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Student motivation and engagement in maker activities under the lens of the Activity Theory: a case study in a primary school

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Abstract
Makerspaces are an area that is of increasing interest in education. While studies exist about makerspaces in tertiary education, not many studies have explored makerspaces in primary and secondary education. The current study focuses on pupils' motivation and engagement in makerspace activities—digital fabrication and physical computing—in the context of a primary school, using the Activity Theory as its theoretical framework. The study follows an explanatory sequential mixed methods design. Primary school pupils participated in a six-week design-based makerspace programme in a Fablab and a school computer lab, and they completed a survey and participated in focus group discussions afterwards. Both quantitative and qualitative findings showed that pupils perceive maker activities as being motivating (in terms of perceived ease of use, perceived usefulness, interest/enjoyment, satisfaction) and engaging (in terms of behavioural, cognitive, emotional, and social engagement). The Activity Theory provides further insights on how motivation and engagement in makerspaces relate to the components of the activity system. The study advocates for the use of maker activities in the primary classroom. Implications on educational practices and future research are discussed.

Keywords Makerspaces · Making · Engagement · Digital fabrication · Physical computing · Motivation · Activity Theory

Introduction

The maker movement is a relatively new global movement in education, suggesting that "making activities", i.e. problem solving, and physical or digital fabrication can lead to effective learning (Halverson & Sheridan, 2014). Maker movement is

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built on the theory of constructionism (Piaget, 1950) where people construct their own knowledge through social interactions by making things. Making activities can take place in environments usually referred to as makerspaces or Fabrication Laboratories (FabLabs). In makerspaces, *bildung* (deep and sustained learning) is achieved through active participation in designing, constructing, and modifying physical or digital products. Research shows that there has been a wide variety of maker platforms and technologies employed in makerspaces (from e-textiles to electronics) in a wide range of subject areas, with different methodologies, reporting diverse learning outcomes (Lin et al., 2020; Papavlasopoulou et al., 2019).

The current study focuses in particular on digital fabrication and physical computing. Digital fabrication in Fablabs usually involves 3D printers, laser cutters, and numerical control (CNC) machines. Physical computing involves programming microcontrollers and other hardware devices with sensors and actuators that can sense and act in the real world. Popular physical computing educational platforms are the single board computers such as Arduino, Scratch Pico Board, Raspberry Pi, and the BBC Micro:bit. While there is a considerable number of makerspace studies that focus on the use of technologies in makerspaces and on student learning outcomes, literature reviews (Lin et al., 2020; Mersand, 2021) revealed that not many studies exist that focus on how students engage in makerspaces. With few exceptions (Giannakos & Jaccheri, 2018), few studies exist that investigate what motivates students to engage in maker activities. Moreover, studies on maker activities in Fablabs in the context of primary school classrooms are rather limited. Our study aims to shed more light on the nature of student engagement and its contributing factors in the context of makerspaces in primary school settings.

Therefore, the current study aims to answer the following research questions:

RQ1: How primary school pupils perceive their motivation in terms of usefulness, ease of use, interest, and satisfaction while participating in maker activities?

RQ2 How primary school pupils perceive their engagement while participating in maker activities?

Background

Makerspaces: digital fabrication and physical computing

Makerspaces and making activities are growing in popularity worldwide with universities, schools, museums, libraries, and community centres to organise making events and programmes in both formal and informal education settings. Making activities range from assembling various products by using low-cost materials (including electronics) to creating various prototypes by utilising advanced technologies such as 3D printing and laser cutting. They span across a wide range of disciplines where people collaborate to solve problems, create knowledge, and fabricate physical or digital products (Martinez & Stager, 2019), supporting a variety of learning outcomes (Kumar et al., 2019). The greatest interest is around science, technology, engineering, and math (STEM) subjects (Mersand, 2021), with the makerspace movement to be an effective approach to STEM education (Buxton et al., 2022). People learn by doing and they become creators instead of being passive consumers of knowledge (Fleming, 2015). Researchers agree that makerspaces, in general, promote knowledge and skills acquisition, students' agency, collaboration, critical thinking creativity, and innovation (Bergner et al., 2019; Bevan, 2017; Katterfeldt et al., 2015; Papavlasopoulou et al., 2019). Digital fabrication and physical computing are two main instances of makerspace activities. Digital fabrication can transform abstract thinking to concrete actions introducing students to design thinking that can lead to creative processes through cycles of iterations and reflection (Smith et al., 2015; Turakhia, et al., 2022). Physical computing interfaces can incorporate a wide range of sensing and control systems and, therefore, introduce programming concepts in a more meaningful way (Przybylla & Romeike, 2014). They also offer opportunities for collaboration (Horn et al., 2012) and creativity (Videnovik et al., 2018). While physical maker activities have a wide range of positive outcomes (Brady, et al., 2017), recent literature reviews (Lin et al, 2020; Mersand, 2021; Papavlasopoulou et al., 2017) suggest that the motivational factors that affect student participation in maker activities and the nature of engagement are two important aspects that need to be further explored.

