

Developing STEM literacy with young learners

An example of 21st century constructionist pedagogy from an Irish primary classroom

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Introduction

This paper offers an insight into the author's recent experience of using a constructionist pedagogy, Bridge 21, as part of an exploratory 21st century STEM learning experience with a small group of young learners (aged five to seven years) in an Irish primary school setting. The aim of the learning experience was to develop pupil participants' STEM Literacy, as conceptualized by Kelley and Knowles (2016). The learning experience sought to meet specific objectives derived from the Irish Primary Curriculum as well as enabling pupils to develop the 21st century skills of critical thinking, creativity and communication (Dede, 2010).

The paper begins by outlining conceptual and theoretical frameworks underpinning STEM Literacy, play-based pedagogy in STEM (Roberts, 2016) and the Bridge 21 pedagogical model (Conneely, Girvan, Lawlor & Tangney, 2015), before presenting a vignette which details the planning, teaching and assessment of the STEM learning experience which the pupils engaged in.

Following this, the author presents their critical reflections on a thematic analysis (Braun & Clarke, 2006) of qualitative data gathered during the learning experience, drawing from Brookfield's concept of critical lenses (2017) and Schön's (1987) concepts of reflection-in-action and reflection-on-action.

The paper concludes by using these reflections to derive implications for the author's own classroom practice, as well as implications for other educators who may be interested in using a 21st century constructionist approach as part of their work.

1. STEM Literacy

STEM Education describes an integrated cross-curricular approach to Science, Technology, Engineering and Mathematics, involving rich learning experiences relevant to all four areas (Kelley & Knowles, 2016). In the Irish education context, one of the goals of STEM Education is STEM literacy (DES, 2016). STEM literacy comprises the dispositions, knowledge and skills that pupils acquire and develop as

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a result of participating in STEM education (Kelley & Knowles, 2016; Liston, 2018). STEM-literate pupils are logical thinkers, problem solvers, inventors and innovators, who are technologically competent, can work with others but are also self-reliant (Huling & Speake Dwyer, 2018). An integrated approach to STEM Education enables learners to develop STEM literacy, that is, to build and apply knowledge, deepen their understanding and develop creative and critical thinking skills within authentic contexts (DES, 2016; Kelley & Knowles, 2016; Liston, 2018).

1.1. The role of Engineering in STEM

While acknowledging that STEM Education involves all four subjects, this paper aligns with the stance that Engineering can act as “the glue” that serves to integrate Science, Maths and Technology (Bagiati & Evangelou, 2015; Liston, 2018; Mooney & Laubach, 2002). In considering the Irish primary STEM context, Liston (2018) posits that the Engineering Design Process (EDP) offers a «systematic, orderly, open-ended way of approaching problems and designing solutions for those problems» (p.1). Engineering is not explicitly mentioned in the Irish Primary Science Curriculum (PSC) (DES, 1999). However, the “Design and Make” section of the PSC espouses the drawing together of each STEM elements, stating that «designing and making should be developed in association with and through visual arts, science and mathematics» (p.8). The process of designing and making in the PSC (DES, 1999) involves four phases: Explore, Plan, Make and Evaluate. Exploring involves pupils examining available materials and possible existing designs. This informs the Plan phase, where pupils create a plan for their design. The sophistication of this plan should relate to the developmental stage of the pupil. The Make phase involves pupils engaging in craft handling to bring their design to fruition. The Evaluate phase involves the pupils engaging in critical reflection on their design, which should focus on the design process as well as the product (DES, 1999).

2. Pedagogical approaches

Having conceptualized STEM literacy in the Irish primary context, discussion now moves to outline the theoretical frameworks which underpin the pedagogical approaches used as part of the learning experience reported by this paper.

