
Proceedings Paper:
Buxton, A., Kay, L. and Nutbrown, B. (2022) Developing a makerspace learning and assessment framework. In: Proceedings of 6th FabLearn Europe / MakeEd conference 2022. FabLearn Europe / MakeEd 2022, 30-31 May 2022, Copenhagen, Denmark. ACM Digital Library , pp. 1-7. ISBN 9781450396332

https://doi.org/10.1145/3535227.3535232

Developing a Makerspace Learning and Assessment Framework

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ABSTRACT

The makerspace movement is an effective approach to STEM/STEAM education. As well as equipping children with knowledge and skills in areas such as electronics, digital fabrication, and crafts, it is also key to supporting other important habits of mind such as creativity, critical thinking and collaboration. Assessing such habits of mind is not straightforward but can be helpful in seeing the value of makerspaces in formal and non-formal educational settings. This paper presents the development of a tool, the 'Makerspace Learning Assessment Framework' that discerns the characteristics of effective learning present when children (aged 3-10) engage in making through an after-school makerspace in the north of England.

CCS CONCEPTS

• **Applied computing** → Education; Arts and humanities.

KEYWORDS

Makerspaces, Maker education, Primary, Assessment, STEM, STEAM, Creativity

ACM Reference Format:
Alison Buxton, Louise Kay, and Beth Nutbrown. 2022. Developing a Makerspace Learning and Assessment Framework. In *6th FabLearn Europe / MakeEd Conference 2022 (FabLearn Europe / MakeEd 2022), May 30, 31, 2022, Copenhagen, Denmark.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3535227.3535232

1 INTRODUCTION

Makerspaces aimed at children are now seen within a range of contexts including informal learning spaces such as museums, libraries and holiday or after-school clubs, and also within the context of more formal classroom makerspaces. As well as equipping children with knowledge and skills in areas such as electronics, digital fabrication, and crafts, makerspaces are also key to supporting other important habits of mind such as creativity, critical thinking and collaboration. While the research literature on makerspaces in education is growing, there is relatively little work relating to assessment in makerspaces with children [1, 2]. Makerspaces set in informal learning environments may not always require participants to attain a certain standard of learning, however schools and other learning environments providing time and funding for makerspaces are likely to be interested in measuring their educational value [3]. To address this we developed a tool, the Makerspace Learning Assessment Framework (MLAF), based on specific Characteristics of Effective Learning (CoEL).

In this paper we provide an account of the development of this assessment tool in collaboration with an after-school makerspace project held in a community centre in a city in the north of England. The following research question will be addressed: How can children's STEM/ STEAM learning be assessed using the Makerspace Learning Assessment Framework (as demonstrated by evidence of the Characteristics of Effective Learning (CoEL))?

The project builds on findings from the MakEY project (funded by the EU H2020 Research and Innovation Staff Exchange (RISE) programme) which ran from 2017-2019 and explored the place of the rising 'maker' culture in the development of children's digital literacy and creative design skills. The after-school makerspace sessions were held once a week and families from the local community were invited to attend. The project took place pre-pandemic in 2019 and was run over the course of twelve weeks. Participating children (aged 3 - 10 years old) were observed undertaking maker activities using the MLAF. In doing so, we were able to record and analyse the ways children displayed CoEL during these activities.

The makerspace phenomenon is gaining momentum on a global level and this work contributes to the movement through the development of an assessment tool that can be used to observe children's learning in a way that aligns with the makerspace philosophy of 'process not product'. The MLAF has subsequently been used in later makerspace projects in early years settings (birth to 5) and primary schools (4 - 11) enabling teachers to document children's learning as well as informing teaching and learning in other areas of the curriculum [4].

2 ASSESSMENT IN MAKERSPACES

Makerspaces focus on creativity, exploration and innovation in collaborative spaces that encourage discovery and problem-based learning [5]. This is in contrast to the 'delivered curriculum' and the attainment of defined learning outcomes through standardised assessments. Kohn (2000) [6] argues that a similar assessment approach would run the risk of squeezing the joy out of learning in a makerspace. Furthermore, many practitioners lack the breadth and depth of makerspace pedagogical knowledge to develop appropriate and meaningful assessment tools. Where assessment tools do exist, they can be difficult to use in a makerspace setting. A recent pilot study by Troxler et al. [7] highlights the demands of teachers who are trying to deliver a makerspace session as well as observing and taking notes. In the same study, where children assessed their own learning, it was reported that a lack of time, and observations being a 'mood killer', were among the reasons for

FabLearn Europe / MakeEd 2022, May 30, 31, 2022, Copenhagen, Denmark

ACM ISBN 978-1-4503-9633-2/22/05…$15.00
https://doi.org/10.1145/3535227.3535232

children not participating in this form of self-assessment. Lock et al. [8] assert that 'Teachers need to be confident and competent in using authentic assessment practices to inform student learning-through-making in fostering the development of transferable skills'. Despite these challenges, we suggest that teacher-led assessment in makerspaces is valuable, given that it is important 'to capture the kinds of knowledge and skills children develop in order to recognise their accomplishments' [4].