Motivation factors in makerspaces

Learning motivation is an inherent aspect of the learning process (Boekaerts, 2016). Academic literature reports various factors that can motivate students towards learning. This study considers four of the most influential variables i.e. interest/enjoyment, satisfaction, perceived ease of use, and perceive usefulness (Giannakos et al., 2018). Students are motivated to participate in a learning task when they consider it as interesting and enjoyable (Pintrich et al., 1993); enjoyment and satisfaction are among the most prominent motivational drivers (Vorderer et al, 2004). Enjoyment positively affects students' intentions to participate in a learning activity or to use a technology (Nikou & Economides, 2018) and satisfaction positively influences students' attitudes and intention to participate and engage (Nikou et al., 2020, 2021). Based on the Self-Determination Theory (Deci & Ryan, 2002), both constructs are associated with intrinsic motivation, the type of motivation that is triggered by the inherent satisfaction and enjoyment associated with an activity, rather than an external reward or punishment. Intrinsic motivation (conceptualised as perceived enjoyment) is also an important factor in technology acceptance models. Davis (1989) argued that motivation is a significant factor in affecting users' acceptance of technologies. Two other important factors are perceived usefulness (the degree to which a person believes that using a technological system will enhance their job performance) and perceived ease of use (the degree to which a person believes that using the system would be free of effort) (Davis, 1989). The variables of perceived usefulness, perceived ease of use, interest/enjoyment, and satisfaction are major constructs in the line of research that combines technology acceptance and motivation (Nikou & Economides, 2017; Lee et al., 2015) and have been used in empirical studies on making activities (Nikou et al., 2020, 2021; Giannakos et al., 2018). In this light, we have used these constructs to explore primary students' motivation in the context of makerspaces.

Engagement in makerspaces

While motivation is an inherent aspect of the learning process, engagement is considered as a consequence of motivation (Boekaerts, 2016). The link between motivation and engagement is well documented in related literature (Kim et al., 2015). Engagement in learning is defined as the extent to which a student is involved in a learning activity. Researchers distinguish four types of engagement: behavioural, emotional cognitive, and social engagement (Fredricks et al., 2004). Behavioural engagement incorporates student's participation and active involvement in learning tasks. Emotional engagement refers to positive or negative students' feelings during the learning task. Cognitive engagement refers to students' willingness and effort to comprehend ideas and master skills. Social engagement refers to the social interactions with peers. Engagement is important because it is usually associated with academic outcomes (Fredicks et al., 2004). There are a considerable number of studies that have advanced our understanding of engagement (Boekarts, 2016). However, the majority of them usually considers individual engagement dimensions and their correlation with single outcomes (Mersand, 2021). Moreover, only few studies exist that explore learning engagement as a multidimensional construct in makerspaces (Nikou et al., 2020).