2.1. The Bridge 21 Pedagogical Model

In order to develop pupils’ 21st century skills of critical thinking, creativity, collaboration, cooperation and communication (Dede, 2010), a 21st century pedagogical approach is advocated (Beetham & Sharpe, 2013). Bridge 21 is a pedagogical model which was developed for use with post-primary students to foster development of 21st century skills (Conneely et al., 2015). The Bridge 21 model involves an active learner-centred approach, which aims to enable the

acquisition of curriculum content while developing and operationalizing 21st century skills (Conneely et al., 2015). Bridge 21 is underpinned by constructionist principles of active and social learning and the creation of artefacts as part of the learning process (Conneely et al., 2015; Papert, 1993). The Bridge 21 model is characterized by a teaching approach which is facilitative rather than didactic, the use of student-led project-based learning with students in groups in order to engage with thematic cross-curricular content and the use of technology as an integral tool in the learning process (Lawlor, Conneely, Oldham, Marshall & Tangney, 2018). There are a number of commonalities between the EDP and the PSC Design and Make process and the Bridge 21 model. These are summarized in Table 1.

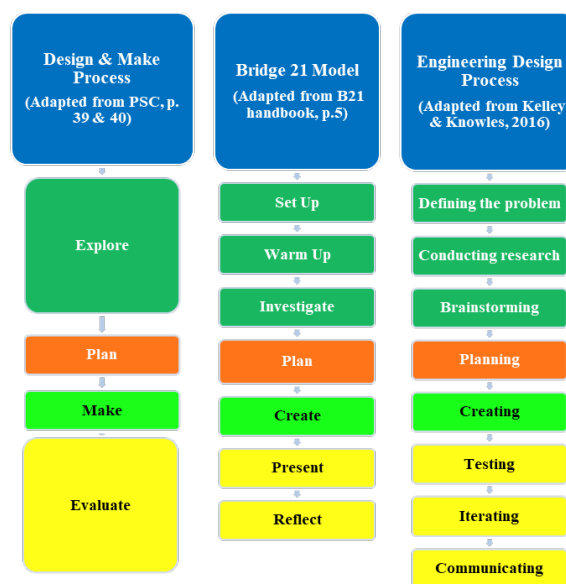


TABLE 1 - COMPARATIVE OVERVIEW OF DESIGN & MAKE PROCESS, BRIDGE 21 MODEL & ENGINEERING DESIGN PROCESS²

While empirical evidence exists in support of the impact of the Bridge 21 model on post-primary student outcomes relating to teamwork and motivation (e.g. Johnston, Conneely, Murchan & Tangney, 2015; Lawlor et al., 2018). However, relatively little research has been conducted to date as per the effectiveness of the Bridge 21 model on similar outcomes relating to young learners at primary level. Thus, for the purpose of the learning experience described in this paper, the Bridge 21 model was adapted to fit within a developmentally appropriate approach, Roberts (2016) 3-Stage Project Based Model, for the young learners taking part. This will be explained in further detail in the next section.

² Adapted from Bridge21, 2013; Kelley & Knowles, 2016; & PSC, 1999.

2.2. Playful Pedagogy

Roberts (2016) makes the important point that the innate and natural curiosity of young children may be diminished by overly structured approaches to STEM activities. Due to the age profile of the learners (five to seven years) involved in this learning experience, playful pedagogy (as described by the NCCA Aistear Framework, 2006) was used to augment the Bridge 21 model. The importance of play as a context for young children’s learning and development has been well established (Broadhead et al, 2010; Van Oers, 2010), with theory suggesting that playing is central to a child’s emotional, physical, social and cognitive development (Piaget, 1976; Vygotsky, 1980).

In the Irish primary context, the Aistear framework (NCCA, 2006) advocates a balanced use of both teacher-led and child-led play. The categories of play drawn upon by the STEM learning experience described in this paper were creative and physical play (NCCA, 2006, p. 54). Initial exploration of materials was predominantly child-led, with teacher scaffolding pupils’ use of STEM specific language. The design and make element (teacher-led) built on the pupils’ initial play experience, in line with Vygotsky’s Zone of Proximal Development (ZPD) Model (1987), and extended this knowledge by applying it to a context (building a marble run).

The design of the learning experience drew from Roberts’ (2016) suggested teaching approach for STEM activities with young learners (birth to 8 years). Her approach is based on a Reggio Emilia concept “progettazione” meaning “project based approach” (Edwards, 1994; Rinaldi, 2004), which suggests that classroom projects should be derived from children’s interests. Roberts’ approach suggests three stages (see Table 2) to projects with pupils engaging in different types of activities at each stage.