3 THE DEVELOPMENT OF THE MAKERSPACE LEARNING ASSESSMENT FRAMEWORK (MLAF)

As a way of creating a workable Makerspace assessment framework it was necessary to trial and adapt various iterations to ensure the final version was workable in the context of a busy making environment. One aim of the original MakEY project was to investigate 'what differences operate when considering makerspaces that are situated in different contexts', in this instance, the after-school community project. Cohen et al. argue that the makerspace works well in these informal learning settings such as the after-school community project, but that this is 'difficult to integrate within the rigid structure of the current formal education curricula and assessment' (p.5). They warn that it is important there should not be a 'technocentric focus on tools' when considering effective learning, but one that is centred on 'the process and the product' [9].

The rationale for choosing to adapt the CoEL framework as a basis for assessment of Makerspaces is two-fold. Firstly, within an English context, teachers should already be familiar with the CoEL that underpins assessment of learning in the Early Years Foundation Stage (EYFS) [10]. Secondly, Tickell (2011) illustrates how these characteristics are 'drawn from the commitment of the Early Years Foundation Stage and describe how children learn rather than what they learn' [11]. This is in contrast to the current 'standardised assessment' culture which 'struggles to capture the creativity and artistic benefits of makerspaces' [12], and is in keeping with the process not product philosophy that underpins makerspace activities.

The starting point for the development of the MLAF (Figure 1) was work carried out by Bristol Learning City [13] which was devised to be used as an assessment tool to identify CoEL in early years practice. CoEL are included in the EYFS and describe behaviours children use in order to learn and make good progress in all areas of learning. These characteristics fall across three areas, as follows:

- Playing and Exploring: finding out and exploring; playing with what they know; being willing to 'have a go'.
- Active Learning: being involved and concentrating; keeping on trying; enjoying achieving what they set out to do.
- Creating and thinking critically: having their own ideas; making links; choosing ways to do things and finding new ways.

Question prompts that were adapted from the Bristol Learning City framework included the following:

Playing and Exploring

- Do they use their senses to explore and make sense of the world?
- Are they eager to try new ideas, or do they stay with what they are familiar with?

Active Learning

- Are there times when they are absorbed in their own learning?
- Do they show persistence – not giving up, even if it means starting again?

Creating and thinking critically

This area was split into two elements, given the significance of both for work in makerspaces. A section titled 'Critical Thinking' includes the following prompt questions:

- Do they extend and challenge their own learning?
- Do they use strategies to solve problems or challenges in their design?

A separate section was also included, labelled 'Creativity and Design'. Some of the prompt questions used are as follows:

- Do they explore the properties of materials and use their understanding of them to achieve their design goals?
- Do they use materials in creative ways?

A final section was added to the MLAF, given the importance of social interaction in learning in makerspaces ('Social learning'). This includes prompt questions such as:

- Do they listen to the ideas of others?
- Do they build on the ideas of others?

It is important to note that the prompt questions listed on the MLAF are not exhaustive and other behaviours observed by teachers may be recorded during makerspace activities. When using the MLAF as an observation schedule, statements can be highlighted as they emerge during the observation and then these are expanded upon in more detail in the observation notes. This helps to give some focus to the observations, as key characteristics are specified for the observer to look out for.

