lesser degree. One of the most interesting findings is that of the 24 apps only Apps 12 and 18 were devoid of any idea, consideration of users or a sense of place in the world. This suggested that for the majority of learners the rich real world framing of the task was valuable. The two apps created with no context were produced by capable programmers who were demonstrating that their interest lay in the technology and they did not desire the distraction of a wider sense of place in the world for their work. Whether this is a good or bad quality in a programmer is a topic for debate elsewhere. There is evidence that the majority of learners engaged well in programming within the bounds of a real world application.

Build: Most of the learners took great pleasure in engaging in the opportunity to use various craft materials as part of the physical app challenge. The top two-thirds of the sort had learners demonstrate the ability to create mechanically intriguing and aesthetic solutions to give their physical app function and form. Of the bottom third, many learners attempted to engage with the craft materials but lacked the necessary skills to successfully construct the structures they desired. It is important to note that craft skills were not explicitly taught in the workshop, although assistance and advice were provided in response to requests. Only three participants did not attempt to engage with the building materials. All were technically competent programmers who most likely viewed this as a distraction from their primary interests. To return to the central premise of this study, the build aspect is to stimulate the learner to take up the challenge of programming. In the case of the three apps where learners chose not to engage with the build aspect of the task, there is little doubt that they avoided the craft as a direct result of their hunger to pursue the challenge of programming with which they had proficiency.

Complexity: this measured the technical competence demonstrated by the learners as they responded to the challenge of developing a physical app. In many respects, this had most in common with the traditional measures of success such as change in knowledge and understanding and the ability to demonstrate what was learned. The top two-thirds of learners were able to demonstrate the ability to apply the morning's tuition in novel circumstance to meet the needs of a self-directed challenge, which is quite an achievement. They mixed and adapted examples to solve their own problems. As for the bottom third, seven out of the nine were able to reproduce examples from the morning and attempt to frame them. Only two learners were unable to produce a working app by the end of the workshop

Group composition: each of idea, build and complexity will be considered in turn,

For **idea** generation, individuals performed well with around 70% of apps created by individual learners appearing in the top half of the idea card sort. The larger groups with four participants were also in the top half of the idea performance. Groups of two and three performed less well in the idea generation stage. Individuals performing well in an idea-generation process perhaps may be unexpected. This may be explained by the large group idea-generation activity that took place before the build. This allowed the whole group to consider and externalise possible app ideas. Individuals may have found it simpler to select one of these ideas, whereas the medium-sized groups spent time negotiating.

For the **build** sort this was flipped, with individuals performing less well. For build, around 70% individual learners were in the bottom half of performance. The pairs, trios and quartets all performed well, which is perhaps unexpected. It is likely that a well-functioning group with more members offered a good opportunity to delegate tasks. Building the physical model was also an activity that could take place in parallel to code generation, thus favouring larger groups.

For **complexity,** pairs and individuals perform best with 60% of individuals in the top half and over 50% of pairs in the top half. None of the trios and only one quartet made it into the top half. This is unsurprising, as many of the more complex apps were produced by technically capable individuals who were focused on exploring the hardware and software. These individuals were less engaged in group work or in placing their hardware in a specific context.

6. Limitations

There is always a need to apply pragmatism when designing a study involving education. In this study, the single observer issue could be described as a limitation. A further limitation is the possibly untruthful or poorly remembered self-reporting of emotions experienced. However, there is no evidence of any learners reporting their emotions other than as best they could. A stronger candidate for consideration as a limitation is the balance between sample size and sample bias. This study has a good sample size, with a rich set of data from 48 learners across Scotland. However, it does suffer a sample bias as a result of being piggy-backed on to a national public engagement event. It is therefore important to reflect on this when considering the results. The sample was taken from across Scotland for a bookable event. Participants who attended were likely to have a good awareness of what they were attending and therefore likely to engage fully and perform well. This has been evidenced from the various measures taken throughout the study where the majority of learners have performed well. These methods will need to be developed across mainstream education to test if the results described generalise to the broader population of young learners.

7. Conclusion

The main findings of this study can be summarised by referring to the research question: *"How is introductory programming learning affected by designing activities that enable personalisation, ownership and purpose?"* The Digital Makers study used ownership, personalisation and purpose to create a highly engaging learning experience that resulted in an evident learning effect and strong positive emotional responses from learners.

The qualitative evaluation of the physical apps gives the best insight into the effect of the rich context that was built around the intended learning. Reflecting on a learner's app, ideas, builds and complexity offers a good indication of the extent to which that learner embraced this approach to learning. Almost all learners engaged very well with this approach to learning, showing commitment to solving the problems they had defined. The ideas for physical apps reflected the culture the learners belong to, such as with notifications for FIFA and Facebook. In some cases, they personalised their product by creating toys for younger siblings (such as a police car with lights and sound). Almost all learners attempted to construct some kind of physical app using the craft materials provided. The complexity of the builds varied from relatively simple extensions of the demonstrations to complex compositions with multiple sensors and actuators. The only learners not to engage fully with the rich context were learners that had come to the session with an existing knowledge of Arduino and had premeditated plans for what they wanted to explore. For these learners, the rich context was a distraction to their intentions.

A combination of quantitative and qualitative methods has provided insights into the value of ownership, personalisation and purpose to design engage learning experiences in programming. Qualitative methods were used to judge the work of learners creating physical apps and to capture their emotional experiences immediately after a programming experience. The former provided evidence of the very positive emotions experienced by learners developing physical apps. The latter allowed identification of links between the emotions experienced and their origin. The empirical evidence suggests that the majority of learners engaged deeply in the rich context in which the learning was situated. This was coupled with a strong learning effect. Jointly, these have helped to confirm the value of creating a highly engaging learning experience that includes a layer of cultural relevance.

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