Makerspaces and the activity theory

We consider the aforementioned constructs of motivation and engagement in the context of the Cultural Historical Activity theory (Engeström, 1999). The Cultural Historical Activity Theory (Engeström, 1987, 1999, 2001), originated from the sociocultural theory (Vygotsky, 1978) where knowledge is constructed through social interactions, further explains how learners can moodily their own understanding and develop knowledge by engaging in transformative activities and interacting with their environment. The Activity Theory describes an activity system as a triangle where the sides represent the Subject, Object, and the Community while the corners represent the mediation artefacts to those relationships (Mediating Artefacts or Tools, Rules, and Division of Labour). *Subjects* are the participants (i.e. students) involved in the maker activities. *Objects* or *Objectives* are the physical products (i.e. 3D-printed and laser-cut structures), or the purpose of the activity (i.e. a BBC micro:bit project) or the learning experience itself. *Mediating Artefacts* are the tools available to students to use (i.e. computers loaded with the appropriate software and peripherals such sensors, displays, buttons, and 3D-printing or laser-cutting facilities) in order to produce the Object(ives). *Rules* refer to the norms and conditions and *Division of Labour* refers to the roles of the participants in the activity. *Community* depicts the interactions among the participants. *Outcomes* are the results of the whole process of making the objects; they can be cognitive (i.e. designing, programming), affective (i.e. learning satisfaction and enjoyment) and psychomotor (i.e. digital fabrication skills). All components of the Activity Theory framework are represented in Fig. 1.

Activity Theory has been used as analytical framework in various empirical studies on human–computer interaction (Kuutti, 1996) and educational technologies such as mobile-assisted collaborative learning (Chung et al., 2019; Liaw et al., 2010; Zurita & Nussbaum, 2007), game-based learning (Plass et al., 2015), serious games (Carvalho, et al., 2015), virtual learning environments (Hanna & Richards, 2012), and on the use of tablet computers (Al-Huneini et al., 2020). Activity Theory provides also a framework to study how learning happens in makerspaces: Subjects collaborate in makerspaces to produce Objects by using Tools in a Community with Rules and Division of Labour. However, only few studies have used the Activity Theory to study makerspaces. In the makerspace context, Walan (2021) proposed a series of maker activities based on the Activity Theory to stimulate interest in STEM and development of twenty-first century skills. Mersand (2021) used the Activity Theory as a framework to analyse academic research on making, makerspaces, and Fablabs. To the best of our knowledge, our study is one of the first that employs the Activity Theory as an organisational framework to analyse motivation and engagement of primary school students in maker activities.

Methodology

The study follows a two-phase design. Phase 1 establishes (by quantitative measurements) the impact of makerspaces on several literature-based utilitarian (e.g. perceived usefulness and ease of use) and hedonic constructs (e.g. interest/enjoyment and satisfaction). Afterwards, phase 2 explores and further interprets the impact of makerspaces on these established constructs through a qualitative approach (the main study approach) and under the lens of the Activity Theory.

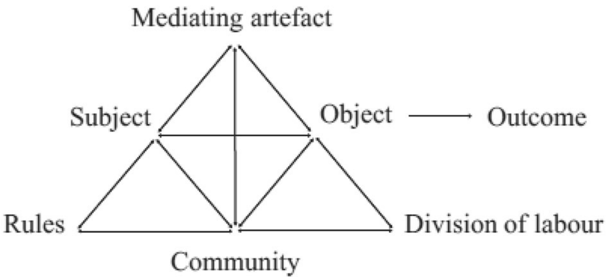

Fig. 1 The Activity Theory model (based on Engeström, 1987)

Participants

The study used convenience sampling; participants were fifteen students (eight boys and seven girls ten to eleven years old) from the sixth and seventh grade of a public primary school in a semi-urban area in country X. Students participated in the programme as part of their regular school curriculum. Participation in the study was voluntary; participating students and their parents/carers were informed in advance, written consent forms that gave permission for data collection were obtained, and the study granted ethics approval from the University Ethics Committee.

Programme design and procedures

The makerspace programme is part of the Vertically Integrated Project for Sustainable Development (VIP4SD) within the University of X. The VIP4SD projects are an innovative approach that embeds research-based education for sustainable development in curricula. The makerspace programme within the VIP4SD project aims to engage primary pupils in digital fabrication and physical computing activities further developing their knowledge and skills in STEM. The programme draws on a design-based learning pedagogical approach where learning is a process of design, exploration, evaluation, and redesign (Anderson & Shattuck, 2012). Design-based learning has been used successfully in similar activities (Gómez Puente et al., 2013). Students were presented a real-world problem, they discussed their ideas, developed their solutions and prototypes based on existing design concepts and technologies and also evaluated, refined their solutions and reflected upon them (Amiel & Reeves, 2008; Turakhia, et al., 2022).

