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Playing, Constructionism, and Music in Early-Stage Software Engineering Education

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Abstract

Understanding that design involves trade-offs, thinking at multiple levels of abstraction, and considering the cohesion and coupling between sub-components of a larger whole is an important part of software (and other) engineering. It can be challenging to convey such abstract design concepts to novice engineers, especially for materials that are themselves abstract (e.g., software). Such challenges are compounded when teaching at the secondary school stage where students have limited experience of large-scale design challenges that motivate the need for abstraction at all. In this paper, we describe a method for introducing these concepts to secondary school students using LEGO® and Raspberry Pi computers, asking them to build musical instruments as an entertaining way of motivating engagement with learning about design through play. The method has been successfully piloted in a series of three classroom sessions and key observations and experiences of using the method are presented.

Keywords: constructionism; construction-blocks; music; design; children; LEGO®

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1. Introduction

Coding is an increasingly important part of school curricula with governments around the world requiring it to be taught from the earliest years (Rich et al, 2019). In Europe and the US, concerns have been expressed about education in informatics (Barendsen & Steenvoorden, 2016) and in the UK a Royal Society (2012) report on unsatisfactory Information and Communication Technology (ICT) teaching in schools led to curriculum changes (HM Government, 2013).

Despite these improvements, student activities are still simple compared to the scope and scale of professional software engineering and it would be unreasonable to expect school students with limited software development experience to immediately assimilate the need for, and appreciate the problems of, large-scale software development. Hislop (2008) claims that it is the scale and complexity of software systems that drives the problems and practices of software engineering, and that until students gain some understanding of this they find it hard to appreciate what software engineering tries to address. Ludewig (2008) states that software engineering is not just a set of topics but is primarily a mindset like that of engineers. Ali aligns software engineering with other engineering disciplines as something requiring a team effort (Ali, 2006). Exposing students to the kind of thinking and practice required at an early stage may therefore better prepare them for the challenges ahead. Monteiro et al. also identify the desirability of signifying broader software engineering (beyond coding) at this stage of education (in their case particularly software quality) (Monteiro et al., 2017).

Wing (2006) argues strongly for "computational thinking" (beyond programming) to be promoted to "pre-college" audiences. Tsai et al. (2021) survey a range of computational thinking studies that characterize it in various ways. Of particular relevance to our work, Brennan and Resnick (2012) defined three dimensions of computational thinking: *computational concepts*, *computational practices*, and *computational perspectives*. The first of these deals mainly with programming, the second with the development of design practices, and the third with designers' views of the world and themselves. Our work here is situated mainly in the second (and to some extent the third) of these dimensions. This focus also aligns with the Cooperativity, Creativity, Critical Thinking, and Problem Solving elements of the framework developed by Doleck et al. (2017), and the Abstraction and Decomposition elements of Selby and Woollard's (2013) definition.

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In this paper, we present a pilot, exploratory, qualitative action-research study built on three sessions of activities to introduce a class of secondary-school children to computational thinking practices whilst being active, engaging and fun (Alanazi (2020) identifies active recreational activities as valuable in the context of the similarly pedagogically-challenging field of mathematics). We applied educational theory (constructivist methods), used teamwork and reflection, and introduced technical concepts using non-technical approaches. Our objective was to explore whether the combination of music and making could lead to effective opportunities for software engineering education and to discover the practical issues involved. The focus was therefore primarily on the exploration and feasibility of our approach to the development of computational practices and perspectives.

2. Theoretical Background and Related Work

Our research is underpinned by the interrelated concepts of constructivist and constructionist learning (most strongly associated with the work of Piaget and Vygotsky). As Gogus notes, “Constructivist learning claims that learners do not just absorb information. Instead, learners construct information by actively trying to organize and make sense of it in unique ways” (2012, p.783) noting also that Piaget asserted that individuals do this through constructing mental models and schemas, which undergo further revision through the processes of assimilation, accommodation and correction. Vygotsky’s contribution was to highlight the extent to which these processes are socially and culturally influenced. Thus, individuals’ constructions depend on interaction with peers, “more knowledgeable others” (often teachers, parents or workshop leaders) and prior experiences with “cognitive tools” such as language, technical, cultural and historical awareness. Papert developed these concepts further to become constructionism, arguing that it is through making tangible things that we consolidate these models and schemas through physical representation (Papert & Harel, 1991; James, 2013). This deep and powerful connection between the concrete and the abstract often leads to descriptions of constructionism such as “thinking through our fingers” or making “objects to think with”. Yet these physical representations also contribute to the social aspects of learning, since they provide a shared focus for group tasks and scaffold communication between collaborators (Jensen, 2017). Whilst Franco and Gillanders’ (2014) work is aimed at masters students

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studying secondary school education, we nonetheless note their positive conclusion that where learners' voices are heard, they take a leading role in their own learning.

The desire to build tangible objects to meet given objectives, and the pride and satisfaction that can result, invokes another of Papert's theoretical principles: "hard fun". Learners, it is argued, will typically persevere in the construction of these objects, overcoming all manner of technical challenges in the process. As Papert (2002) once observed, children often describe constructionist learning activities as fun because they are hard, rather than in spite of them being hard.