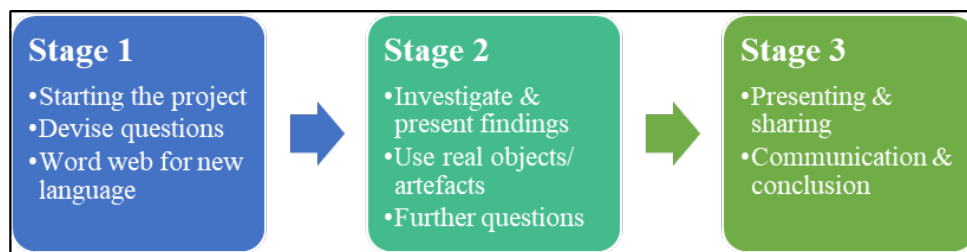


TABLE 2 - OVERVIEW OF ROBERTS’ (2016) 3 STAGE PROJECT-BASED MODEL

There are a number of similarities between Roberts’ (2016) model and those previously outlined in Figure 1. However, one notable difference is Roberts (2016) omission of a stand-alone “plan” stage, as this is incorporated into the activities of Stages One and Two. The choice of topic and use of artefacts of interest to learners and the active hands-on nature of Roberts’ (2016) approach resonates strongly with Papert’s (1987) theoretical principles of constructionism. While constructionist

approaches are often associated with the creation of digital artefacts, Papert (1991) conceptualizes constructionism more broadly, to include the designing and making of physical artefacts, for example, sandcastles and artistic sculptures. Furthermore, Papert (1991) suggests that the process of designing and making, both physical and digital, can be useful in supporting learners' construction of knowledge.

3. Components of STEM learning experiences

So far, a number of theoretical considerations have been highlighted regarding what components an appropriate STEM learning experience for young learners might involve. In order to bridge this theory with classroom practice, Jolly (2017) offers a useful practical framework which suggests a series of STEM components, to aid classroom practitioners in constructing STEM learning experiences. The framework has been adapted to create a reflective checklist, which acknowledges constructionist principles, particularly in relation to the authentic and learner-centred nature of suggested components and the foregrounding of active, hands-on and socially mediated learning processes. The checklist in Table 3 informed the design of the learning experience reported on in this paper and also supported the author's follow-up reflections on the learners' engagement with the planned activities.

| Component | Prompt questions for reflection |
|-----------------------------------|---|
| Authentic problem | Does the learning experience present a real problem (an engineering challenge)? |
| Pupil-centred | Will pupils relate to the problem? |
| Open-ended | Does the learning experience allow pupils multiple and creative approaches and solutions for successfully solving the problem? |
| Cross-Curricular | Does the learning experience integrate and apply science and maths curriculum content and skills? |
| Design & Make/ EDP | Does the learning experience: a) clearly use the engineering design process as the approach to solving problems? b) lead to the design and development of a model or prototype? |
| Hands-on learning | Does the learning use a child-centred, hands-on teaching and learning approach? |
| Technology | Is the role of technology in the lesson clear to the pupils? |
| Teamwork | Does the learning experience successfully engage pupils in purposeful teamwork? |
| Evaluation & iteration | Does the learning experience include testing the solution, evaluating the results, and redesigning to improve the outcome? |
| Communication | Does the learning experience involve students in communicating about their design and results? |

TABLE 3 - STEM LEARNING EXPERIENCE REFLECTIVE CHECKLIST³

³ Adapted from Holden, 2020; Jolly, 2017.

4. Description and organisation of the STEM learning experience

The learning experience took place over the course of six thirty-minute sessions, the sequence and content of which is summarized in Table 4.

| Project Stage | Bridge 21 Phase | Activity | Pupil learning focus |
|---------------|-----------------|--|--|
| Stage 1 | Set Up | <i>Seesaw plenary</i> | <ul style="list-style-type: none"> • Introduce new tool to pupils |
| | | <i>Tumble tracks & Wooden marble run</i> | <ul style="list-style-type: none"> • Language development • Trigger for curiosity |
| | Warm Up | <i>Free play with project materials</i> | <ul style="list-style-type: none"> • Enjoyment • Language development • Trigger for questions • Motor skills |
| Stage 2 | Investigate | <i>Structured (teacher-led) play with slopes</i> | <ul style="list-style-type: none"> • Language development • Conceptual understanding • Trigger for questions |
| | Create | <i>Structured brief presented to pupils, pupils use materials from earlier to create marble runs</i> | <ul style="list-style-type: none"> • Creativity • Critical thinking • Motor skills development • Language in context |
| Stage 3 | Present | <i>Pupils present their artefacts (marble run) & photograph/video for Seesaw</i> | <ul style="list-style-type: none"> • Communication • Language in context • Celebration of learning |
| | Reflect | <i>Pupils engage in verbal reflection using Seesaw</i> | <ul style="list-style-type: none"> • Critical thinking • Self-assessment |