The study implemented a series of six makerspace workshops in six consecutive weeks (Fig. 2). There was one workshop per week, and the duration of each workshop was three hours. The workshops delivered by a university teaching fellow in Digital Design and Manufacturing and a primary class teacher with the support of two 4th-year undergraduate students at the School of Education. During the first three-week period, students were engaged in digital design, laser-cutting, and

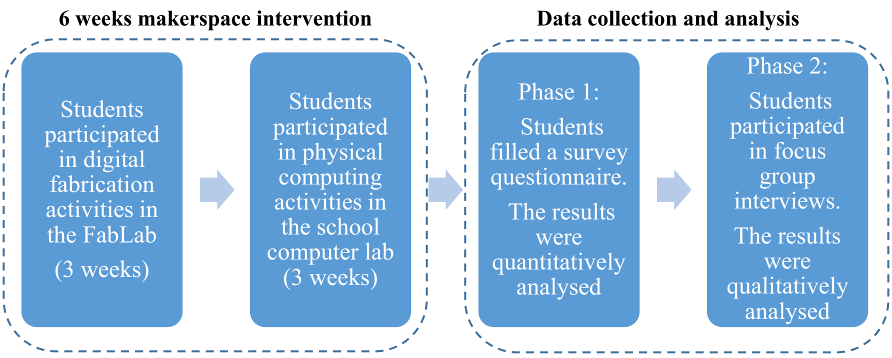

Fig. 2 The experimental procedure

3D-printing activities at the University Fabrication Laboratory (FabLab). Students were firstly introduced to basic computer-aided design principles and then, in groups of two, they used a 3D modelling online software (Tinkercad) to design their artefacts, e.g. keychains and various decorations. Tinkercad is a free online 3D modelling programme running in a web browser and allowing for 3D design, electronics, and coding. Finally, they had their objects and structures laser-cut 3d printed, with the help of the FabLab personnel. During the second three-week period, students were engaged in physical computing activities in their school computer lab. Students were introduced to basic coding skills and, in groups of three, they used a small physical computing device (BBC micro:bit) to code their programmes, e.g. to build a light sensing device, or to explore technology as a solution to save newly-hatched sea turtles to find their way to the sea. BBC micro:bit is a pocket-size single board computer with built-in individually programmable LEDs, programmable buttons, light, temperature, and motion sensors, with a couple of web-based interfaces (e.g. Microsoft MakeCode).

Data collection and analysis

Following the aforementioned makerspace intervention, our study follows a two-phase data collection and analysis process (Fig. 2). For the first phase, data were collected through a survey questionnaire. The survey questionnaire was delivered after the last makerspace intervention. In order to address our research questions, quantitative data were obtained by a literature review-based survey aiming to gather student feedback on their perceived usefulness, perceived ease of use, interest/enjoyment, satisfaction, and engagement while participating in the maker activities. Questionnaire items were based on previously validated instruments. The perceived ease of use and perceived usefulness items were obtained from Davis (1989) on technology acceptance. For satisfaction, we adopted items from Lin et al. (2005). For the Interest/Enjoyment we adopted the interest/enjoyment subscale from the Intrinsic Motivation Inventory (McAuley et al, 1987; Ryan & Deci, 2000). For student engagement, we used the engagement questionnaire developed by Wang et al. (2016) that evaluates student engagement in learning activities in terms of their behavioural, emotional, cognitive, and social engagement. The questionnaire consisted of closed-ended questions where items were measured on a pictorial five-point Likert-type scale with responses ranging from “strongly disagree” to “strongly agree” using smiley faces to capture children’s attitudes adopted from Hall et al. (2016). Students took the survey during the last week of the programme. Cronbach’s alpha tests were applied to examine the reliability of the instruments with the results to show acceptable (> 0.70) levels of internal consistency (behavioural 0.73, cognitive 0.88, emotional 0.84, social 0.86, perceived ease of use 0.81, perceived usefulness 0.74, interest/enjoyment 0.85, satisfaction 0.89). For an external validation of the scale properties, we compared the findings with measurements from similar studies (Nikou & Economides, 2018; Giannakos & Jacherri, 2018).