The term 'flow' is most associated with Csikzentmihalyi and refers to "a state of optimal experience characterized by total absorption in the task at hand; a merging of action and awareness in which the individual loses track of both time and self" (Schmidt, 2010, p.605). Similarly, and particularly during group-based activities, rich instances of "divergent thinking" may also occur which result in the generation of many diverse ideas of tackling the same problem. This typically involves "breaking a topic down into its various component parts in order to gain insight about the various aspects of the topic" and implies that "not only one solution may be correct" (Razumnikova, 2012, p.1028).

There are strong links here with another concept associated with Papert and collaborator Sherry Turkle, but originally due to the anthropologist Levi-Strauss. In their analysis of computer programming style, Turkle and Papert (1990) famously drew distinctions between "top down planners" and "bricoleurs" who were observed to hone in on a programming solution from amongst many alternative approaches through a playful, interactive approach: "bricoleurs have goals, but set out to realize them in the spirit of a collaborative venture with the machine… bricoleur programmers prefer negotiation and rearrangement of their materials" (p.136). The term bricoleur derives from the French verb bricoler, meaning "to tinker" and, more recently, proponents of the educational maker movement have adopted the English term to describe making activities which realise learners' personal creative goals through various "scientific and technical tools, processes, and phenomena" (Bevan et al., 2015, p.99). Tinkering invokes the principles of "exploration, questioning, iterative designing and testing, and problem solving" (ibid., p.99–100) to achieve creative, aesthetically satisfying and self-expressive goals.

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Ben-Ari (1998) explored constructivism and bricolage in computer science education arguing that, whilst bricolage can help in introductory courses, it can manifest in computer science as endless debugging and ultimately fail to develop the skills of hypothesis creation and testing based on models, needed for professional practice. Our aim in the work reported here was in part to lead students towards design reasoning activities that could lead to a more model-based approach.

Baretè, Formica et al. (2017) identified music as an effective way to engage secondary-school children in learning computational thinking. They focus on coding tasks by which music is manipulated and computational thinking thereby learned. This addresses motivation but not necessarily scale and complexity. Baratè, Ludivico and Malchiodi (2017) and Ludovico, Malchiodi and Zecca (2017) report work in which LEGO® bricks are used as a physical representation of musical elements such as scores and score segments. Other authors have successfully tapped into the attraction of music performance for computing education (Ruthmann et al., 2010). These works lean more towards code-level representations (either directly or in musical equivalents); while acknowledging the necessity and value of this, the work we report here was focused more on larger-scale software engineering issues and computational practices (see Brennan and Resnick, 2012). The reported success of LEGO® use in computing education suggests the potential for making-related work more broadly. Rode et al. extended previous work on computational thinking to computational making, identifying several relevant concepts: creating, constructing, and material understanding (Rode et al., 2015). We consider and incorporate these concepts in our work. Our approach shares some characteristics of Bellettini et al.'s algomotricity (Bellettini et al., 2014) in the sense of having three phases and combining tangible and abstract learning about a topic at a high school level. Although exploratory activities are incorporated in our work, our approach is a little more instructor-directed, focuses more on explicit reflection rather than scaffolded discovery, and addresses broader concepts.

LEGO® has also been used in professional software (and other) engineering training and education e.g. SCRUM (Paasivaara et al., 2014; Krivitsky, 2017), team communication (Schulz & Geithner, 2011) and development (Bulmer, 2009), and requirements engineering and dependability (Kurkovsky, 2015). These works do not incorporate musical aspects in their methods.

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In summary, our work is related to but distinct from that described in this section. It draws on theories of constructionist and constructivist learning, is motivated by the desire to lead students towards design reasoning at a relatively early educational stage, and draws on evidence of success in using music and making as motivational and educational strategies in coding and computational thinking, and the use of LEGO® in software engineering education itself. It explores broader practices and concepts than coding, uses music performance built on LEGO® construction activities as both motivation and a tangible material exploration, and through this aims to stimulate the development of the design skills and reflection needed for large scale software development in future.

3. Pilot Study

3.1. Design

The concepts we were interested in conveying to students are interconnected through a key principle: 'separation of concerns' (SoC). Dijkstra (1982) describes SoC as focusing attention on one isolated aspect (among many) of a subject whilst being aware that this is what one is doing: not ignoring other aspects but regarding them as irrelevant from the perspective of the aspect in focus. Dijkstra summarises this as "…being one- and multiple-track minded simultaneously" (p. 1). From this fundamental principle flow the concepts of *abstraction*, *modularization*, and *sub-component interfacing* that become increasingly relevant (indeed necessary) as the scale of systems increases, and act as the foundations of more advanced techniques such as object-orientation. These concepts require *multi-level* thinking and *design trade-offs* to consider how to arrange desired functionality among the components of a system and balance various possible solutions. Abstraction (and some related concepts) also strongly feature in discussions of computational thinking (e.g. Wing (2008), and Selby and Woollard (2013)). In musical terms, they might translate, for example, to keeping the properties and design of a guitar body in mind while focusing on the neck (and vice versa), and not losing sight of the interface that will connect them.

Since our aims were exploratory, we designed activities to allow observation of students' responses without overly constraining our stimuli. We assumed they would have some familiarity with LEGO® and would be ready for music-related activities consistent with their regular curricular

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experiences, although did not assume specific musical knowledge. We also did not assume any explicitly-evidenced skills or knowledge of things like abstraction, design, and trade-offs. Students would encounter teamwork and organisation, affordance, instruction following, creative thinking, and reflective consideration of the materials and methods produced.