4 METHODOLOGY

The project took place over 12 weeks in an inner city community centre with a broad demographic. Families who attended were diverse both in terms of heritage (i.e., white and BAME British, Pakistani, Bangladeshi, Iranian) and socio-economic backgrounds, and included children from families who were home educating. The community project was publicised through local schools, social media and word of mouth. The sessions took place after school and children were provided with snacks and a drink when they arrived. The sessions were organised and run by a local social enterprise venture and were funded through the university. Volunteers, parents and academic staff supported the children during the sessions which took place over two hours and during this time the children were able to freely choose from a range of makerspace activities. An example of the scheme of work aims on the light and shadow theme is below (1):

The makerspaces usually attracted between twenty and thirty children with ages ranging from three to ten, and there was a balance of girls and boys participating. The room was laid out using tables, each of which had activities led by an adult linked

MAKERSPACE LEARNING ASSESSMENT FRAMEWORK

Name: Age:
Date of Observation:
Details of Activity/Context:

OBSERVING HOW A CHILD IS LEARNING

PLAYING AND EXPLORING
PE1: Do they use their senses to explore and make sense of their world?
PE2: Do they transform resources?
PE3: Do they demonstrate sustained interest in the task?
PE4: Do they demonstrate a 'can do' attitude?
PE5: Are they eager to try new ideas or do they stay with what they are familiar with?
PE6: Are they unafraid to make mistakes and work outside their comfort one?

ACTIVE LEARNING
AL1: Are there times when they are absorbed in their own learning?
AL2: Do they demonstrate a sense of purpose?
AL3: Do they show persistence – not giving up even if it means starting again?
AL4: Are they able to set their own goals?
AL5: Do they demonstrate pride in their achievements?
AL6: Do they enjoy meeting their own challenges?

CRITICAL THINKING
CT1: Do they have their own ideas and use their own initiative when planning designs?
CT2: Do they demonstrate curiosity, imagination, spontaneity and innovation?
CT3: What strategies do they use to solve problems or challenges in their designs?
CT4: Do they challenge and extend their own learning?
CT5: Do they try something different rather than follow what someone else has done?
CT6: Do they try out and repeat their ideas to see if they work?

CREATIVITY & DESIGN
CD1: Do they explore the properties of materials and use their understanding of them to achieve design goals?
CD2: Do they use materials in creative ways?
CD3: Are they confident in using a 'trial and error' approach and do they show or talk about why some things do or don't work?
CD4: Do they use their previous experience and knowledge to develop workarounds?
CD5: Do they adjust their goals based on feedback and evidence?
CD6: Can they make suggestions as to how the artefact could be improved?

SOCIAL LEARNING
SL1: Do they listen to the ideas of others?
SL2: Do they build on the idea of others?
SL3: Do they support the learning of other children?
SL4: Do they collaborate effectively with other children?
SL5: Do they seek ideas, assistance and expertise from others?
SL6: Do they give feedback on the outputs of others (including when asked to do so)?

OBSERVATION NOTES

Figure 1: Makerspace Learning Assessment Framework (MLAF)

Table 1: Examples of activity planning

Shadow boxes	The aim of the activity is for children to create shadow boxes that will develop storytelling skills and enable them to learn about simple circuits.
Torch and light shows	The aim of the activity is for children to make a torch and create a light show shadow that will help them to learn about simple circuits and light.
Playing with light	The aim of the activity is for children to play with shapes and transparent materials to create and learn about shadows and reflections on an overhead projector.

to a specific theme which changed weekly. There was supervised access to technologies such as a 3D printer and a green screen and children were also able to access independent activities such as Lego, and arts and crafts resources.

During the makerspace sessions children were observed by a university researcher. In the first few weeks these observations were done using standard field notes. It soon became clear that important information about children's learning may have been missed using this method. It was then decided to develop an assessment framework that could be used to provide more detailed insights into children's learning. The research team started to use the prompts on the Bristol Learning City framework [13] as a way of capturing children's learning in a more meaningful way. This was then adapted to form the MLAF by including questions and

prompts that linked to skills that would be specifically observed during makerspace activities (i.e., problem-solving, creativity, design, collaboration).

Over the course of the project 12 in-depth observations were carried out using fieldnotes and the MLAF observation schedule. The researcher highlighted the statements on the framework that were observed during engagement with the activities and also recorded in-depth field notes that provided further details of what the children were doing and saying. Photographs were also taken of children participating in the activities.

The field notes were coded to highlight different aspects of CoEL that were observed during the makerspace activities. In the following section, vignettes of learning in each of the five separate sections of the MLAF are presented.

5 FINDINGS

In this section we present snapshots of five of the observations to highlight how the framework was used to capture children's learning in each of the five areas of the MLAF, and how this also provided a scaffold for the observer to look for specific behaviours. The data is presented in five tables with the name of the activity, anonymised name and age of the child and a short extract of the observation. There is also a short discussion for each vignette to illustrate how the questions/ prompts on the MLAF were used to highlight what skills the child was demonstrating (linked to the shortened descriptors in the MALF).