For the second phase, data were collected through focus group interviews conducted by the researcher and the teaching fellow who delivered the course. The interviews were conducted immediately after students completed the questionnaire. There were two 30-min focus group interviews of seven and eight students each. All fifteen students participated in the discussions in order to capture the experience of the whole class. The point of saturation has been reached towards the end of the second focus group. Interview questions were developed with the consultation with two experts in educational technologies. Questions were aiming to probe aspects of students experience during the maker activities. During the focus groups, students were asked to discuss and further explore their makerspace experience regarding the factors established in the first phase, i.e. perceived usefulness, perceived ease of use, enjoyment, satisfaction, and engagement. Students' responses were audio recorded and transcribed.

Qualitative data from the second phase were analysed using thematic analysis (Braun & Clarke, 2006) following a deductive approach using a pre-determined coding scheme rather allowing the themes to be determined by the data (Saldaña, 2015) and aiming to further analyse the experience of the children engaged in makerspaces in terms of motivation and engagement shedding more light in the quantitative results. Figure 2 summarises the experimental process.

Results and discussions

Phase 1

The data collection and analysis comprised two phases (Fig. 2). During phase 1 students responded to the survey questions for the motivational and engagement subscales.

Table 1 presents the descriptive statistics for the motivational variables. Students *agreed* that maker activities are useful, easy, interesting, and satisfying with the mean values (in the scale 1–5) to be for perceived ease of use 3.96 (SD = 0.48), for perceived usefulness 4.25 (SD = 0.46), for interest/enjoyment 4.03 (SD = 0.47), and for satisfaction 4.20 (SD = 0.55).

Figure 3 shows the plot of the average scores of individual items for each variable. Comparison of the medians of the motivational variables did not yield any significant difference. Visual inspection of the boxplots suggests that more than 50% of the students reported perceived usefulness and satisfaction more than 4 (in a scale 1–5).

Table 1 Descriptive statistics for the motivation variables

	N	Min	Max	Mean	Std Dev
Perceived Ease of Use	15	3.25	4.50	3.96	0.48
Perceived Usefulness	15	3.75	5.00	4.25	0.46
Interest/Enjoyment	15	3.50	5.00	4.03	0.47
Satisfaction	15	3.50	5.00	4.20	0.55

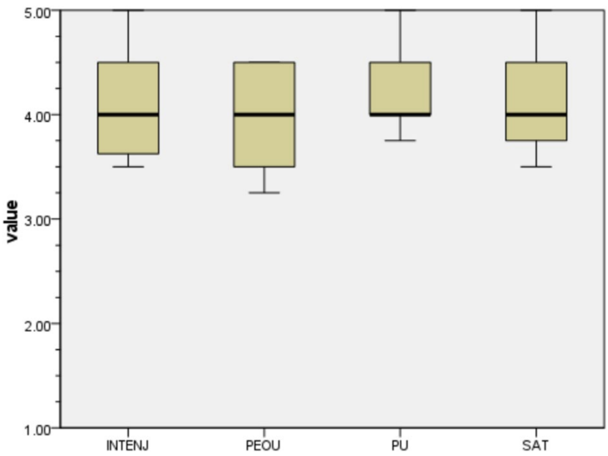

Fig. 3 Boxplot visualisation of the motivation subscales

Table 2 presents the descriptive statistics for engagement. Students *agreed* that maker activities are behaviourally, cognitively, emotionally, and socially engaging with the mean values (in the scale 1–5) to be for behavioural engagement 3.86 (SD = 0.51), for cognitive engagement 3.91 (SD = 0.46), for emotional engagement 4.08 (SD = 0.49), and for social engagement 3.96 (SD = 0.33).

Figure 4 shows the plot of the average scores from individual items for each dimension of the engagement. Outliers are depicted with empty circles. Comparison of the medians of the engagement variables did not yield any significant difference. Visual inspection of the boxplots suggests that more than 50% of the students reported behavioural, emotional, and social engagement more than 4 (in a scale 1–5).