Our programme delivery was structured into three sessions; (1) material familiarization and creative free-building of instruments, using musical performance to motivate students and help them understand physical sound creation; (2) promoting team-work aspects through a more structured instruction-led build of an mbira (a generic name for Sub-Saharan African instruments of the lamellophone family, consisting of a resonating chamber, sound board and a series of plucked thin metal plates called lamellae (McNeil & Mitran, 2008; Montague, 2011)), and introducing standardization in design; (3) introducing standardization to sound excitation through mechanism, and the separation of production from actuation by substituting physical sound production for digital synthesis.

We procured many LEGO® Technic parts (and some from previous LEGO® Serious Play work (Purves, 2019)) to create sets for the mbiras and other activities. Sets were assembled in plastic sorting boxes before transportation to school. Other items included tablecloths to damp classroom noise (Jensen et al, 2018), sticky notes, rechargeable speakers, and instruments (our own and classroom resources) for scaffolding and performance. Instructions were created as a photo sequence (see example step in Figure 1).

We provided a pre-built synthesizer platform of Raspberry Pis with BrickPi kits (Dexter Industries, 2019) to allow LEGO® EV3 sensors to trigger Sonic Pi (Aaron & Sonic Pi Core Team, 2021). We extended BrickPi and Sonic Pi demo code to scan buttons, trigger notes, and select voices. A 'modifier button' permitted pitch shifts (allowing an octave compass over a pentatonic scale: [C, D, E]/[G, A, C]).

Detailed consideration was given to ethics issues. Multi-stage informed consent from all relevant parties was obtained (gatekeeper consent from school senior management first, then parent/guardian consent for each child, and staff, covering photography, video, and feedback). We

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sought information from the school in advance to ensure inclusivity and access, and controlled for physical health and safety risks (the fieldwork took place prior to the Covid-19 pandemic).

The study was carried out in accordance with the British Educational Research Association 2018 Ethical Guidelines for Educational Research. It was approved by the UCL Institute of Education Research Ethics Committee (1229 / Z6364106 2019 05 174 social research).

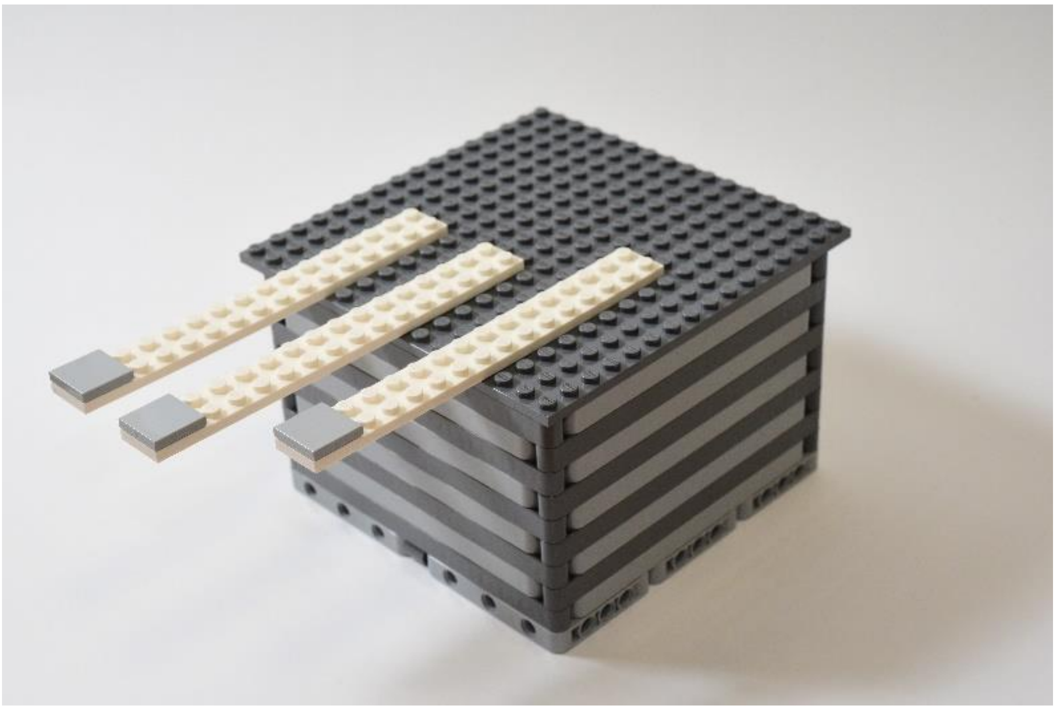

Figure 1. LEGO® Mbira designed for this activity.

3.2. Experiences

For our three sessions, we worked with a class of 22 UK secondary-school children aged 11–12 and their teacher. Sessions took place during weekly music lessons of about an hour. We led each session with the support of the teacher. During the sessions we took notes, photos, and video,

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and (with the teacher) helped students with questions and suggestions. Students sat around tables in groups of two to five.

3.2.1. Session 1 - Affordance and Performance

Session 1 aimed to give students understanding of the material affordance of LEGO® in the context of making and playing musical instruments (reflecting recent trends in English education policy that stress the importance of musical sound as the dominant language of school music lessons (Atkinson, 2018)); performance became a motivation for making. We had approximate timings in mind but adapted "in the moment" to student and session progress. As students entered the room, we played live music (improvising around a simple salsa montuno pattern), the same kind of piece within which students were asked to join at the end. We introduced the project motivation, the series of sessions, and this session in particular. Students were started on the first activity: freely building a shaker out of the available bricks. We then suggested alternative instruments to build (guiro, zither, drum). Once all had created instruments, we verbally taught simplified versions of standard salsa rhythmic patterns (e.g. son clave and tumbao) to each instrument group through imitation, then joined in as at the start. Finally, we asked students to reflect on their activity, noting anonymous thoughts on sticky notes.