5.1 Playing and Exploring

The observation in Extract 1 was done during an open-ended activity where the girls used different materials to create a model school.

Extract 1: Open ended play - making a 'school' (S & K - aged 10)

> S glues a piece of paper and sticks it into the box. She says "how does that look" to her friend – her friend replies "it looks nice". K asks what they are going to put in their school and she says "desks". K suggests a fire alarm and they discuss what the fire alarm is for and what happens at school when the alarm goes off. The girls get back to their task and S says "pretend its reception and Y1 and Y2"f as she cuts some cardboard. She pulls the cardboard apart and says "we could make some slime out of this" (the glue on the cardboard).She then says "science classroom, maths classroom, English classroom and art classroom – so we can do a whole school. We need a bottom". Sara says "I need sellotape – yes it's done – how do you like that?".
>
> An adult asks how the school is going and S replies "nice – it's going to have sections – English, maths, science and art – we need some tables – where are the circles? – we can make these as tables".
>
> She asks her friend "what are you making?" and she replies "a swing". The girls come back from their snack and S says let's get back to our school". Both girls absorb themselves straight away – I ask S what she is making and she says "a door". She says "I think this is going to be a school for mice – look how small this door is – yes finally!"
>
> Her friend says "get a Barbie doll" – she picks up the swing and S says "this could be for our PE room – we need some lights or our school will be in the dark". The girls have found some small dolls and S says "so we have some people. She picks up a circle and says "what is this?" – they decide it will be a fire and cut out a red balloon.

Figure 2: Photograph of open ended play - making a 'school' (S & K - aged 10)

There are numerous examples in this observation that highlight how the girls use their senses to explore and make sense of the world (i.e., discussions about fire alarms, classrooms in their primary schools, slime, a 'door for mice', school curriculum) (PE2). They use the materials to represent different aspects of their school environment and the dolls add an extra 'human' dimension to their creation (PE3). Throughout the activity they present a 'can do' attitude through the language they use ("yes finally!", "yes it's done - how do you like that?", "it looks nice").

5.2 Active Learning

The following vignette in Extract 2 describes an activity undertaken by H where he has chosen to make a pop-up book.

Extract 2: Making a pop-up book (H - aged 6)

> H chooses some card and folds it in half. He asks 'what do we do next?' I explain to H what he needs to do and help him to draw the character he has chosen – he says 'and then cut!' I ask H if he wants help to draw his character and he says yes. He then takes the scissors and carefully cuts out the frog. He struggles to cut out the fingers and says 'miss it's hard to cut!' – he is completely absorbed in the task. He finishes and says 'yeah!' – he looks at the card and says 'what's that?' – I tell him it is the tongue and he says 'I want to do a tongue' – I ask him what he needs and he says 'red card'. He goes and selects some red card and draws a tongue shape the correct size for his card and cuts it out carefully. He says 'when you open it it is going to pop up .. I need a glue stick'. We discuss

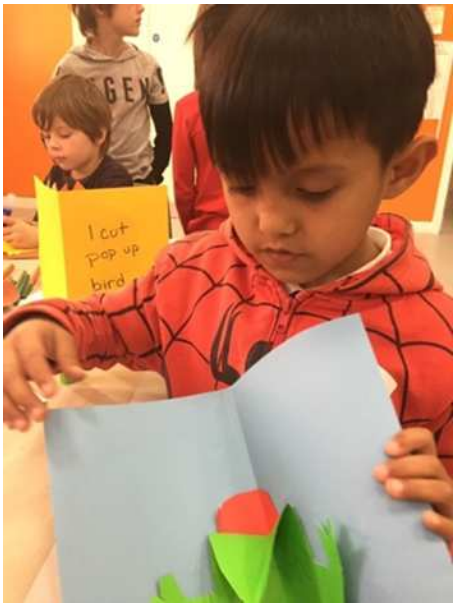

Figure 3: Photograph of boy with his pop-up book (H - aged 6)

> where the tongue will go in the card. H sticks his tongue in the right place and I help him fold the frog. He tries the card but it doesn't work very well – I ask him what he notices about the card and he says 'it's not stuck all the way down' .. he takes the glue and reapplies, sticking the frog firmly into the card.

During this observation the researcher highlights how H was 'absorbed in his own learning' (AL1) and despite finding the card difficult to cut persisted with the activity (AL3). Again, at the end of the observation H struggles to stick the tongue on the card but tries again and is successful. His declaration of 'yeah!' when he finishes demonstrates pride in his achievement (AL5).