Phase 2

During phase 2, qualitative data for motivation and engagement have been analysed using a deductive approach with a pre-determined coding scheme based on the motivational and engagement variables from the literature, framed by the Activity Theory. The deductive analysis that sought to address the pre-determined literature-based specific motivation and engagement subscales helped to maintain an alignment with the research questions (Bingham & Witkowsky, 2022). Moreover, the

Table 2 Descriptive statistics for the engagement subscales

	N	Min	Max	Mean	Std Dev
Behavioural	15	3.00	5.00	3.86	0.51
Cognitive	15	3.00	4.88	3.91	0.46
Emotional	15	3.50	5.00	4.08	0.49
Social	15	3.50	4.50	3.96	0.33

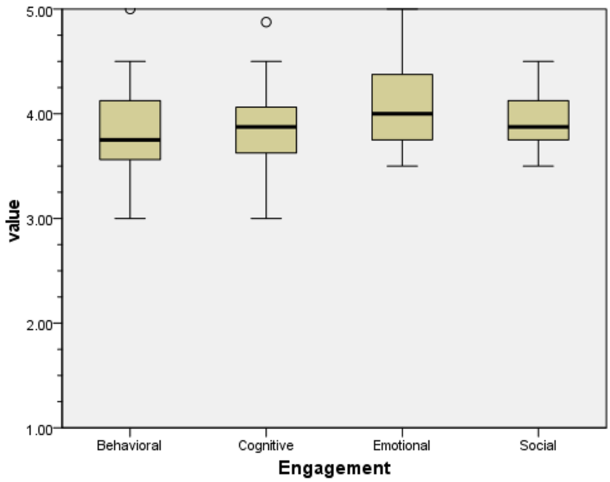

Fig. 4 Boxplot visualisation of the engagement subscales

Activity Theory perspective can offer a few more insights to be considered when designing maker activities that are aimed to be motivating and engaging.

For motivation, our predefined codes of perceived ease of use, perceived usefulness, interest/enjoyment, and satisfaction have been assigned to the qualitative data. Students agreed that the *Objects* they created were *useful* because of their relevance to their lives. A student said that the turtle project could "help baby sea turtles to find their way to the sea" and another one said that they created useful things because they could "take home the keyrings and decorations". Students found the *Mediating Artefacts,* i.e. the computer-aided design and the physical computing environments *easy to use* and *useful*. They reported their programming experience of using BBC Micro:bit as easy. A student said that it was "easy and fun to remix the blocks and watch what's being happened on the board". They also found that programming is useful because it helps solve real-life problems, i.e. "I learned programming that I can use not only in school but in my everyday life".

The *Community* interactions and the *Division of Labour* were perceived well by most of the students who reported that they *enjoyed* working collaboratively, i.e. designing and programming with their classmates. Most students said that "working together is fun". Regarding the *Outcomes*, students perceived them as *useful, satisfying and enjoyable*, i.e. a student said that they "learned interesting stuff", they actually "could take home" and use what they created (i.e. keyrings and decorations) and at the same time it was enjoyable to work in groups trying to solve problems.

Table 3 provides an overview of the motivational variables along with example quotes and the corresponding components of the Activity Theory system.

To analyse the qualitative data for engagement, we also used a deductive approach based on the pre-determined coding scheme of the engagement subscales (cognitive, behavioural, emotional, and social), framed in the components of the Activity system.

Table 3 Sample subthemes for the motivation in the maker activities

Subtheme	Example quotes	Corresponding component of the AT system
Perceived Ease of Use	"Once we introduced to design with the computer, it was easy for me to design my keyring"	Mediating Artefact
	"I was not difficult to code with the [MakerCode] blocks. You can always see what you do and if you do not like it, you can change it"	Mediating Artefact
	"I thought I could not make it, but the teacher showed us how to do it and then it was easy for me. I also could ask my classmates for help"	Community, Division of Labour
	"In my group one was reading the instructions and the other two were building the blocks, it wasn't hard to make it finally."	Community, Division of Labour
Perceived Usefulness	"I now know how useful programming can be to build tools that can do useful things for us"	Mediating Artefact
	"I not only learned cool stuff. I also made a gift for my grandfather!"	Object
	"I can create my Christmas decorations that I can take home, this is awesome"	Object
	"I felt that it was a very useful class because I learned how to make real things"	Outcome
	"I learned programming that I can use not only in school but in my everyday life"	Outcome
Satisfaction	"I am very satisfied with what I have learnt. Programming is so cool"	Outcome
	"I am very pleased with the decorations I created and proud to show them to my parents. I would like to do more."	Outcome
Enjoyment	"Yes, this class was fun. I would like to have more classes like this"	Outcome
	"I learned real interesting stuff and it was fun"	Outcome
	"I enjoyed working with my group to build the light sensor. I felt like being a scientist"	Outcome

Behavioural engagement is about involvement and participation in the activities. Students' quotes addressed the interactivity and playfulness of the designing and programming environments (*Mediating Artefacts*) as positively affecting their *behavioural engagement*, i.e. "programming was like playing" and by changing the programming blocks they could "easily see the changes".