Session 1 was very successful, with all students occupied, excited, and participating fully. There was a palpable sense of 'flow' throughout, evidenced through very little off-task pupil behaviour and the speed at which many groups completed activities. The simplest instruments were built quickly, needing our contingency plans for additional instruments. Some groups worked more collaboratively (emphatically discussing their ideas with each other, sharing or copying ideas) and others "alongside" each other rather than in collaboration, illustrating important differences between "cooperative learning" and "parallel learning" within team-based activities (Kindred, 2017).

The exercise led to considerable divergent thinking. Shakers were produced in a variety of shapes and sizes, with some joined to each other, others including handles (initially one girl added a handle, then others on the table adopted the idea), and one a long 'baton'-style shaker. Handle strength was initially poor but, in line with constructionist theory, the designs improved following discussions between pupils and with the researchers. Some shakers were subsequently repurposed as

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drums. One group focused more on aesthetics and ornamenting their shakers using doors and windows. Such adornments may at first seem trivial but constructionists also stress the importance of complementing the technical or scientific effectiveness of learners' creations with personally-meaningful decoration (Resnick, Berg & Eisenberg, 2000).

In plenary reflection, one boy observed that larger, flatter and thinner 'white wall' bricks worked well because they "bang against things". Students also noted that using smaller pieces made more noise and rattled more, and that the 'gate' pieces have holes in them that release the sound more. Notwithstanding the earlier point regarding decoration, they also noted that making shakers look good may not, in itself, lead to instruments that feel or sound good. Reflecting on the design of handles, they noted that thicker handles were needed to avoid them breaking.

When building instruments in the second stage (Guiro, Large Shaker, Hand Drum) students engaged spontaneously in comparison to a real drum, or lifting the drum to extract more sound, re-engaging students whose attention was starting to wane.

There is evidence here of some of the concepts we were aiming to draw students towards. They were clearly considering design trade-offs between aesthetics and functionality. They also showed aspects of modular thinking in terms of developing shakers and handles separately (although it is not clear from the evidence that modularization as a concept was an explicit consideration in the minds of students). Moreover, in both their descriptions of effective features of shaker design and in their ability to derive and replicate key properties of other instruments, they were demonstrating an ability to abstract particularly salient features. Some of the instruments resulting from this session are shown in Figure 2.

3.2.2. Session 2 - Consolidation, Reflection and Direction

The second session was designed to remind students of their previous work, provoke further reflection on Session 1 outcomes, and prepare them for Session 3. We started by recapping our aims and the salsa patterns before playing together again. We had swapped the instruments so that students were unlikely to be playing one that they created themselves, to provoke deeper reflective discussion based on inspection and playing experience of others' designs. It was intended as a means of

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consolidating and extending prior learning through exposure to novel scenarios (Mintzes & Wandersee, 2005).