5.3 Creativity and Design

Extract 3 shows a short extract that highlights aspects of creativity and design in the children's making activities. In this observation B demonstrates how he uses the materials in a creative way to make his "house" (i.e., the use of the lolly sticks as "floorboards") (CD2).

Extract 3: Junk modelling (B - aged 8)

> B takes a big box and covers the inside with glue. He uses the scissors to cut out bits of card from another box and places it on the glue. I ask him what he is making and he said 'a house' – I ask him what he is sticking in the bottom and he said 'the floorboards'. He says 'I think this cardboard will be enough or not enough .. I just cut some and it flew into the box and sticked .. there are small gaps' – I ask if he is going to fill all the gaps and he says 'yes'. B picks up a box and says 'it's too thick' and selects a thinner piece of card and starts to cut it. B has spent a long time doing the floorboards so I ask him what else is going in his house and he says 'I'm going to put something cosy and warm' .. Beth asks what he's going to make and he says 'furniture' .. I ask what type of furniture and he says 'chairs .. when I get home I'm going to do the chairs'.

He understands the properties of the card and how these can be used in his creation in different ways when he points out that the card is "too thick" before selecting the thinner card (CD3). B tells the researcher that he is going to make furniture for the house when he gets home and make it "cosy and warm" (CD6).

5.4 Critical Thinking

In the observation in Extract 4, A is making a 'night light'. A clearly demonstrates that she has her own ideas about the design of the lamps. She discusses the different types of lamps that she has made and her plans to make a 'night light' using the LEDs with the different colours (CT1). Her discussion is creative and imaginative illustrated by her comment about being 'hypnotised' by the glowing blue lights (CT2). In the second half of the observation we clearly see A's problem-solving skills when the batteries do not work (CT3). She challenges her own learning by applying a test-based strategy to her design (CT6) and her assertion that the lights would still shine through the sticky tape (CT4).

Extract 4: Making lamps (A - aged 6)

> A is sat making lamps out of cones and is decorating them with tape. She says 'there are all different types of lamps and they are all going to have lights in – so at night you can turn them off and on". A shows the one she has already made and says 'This is a space one .. I'm going to get some LED lights and then I'm going to put them in the lamp and then at night they can glow and it's going to be like a night light'. I ask what will happen if she covers all the holes with the tape and she says 'I'm going to do half and then it's going to glow blue and make me hypnotised'. She sticks the tape on but it doesn't reach the bottom so she takes the tape and repositions it – 'perfect – now I took a little bit out and I'm going to put the lights on the back and a battery pack for the night light – but first before I test them I need to make it – I'm going to put multi-coloured lights on that one so yellow lights where it's yellow – the more I make the more lights I can try out' .. A goes to get a battery pack and crocodile clips and carefully clips them to the end of the wire. She asks me to pull the wire out of the casing and she is happy to hear my suggestions in getting the batteries to work. I ask her what she needs now for her light and she gets a light bulb. She takes each crocodile clip and places them on each side of the bulb but it doesn't work. We change the batteries over and the bulb works this time. A places the bulb under her cone and lights it up. She says 'That's what I was planning to do – I'm going to get different coloured lights with blue lamps and red lamps – you thought because I'd covered the holes it wouldn't work but

Figure 4: Photograph of girl making a lamp (A - aged 6)

look it still shines through – it shines through the sticky tape – I'm going to test it at night'.

5.5 Social Learning

This observation highlights the potential for social learning during makerspace activities where the children work together over a substantial period of time to create a marble run.

Extract 5: Making a marble run (Group of 2 boys & 2 girls - aged 9)