Emotional engagement involves the feelings of happiness and enjoyment by engaging in tasks that produce useful *Objects* (i.e. "I was happy with my keyring") and *Outcomes* (i.e. "programming will be useful for me").

Cognitive engagement is conceptualised as mental effort investment in the cycle of designing, developing, and evaluating. Students were willing to comprehend and master the ideas and instructions required to perform the tasks and they were committed to complete the projects successfully (i.e. "I made a good effort to understand programming"). They enjoyed the process of design-based learning (*Rules*) aiming to produce the *Outcomes* (i.e. "it was pretty cool to think of stuff, trying to make it yourself and finally make it").

Social engagement revealed through the positive attitudes towards working together in a collaborative and cooperative way (*Community*). Students felt that working in groups was motivating and enjoyable (i.e. "it is fun when I work with my classmates") and easier (i.e. "programming is not hard when I work with my classmates". Table 4 provides an overview of the engagement subthemes along with the example quotes and the corresponding component of the Activity Theory system.

Discussions and conclusions

Maker movement is gaining growing interest in school curricula and educational policies raising key questions regarding student engagement and outcomes (Howard et al., 2014; Rosa, et al., 2017). Studies exist about maker spaces in tertiary education; however, few studies have explored makerspaces and Fablabs in the context of primary and secondary education (Ford & Minshall, 2019). Also, while most studies address the use of technologies in makerspaces and student learning outcomes, recent literature reviews (Lin et al., 2020; Mersand, 2021) highlight that not many studies focus on how students engage in makerspaces. Moreover, researchers agree that further research is needed about how making can engage students in scientific exploration (Bevan, 2017).

The current study contributes to the current debates on further exploring primary pupils' motivation and engagement in makerspaces—digital fabrication and physical computing. The study focuses on motivation (in terms of perceived usefulness, perceived ease of use, interest and satisfaction) and engagement (in terms of cognitive, emotional, behavioural and social engagement) of primary school pupils while participating in digital design, digital fabrication and physical computing activities.

The variables of perceived usefulness, perceived ease of use, interest/enjoyment and satisfaction are among the most influential drivers of motivation (Nikou & Economides, 2017; Lee et al., 2015). They have already been used in empirical studies (). Regarding engagement, this is defined in terms of the following dimensions: behavioural, emotional cognitive and social engagement (Fredricks et al., 2004).

Table 4 Sample subthemes for the engagement in the maker activities

Subtheme	Example quotes	Corresponding component of the AT system
Behavioural	"I thought programming was boring, but with the micro:bit this was like playing, I could do it myself"	Mediating Artefact
	"I could play with the [MakerCode] blocks and see the changes right after, this kept me excited to see the LEDS blinking"	Mediating Artefact
	"I listened carefully to what the teacher was saying, because I really wanted to make my keyring"	Division of Labour
Emotional	"I was happy and proud of myself when the teacher gave me my own keyring I had designed. It was perfect and, I learnt a lot"	Object
	"I think programming will be useful for me"	Outcome
Cognitive	"I made a good effort to understand programming"	Outcome
	"I think it was pretty cool to think of stuff, or anything else, trying make it yourself and finally make it"	Rules
Social	"Working alone sometimes is boring, but it was not the same when we work with my group"	Community
	"Programming is not real hard, and it is fun when I work with my classmates"	Community