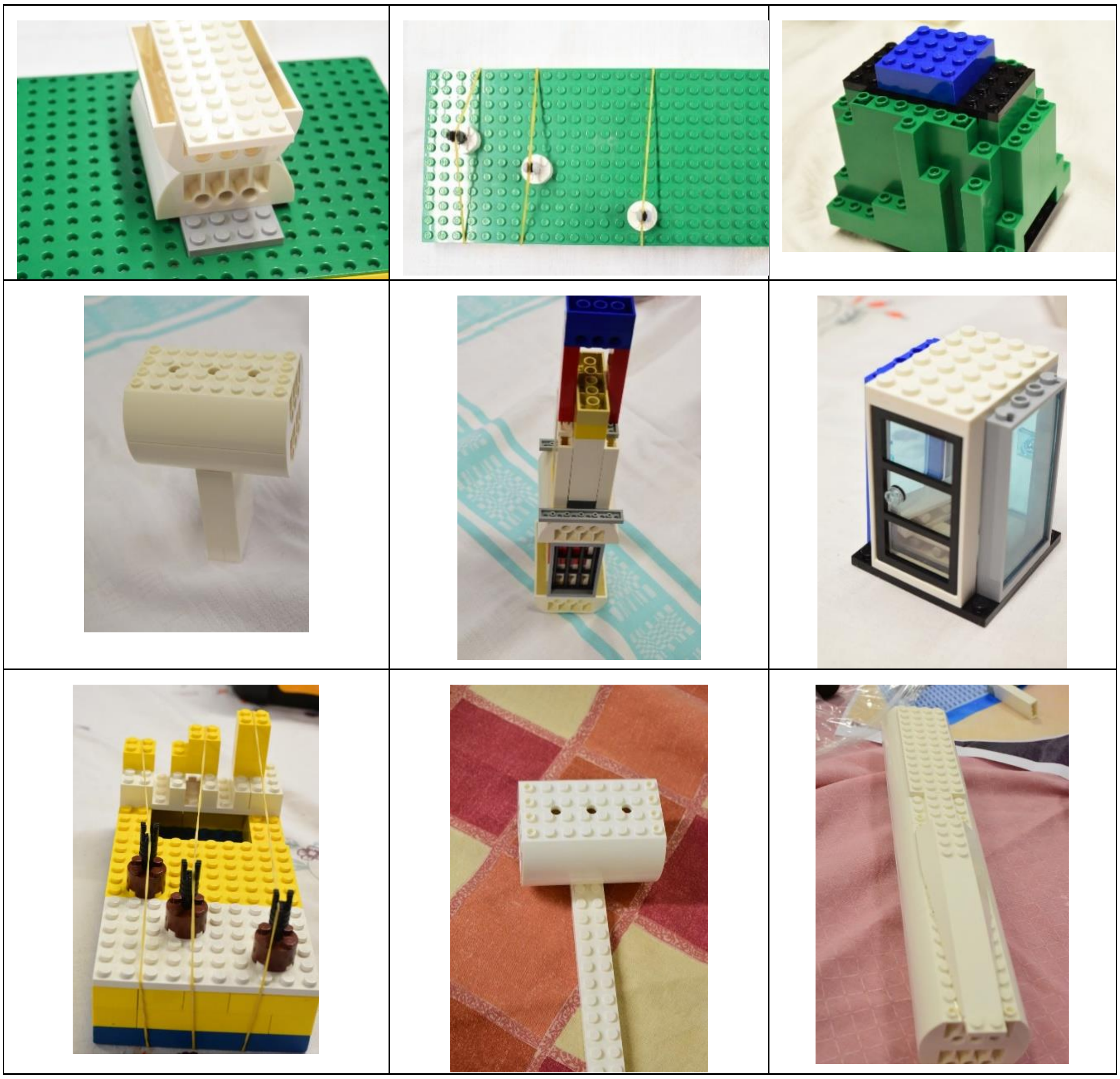

Figure 2. A Selection of the Free-Build Instruments

Students were then directed to the mbira components and instructions and the exercise explained to them. They then started building the mbira (shown in Figure 1 with two lamellae at the

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same length (pitch) and one shorter — they can be adjusted to any desired length that permits vibration and thus cover three separate pitches).

We asked each group to make anonymous notes about their team organization and working practice to get them thinking about their work organisation. After a period, we paused the building to present some technical points on string excitation. This "lesson closure" (Ganske, 2017) was intended to highlight links between their experiences and the issues of interaction, regularity, uniformity and length of lamellae in the human interface, thus preparing them for the exercises to come in Session 3.

Excitement was again evident on entry, with one student exclaiming "LEGO!". Students generally disliked playing others' instruments (predicted by the teacher, but, in hindsight, consistent with constructionism's emphasis on personally-meaningful object making). Students grabbed shakers and started making noise, having to be calmed down. One girl remembered the rhythm to the salsa almost perfectly and the others picked their parts up once reminded.

Swapping the instruments was successful in terms of reflective thinking. Despite their annoyance, students identified salient properties in novel designs *("I like how big it is and how it makes a loud sound", "this one didn't have enough space for the pieces to shake around inside so it wasn't very loud"*), comparisons (*"this one was nice but it broke so I think this one was better"*) and tradeoffs (*"this one sounds good but it falls apart easily"*). We used these observations to introduce the role of constraint in design.

Some intervention was needed in this session, partly for timely completion of builds and to correct a minor error in the ordering of the mbira instructions that had confused some students. Persistence is a key conative quality for engineers (Adams et al., 2015) and we could model it through our resolution of this issue.

In hindsight, this session did not contain sufficient parallel building activity to keep students occupied throughout, although this offered opportunities for teamwork discussions and practice. Engagement was variable, with some tables working in focused sub-groups alongside other students less engaged. There were also elements of competition *("I'm ahead of you, and I haven't even looked*

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at the instructions"). Our (and the teacher's) engagement with students during this period tended to refocus them.

Students did not always follow the instructions precisely (we failed to anticipate this), perhaps because photo sequences require careful interrogation. Thus critical parts were unavailable when subsequently needed and we had to supply spares (from a limited number) or help with rebuilding to free those needed. This offered opportunities to educate students on building techniques that they had missed in the instructions. Some teams exhibited resilience to these issues through teamwork, with members correcting each other as they worked.

Students had fewer opportunities to evidence design skills in this session: the instruction-led nature meant that problem-solving was more at the level of substituting parts, e.g., we pointed out that if there was a shortage of 13-hole lift-arms, two 5-hole and one 3-hole lift-arms could be used together to replace them. Students picked up on this with one later telling another: *"That's why you use two fives and a three!"*.

Student notes indicated a range of organizational schemes including subdivision of labour for speed and improved concentration, turn-taking, explanation to peers, mutual help and support, and looking ahead to understand instructions better. As described above, they were clearly able to exhibit thinking about trade-offs in others' designs, engage in reflection, and consider multiple aspects of what they were doing (e.g. aesthetics vs function, physics of instruments).

3.2.3. Session 3 - Interfacing and Replacing

The final session aimed to engage students with mechanical activation of the lamellae and then substituted physical sound production for digital synthesis, with the physical same interface. We completed any unfinished student instruments beforehand to level the scaffold for all groups and created one example trigger mechanism per group. We also prepared the Pi-related components (Figure 3) since parts arrived too late to prepare instructions.