> The boys are asked if they want to carry on making the marble run or swap over and make a Ferris wheel but they decide to stay on the activity. The boys test the marble run and are pleased that it works. A says "I have an idea to make it go faster – you know what – no railing – and we are going to use lolly sticks". The boys are incorporating lego into their design. A uses double sided tape and sticks 3 sticks to the tube. The adult asks A about his design and A says "It's basically this but without the decorations – we wanted to get it (the marble) to go through the balloon but we scrapped that idea". When asked why A responded "It was too hard – I couldn't do it in time". The adult asks why they have used play dough at the end and A replies "so it doesn't fall out". He is asked where the marble travels the fastest and he says "The marble goes fastest here because it's the steepest and when it goes through it loses momentum".
>
> The children then decide to attach their marble run with the one the girls have been working on. A says "First I need the tape". He shows E where to put the tape and then says "Now we need this cup to make it go higher". A holds the cups while E puts the tape on. He says "now we need to tape it over here". E points out that it won't balance but A says "just tape it". The children test the marble run again but it gets stuck and the children cannot find where it is stuck. A says "we need more height at the start" and adds another cup but the girls realise the next junction also needs a cup to make it higher as well. The children decide to remove "the trampoline" another child has made and they apologise to the child saying "we can put the trampoline at the end". One of the girls wants to put lolly sticks to attach the two tubes but the other two children do not agree. The children are trying to work out which bit needs to be made higher and A points out "But then it will be too low here". The children reach a solution and use 3 cups at the end and then 2. The girls test the marble run but it gets stuck again – they try again but it gets stuck further down this time. A comes back from getting his snack and say "I see you have made some modification". The children try the run again and one of the girls says "we'll never do this" to which A replies "we will".

In this observation (Extract 5) the children clearly listened to each other's ideas illustrated when they struggled to get the marble to move through the tubes properly and tried out different ideas to solve the problem (S1). They build on the ideas of others as they experiment with the height of the tubes (S2). The group supports each other in their endeavour (S3) but are also respectful of the work of other children (i.e., when they apologise for moving the trampoline and ensure they find somewhere else to put it). They are able to disagree with each other in a constructive way and use the discussion as a way of collaborating with the shared goal of solving the problem (S4).

6 DISCUSSION

The observations presented in this paper highlight how the MLAF is a useful tool when recording the more 'difficult-to-measure, qualitative pedagogic and leadership skills that children regularly demonstrate during makerspace activities' [4]. Makerspaces are not simply a space, filled with tools and technology, in which making takes place. They are recognised for promoting habits of mind such as creativity, critical thinking and problem solving through hands-on making using both physical and digital applications [14]. Makerspaces offer the opportunity to tinker, explore and use tools, engage in design thinking, build, test, and present designs to others through open ended experimentation, design and play [15]. As such it is important that a correct approach is applied to assess the learning that occurs in these spaces so the essence of motivation and engagement is maintained [12].

In line with the ethos of makerspaces the outcomes that occur through this pedagogical approach to learning may be self-directed, driven by an intrinsic motivation which does not comfortably align with standardised assessment practices. Therefore, it is important to consider not just the outcomes but the narrative behind the processes that the children have worked through to reach their goal, or end point. The qualitative nature of the MLAF allows makerspace leaders to highlight the given prompts and then record the narrative that captures the richness of the children's learning. Furthermore, the range of skills such as a practical and technical knowledge of the resources on offer, and the 'soft skills' or mindsets such as collaboration, problem-solving and critical thinking also

needs to be addressed. The observations using the MLAF in this paper highlights the range of skills displayed by children including teamwork, creativity, problem finding and solving and iteration.

Further to the potential for the MLAF to identify these difficult-to-measure skills, the framework can also be used to support ongoing professional development for teachers. Many primary school teachers are not familiar or confident with STEM education and therefore many children within their schooling are missing out on the opportunity to develop an affinity with STEM learning [16]. Whilst work is being done to develop teachers' knowledge and understanding when working with STEM subjects through makerspaces [17–19], the MLAF provides further support by highlighting what behaviours teachers should be looking for during their observations of children's learning.

7 CONCLUSION

This project has demonstrated that, for the children in this community project, engaging in STEM/ STEAM activities in a makerspace context can enhance their learning. The limitations of the study mean that such findings cannot be extrapolated to all children, as this was not an experimental study.

The findings from the project have led to the identification of a number of recommendations to enhance future educational policy and practice. Makerspace leaders who are carrying out makerspaces in their settings have a way of capturing children's learning but in a way that does not take all the joy out of the activity. This allows teachers/leaders to evidence in a more holistic and creative way, and exemplify ways in which children use different skills during makerspace activities.

The project also has implications for future research. There is a need to identify the extent to which the greater evidence of the CoEL that was observed in this project can be sustained over time. It will also be important to track the individual differences in children's responses to the use of makerspaces in greater detail, in order to identify those factors which are particularly significant in sustaining children's interest. If children are to become oriented to STEM subjects during their primary education, then it will be necessary to offer them the most appropriate approaches for this to take place. Makerspaces demonstrate much potential in this regard, and there is a need to explore this further in the years ahead.

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