Quantitative and qualitative data highlighted that pupils perceived maker activities as easy to use, useful, satisfactory, enjoyable and therefore motivating. Also, they found maker activities to be engaging in terms of behavioural, emotional cognitive and social engagement. Quantitative results on the levels of students' motivation and engagement agree with previous research (Nikou & Economides, 2018; Giannakos & Jacherri, 2018) as well as qualitative results do (Lin, et al., 2020). Specifically, the study in line with previous studies on digital design and fabrication. Giannakos and Jacherri (2018) and Bower et al. (2020) provided evidence that maker activities increase collaboration, motivation and intention to participate. Vongkulluksn et al. (2021) argued that design-based makerspaces increase students' motivation while Bevan (2017) showed that maker activities can engage students in scientific explorations. The study findings are in line with previous studies on physical computing implementations as well (Bergner et al., 2019). Tangible interactions can support active and collaborative learning (Horn et al., 2012), can stimulate creativity (Videnovik et al., 2018), have a positive impact on the coding confidence of less experienced in programming students (Barba & Chancellor, 2015), and eventually enhance student motivation and engagement (Bergner, et al., 2019; Cápay, & Klimová, 2019; Sharma et al., 2019). In-line with previous studies (Vongkulluksn & Sinatra, 2021; Zhang et. al., 2020), the study provides extra evidence for the pedagogical value of the design-based makerspaces in primary education.

The Activity Theory perspective used in our study offers a few further insights. Under the lens of the Activity Theory, during making activities, Subjects (pupils) within a Community (Fablabs), following the Rules and the Division of Labour (instructional method, i.e. design-based learning), use Mediating Artefacts (digital fabrication and physical programming) to create Objects (digital and physical artefacts) aiming at particular Outcomes (learning). Previous studies (Mersand, 2021) highlighted how each of the aforementioned components can function in a dynamic system to produce outcomes. Regarding motivation, students appreciated the *usefulness and ease of use* of the 3D-printing and programming facilities (Mediating Artefacts) to create *useful* digital and physical artefacts (Objects) having at the same time a *satisfactory and enjoyable* learning experience (Outcomes). Also, makerspaces (Community) and design-based learning (*Division of Labour and Rules*) perceived as an *easy-to-use* context. In summary, Mediating Artefacts, Division of Labour and Community can positively influence perceived ease of use. Objects and Outcomes can impact perceived usefulness, satisfaction and enjoyment. Regarding engagement, students perceived Mediating Artefacts (digital fabrication and physical programming) and Division of Labour as *behaviourally engaging*. The creation of the Objects (digital and physical artefacts) *emotionally engaged* the students while the Outcomes (learning experience) were considered both *cognitively and emotionally engaging*. Moreover, Rules (instructional method) *cognitively engaged* students and Community (makerspaces) enhanced their *social engagement.* In summary, Mediating Artefacts, Objects, Outcomes, Rules and Community can impact engagement in makerspaces.

The Activity Theory perspective can inform our understanding on how the design elements of the makerspace activities can relate to student motivation and engagement. In agreement with Giannakos and Jacherri (2018) and Kim et al.

(2015), when the components of a makerspace are perceived as easy, useful, satisfactory and enjoyable, students feel more motivated towards using it. Similarly, as Lin et al. (2020) highlighted, engagement dimensions are important factors in makerspaces.

The current study can be helpful for instructional designers and education practitioners to gain a better understanding on how to design and implement more motivational and engaging makerspace activities, from the Activity Theory perspective. Considering the high levels of student motivation and engagement in digital fabrication and physical computing, maker activities overcome the challenges associated with abstract concepts, algorithmic thinking and computer programming as well as other barriers that computing education faces today, and therefore, further support STEM education (Rogers & Siever, 2019) and twenty-first century skills (Adler-Beléndez, et al., 2021; Bocconi, et al., 2016). In particular, considering the specific context of the study, i.e. public primary school in a semi-urban area in country X, the findings can help to transform makerspace education from an informal approach to one that is integrated within in school STEM curricula (Campos & Soster, 2018; Iwata et al., 2019;).

The one-group post-test-only design with a lack of a control group is a limitation of the study; however, the follow-up qualitative analysis can compensate this. Another limitation is the small number of participants. A future study will employ a two-group design to further explore motivation and engagement under the lens of the Activity Theory. The study may also consider other hindering factors such as the lack of teacher experience in implementing maker activities, the overload due to hardware assembly arrangements or timing constraints.

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Declarations

Conflict of interest The Author states that there is no conflict of interest.

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