We began by briefly introducing the Pi-based system, reminded students of how things were left at the end of the previous session, and explained our finishing of their instruments. We asked them to investigate the effect of lamella length on pitch, then discussed the need for a standardised

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interface (e.g. by considering the viability of an mbira with the compass of an 88-key piano). Students then built 'triggers' from our instructions (three per instrument; see Figure 4). Many students completed their build and we followed-up by presenting material on standardised interfaces starting by explaining piano-key mechanisms, then moving to robotic instruments to introduce the idea of separating control and sound production. Students then moved to the Pi systems and were supported to integrate these with their instruments and experiment (see Figure 5).

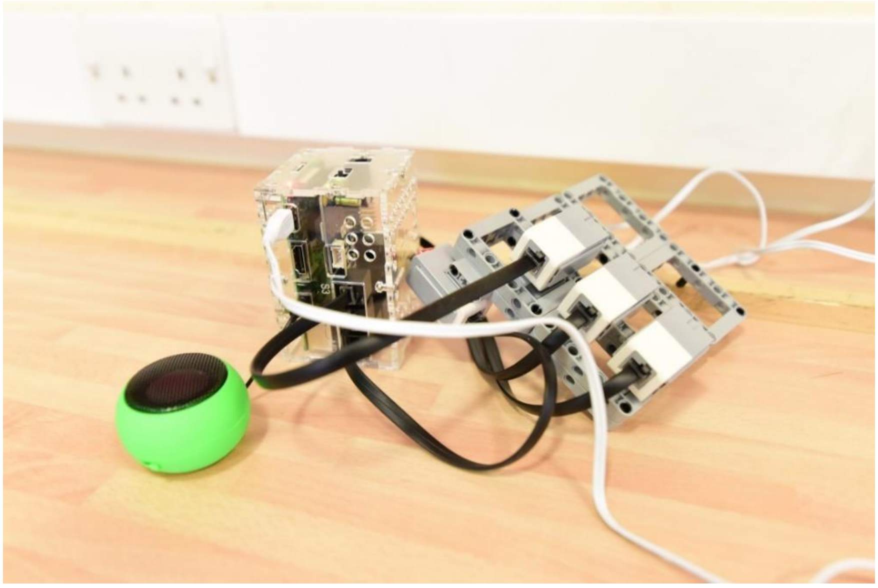

Figure 3. Pi-related Components (encased Pi and BrickPi, frame with four sensors, portable speaker).

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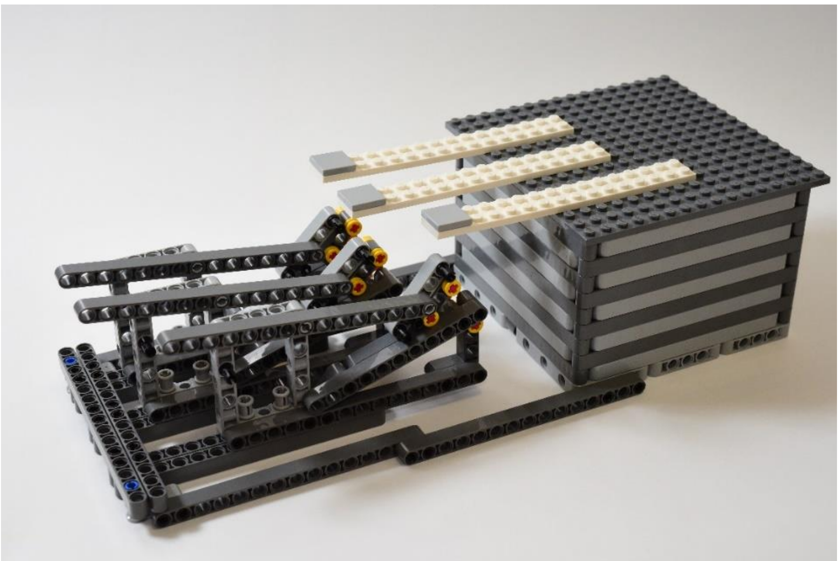

Figure 4. LEGO® mbira with moveable lamellae/triggers.

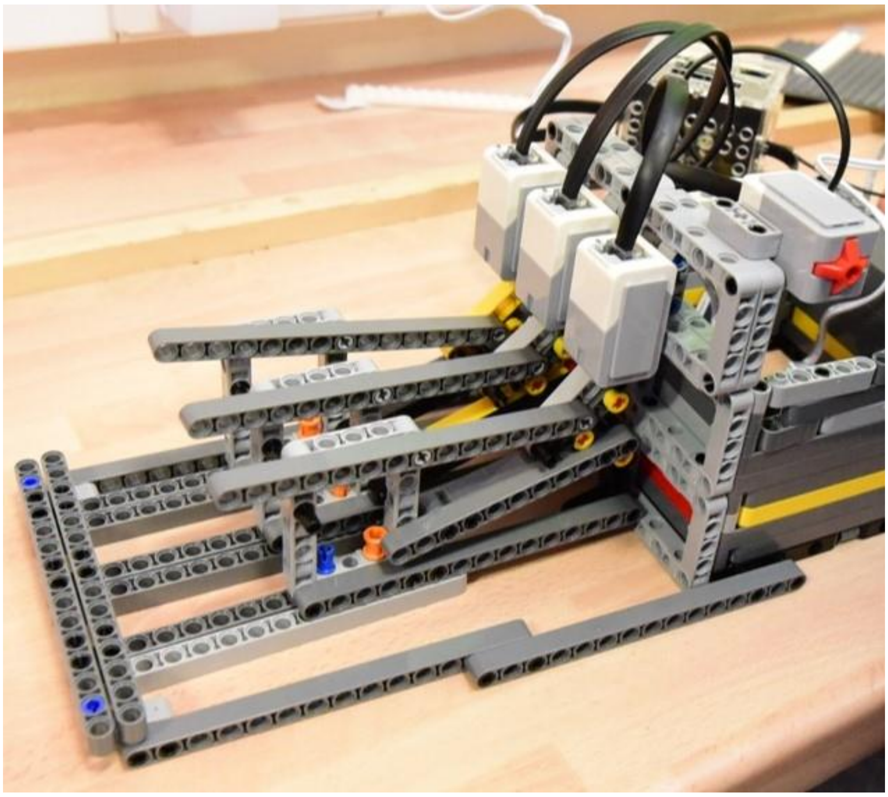

Figure 5. Pi system installed on mbira.

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A final feedback sheet featuring both open and closed questions was completed by the students.

Students were excited at seeing the Pi partial set-ups when they arrived. They found their own work from the previous week and some began to play with it while others talked. Students again responded well to a reflective question about how to make the best sound: *"by taking it off the bricks [base board] and holding it down"; "if you pluck them further out they are louder"*.

Students were initially very focused when building triggers (*"who wants to build the trigger?", "have we got more of these bits?", "I want to try to play this how it is", "separate them into bits", "can I borrow that yellow bit, please"*) although this ebbed and flowed a little after five minutes. As previously, missing pieces caused challenges owing to the diverse ways in which students had built their mbiras. Specific parts were more critical to the trigger mechanisms than in the main box walls. Connecting-pin colours also raised an unexpected issue. We told students that colour of bricks was not important (to free them from concerns about matching particular brick colours), however, LEGO® pins vary in their frictional force and this is indicated by colour (black=high friction, light grey=low friction). It was critical to use high-friction pins for the trigger frame and low friction-pins for the rotating parts to ensure correct mechanical operation.

In discussion of mechanisms, students were able to identify various things in their classroom that operated when instructed rather than by direct manipulation (computer, electronic keyboards and electric piano). There was much visible excitement when students moved to the Pi systems, particularly when introduced to the ability to change the sounds (thereby evidencing an appreciation of the concept we were aiming to convey: that by abstracting sound production away from the physical properties of the object, the same interface could be used more flexibly).

This session exposed students to concepts of modularization and abstraction (through the separation of actuators and sound production. Students clearly understood that an external interface might be separate from the instructions that it gives to an attached operational system by their ability to identify such systems when asked. Whether this translated to understanding in the context here was less explicitly evident.

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4. Feedback

4.1. Students

70% of students reported in their Session 3 feedback sheets that they preferred free-build to instruction-led activities, clearly enjoying the creative opportunities for imaginative exploration these presented. A third of answers explaining pupils' preferred activities referenced 'fun' or 'enjoyment'. A third of the reasons given referred to the independent and imaginative decision-making opportunities that were involved (e.g. *"…really fun…helped us to use our imagination"*, *"…liked exploring which shakers are better…choosing the design"*).

Only 25% of pupils indicated that they preferred instruction-based activities; of those that did, this appeared partially rooted in a belief that following the adult guidance would result in better-quality instruments (*"…there was a reason for them…"; "following instructions means that you can make something cool that works…"*). A further two comments suggested that following instructions was *"fun"* and something they liked to do. One noted elsewhere that they had *"learnt how to follow instructions better and to create something that someone else has designed"*.

Given the engagement observed, it was unsurprising that all but two students explicitly mentioned enjoyment and fun in Session 1 sticky-note feedback, with the combination of LEGO® and music clearly very popular. In line with Papert's concept of 'hard fun', a small number of notes mentioned that the session had *"tested their creativity"* (two different notes) and that their constructions *"improved every time"*. Perhaps indicating a yearning to continue experimenting, a further note read, *"if only there was a way to make the drums/other things sound deeper and more real"*. There was also a sense of discovery: *"I didn't actually know you could make music out of LEGO.", "…No boring stuff."*

Some students focused in their Session 3 feedback on the importance of methodical, detailed, persistent and collaborative approaches in design work (*"…keep trying and making it stronger…","…take time and think…", "…sometimes going slower makes them better…"*) and two mentioned creativity and flexibility (*"You can be as creative as you want", "Anything is possible with any materials even LEGO", "…make music out of many different things…"*). This theme also

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emerged in responses to the question 'have the sessions changed the way you think about musical instruments?'.: *"…I think more about how they produce noises."*

Pupils were asked to consider how they might approach building another instrument if given the chance. Some wished to make 'bigger' or 'different' instruments, two would have employed more colourful designs. Other answers suggested that their approach to building (as opposed to the instruments themselves) would be different e.g. making sure they *"have all the parts"*, or *"thought a bit more about the design"* or *"think about the sound"*. Two were in contrast: *"follow the instructions really quickly"* vs *"be slower so I don't mess up"*.

The 'electronic mbira' was rated as most exciting to play (~59%) vs the trigger version (~12%), original (~6%), or no difference (~24%).

4.2. Teacher

Following examples of participatory research (Cancian & Armstead, 2001), the class teacher was central to the planning and delivery of the sessions and her feedback is integral to our understanding of what was achieved. She expected that the approach would likely succeed, with LEGO® use combined with the idea of making instruments and physically creating sound being important motivations for children. The teacher anticipated that the children would learn about collaboration and working together, and as a practitioner was interested to see how this collaboration (regarded as natural in the arts) would appear in an engineering task. The activities fitted well into the curriculum and overall planning.

The teacher felt that Session 1 was pitched just right and achieved its aim, introducing the concepts, engaging the children, and involving considerable evaluative activity. The children learned what made effective shakers and to describe their thinking from a design viewpoint but apply it from a musical viewpoint. They were more invested in playing the music because they had created the instruments: ownership had an important role.

Session 2 was paced correctly but the teacher suggested improvements: split the instructions so that sub-groups produce and reflect upon sub-assemblies, and predefine team roles (e.g. searchers and builders; one pair developed a process of preparing and building) and then swap them to get

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students thinking about different roles, help make design concepts more overt, and support easier reflection on team structure. The teacher also observed that, overall, the boys in the class had tended to race ahead in the instructions (perhaps causing inaccuracy in builds), whilst the girls had tended to work steadily.

The final session was felt to be paced as well as possible given the time available, however, the teacher's view was that a 4–5 week plan would have been better to fit in all the content. Showing the Pi at the start might have led to greater motivation and more timely completion of the builds. Although students did not see the separation of concepts/concerns during building, the teacher perceived that once they were using the Pis, they had recognised the concept.

In terms of overall teacher feedback, the extent of evident collaboration was more than expected (she was most interested to note that there were high levels of engagement across the classroom in different students). Design aspects were conveyed as well as possible given children's desire to get going with the activities; to cover them more explicitly would need more time. Learning through doing was very important and the modelling used was helpful: a scaffolded process might work well in future (with more time). Although present, more explicit links to the English National Curriculum in terms of learning outcomes would help engage staff. It would also be useful to provide a less specific set of builds that rely on particular pieces, but instead give examples (e.g. pictures) and let teachers drive the activity. Training may be required for the computing aspects. The sequencing of activities was correct, worked effectively and had a sense of progression. The teacher felt that we had done well to get everything into three weeks, and it could even be run as a six-week exercise with additional facilitated reflection at the end, including some more explicit programming aspects to show how digital instruments could be created. Despite this, the teacher felt that we had been appropriately ambitious and that this drew the children along.

5. Conclusions and Future Work

Our aim was to assess whether music and making would be effective at conveying software engineering concepts in secondary schools. Our evidence suggests that students engaged practically

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with all of the concepts in which we were interested. They developed subsystems (e.g. handles and shakers), reflected on the interfaces between them and the quality of function of the components and their integrated whole. In plenary discussion, they evidenced awareness of the separation and abstraction of control and sound production. Alongside these primary goals, they engaged and reflected on teamworking, played music, engaged in spontaneous experimentation, and importantly, had fun while doing so. Overall, this pilot has shown that our approach has significant promise. It worked motivationally and engaged students practically with many of the target concepts.

We learned a number of lessons that will be helpful in developing future similar interventions:

- Explicit presentation of key concepts is important for students to understand and apply them transferably e.g. present modularity in this context and refer back to it later from another "you've seen modularity in design before when you built shakers and handles in LEGO®". This is congruent with Ben-Ari's (1998) position that the 'model' (at an appropriate level) needs to be explicitly taught. Our approach is (appropriately) bricolage-oriented in sensitizing students to the desired concepts, but this does not deny the need for later more-explicit teaching to support subsequent formal study.
- The concept of abstraction needs appropriate time to be introduced fully.
- Following instructions likely slows down progress compared to free-building (but, as Gunn (2002) argues, is a vital engineering skill).
- Scaffolding (e.g. staff completing partial builds) needs to be balanced with potential loss of ownership by students (teacher observation).
- Directed or instruction-based builds may benefit from a more explicit division of roles to improve engagement and permit parallel activity.
- Having all materials on-hand and a significant reservoir of spare parts is critical for success.

This pilot project was conducted with school pupils aged 11-12 years. However, there are grounds to believe in the potential of similar kinds of activities to support older learners, including those in higher education. As noted, the presented activities drew heavily on constructivist learning theory. In particular, they were characterised by experiential learning, problem solving and – to a

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lesser extent – ownership of the learning process by the pupils themselves. As Knowles et al. (2020) note, all such aspects are consistent with core principles of andragogy – the theory and practice of teaching adult learners. Moreover, research evidence in a range of disciplines suggests that practical engagement with LEGO® is no less motivating for older learners (Nerantzi and James, 2018). Similarly, the inclusion of music-based practical activities in higher education programmes of computer science has been shown to have potential as a means of engaging learners effectively in creative, culturally-embedded and social programming tasks (Bhattacharya et al, 2019). One interesting area of future work will thus be to explore this potential application to adult learners.

Future work with schools will be planned over a longer timescale (e.g., four to five sessions), with stronger emphasis on things like message passing and abstraction (e.g. students physically passing messages around to actuate instruments) to strengthen understanding. Longer timescales will also permit the use of formalized assessment frameworks e.g., the computational thinking assessment tools of Tsai et al. (2021). In addition, the breadth of topics tackled can then be increased, e.g., aspects of coding can be introduced to provide additional creative opportunities for shaping sounds in combination with physical controllers, allowing Brennan and Resnick's (2012) computational concepts to incorporated in addition. Other curriculum areas such as art, design, and science could also be explored.

In summary, this has been a very successful pilot study, providing direct benefit to the students concerned, evidencing the potential of the approach, offering lessons to be learned for the future, and giving a strong foundation for development.

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