TABLE 4 - SEQUENCE AND CONTENT OF STEM LEARNING EXPERIENCE

4.1. Success criteria: content & skills development

The learning experience focused on the development of pupils' conceptual understanding of gravity as well as their STEM skills. The following success criteria were used in order to assess pupil learning in each domain:

- pupils show their understanding through a combination of explanation, photographs and demonstration-by changing the slope of a ramp, they can affect the distance and direction travelled by a marble;
- pupils use a combination of media (photographs, videos and audio recordings) to communicate the findings of their investigations on slopes;
- pupils create their own unique STEM artefact/prototype of a model marble run;
- pupils upload the recorded media of their marble run and reflections on their work to their Seesaw portfolio.

4.2. Assessment of learning

Pupils’ learning was assessed using teacher observation during play, in addition to the work samples uploaded by pupils to their Seesaw portfolio. The age of the learners meant that their capacity for written communication was limited. However, the record function within the Seesaw tool allowed the pupils to verbally record and reflect on their learning throughout the project. A rubric was devised in order to assess the pupils’ uploaded work samples. An extract from this rubric is shown in Table 5.

| Standard→ | Below average | Average | Above average |
|--|---|---|--|
| Learning domain: 21st century skills | | | |
| Communication | <ul style="list-style-type: none"> • Difficulty communicating ideas about their work • Used little or no STEM language in their communication | <ul style="list-style-type: none"> • Communicated some ideas about their work • Used some new STEM language | Clearly communicated ideas about their work in variety of ways (verbal, photo & physical demonstration) |
| Critical thinking | Difficulty stating what they might do differently next time | Gave one suggestion on what they might do differently next time | Gave multiple sensible suggestions on what they would do differently next time and backed these up with evidence from their work |

TABLE 5 - RUBRIC TO ASSESS PUPILS’ DEVELOPMENT OF STEM LITERACY

Illustrative examples of pupil work, which met the criteria for the “Below average” and “Above average” standard are shown in Figure 1a and 1b.

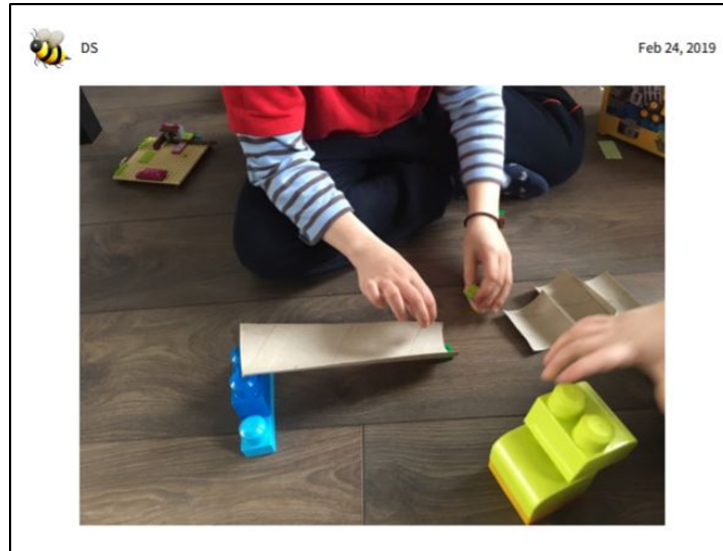


FIGURE 1A- PUPIL WORK SAMPLE WHICH MEETS “BELOW AVERAGE” CRITERIA

In Figure 1a, the pupil has used the teacher-suggested design unchanged. They have taken a picture of this, but have not added any annotation or communicated their thinking about how their model works, or how they might improve it or make it more sophisticated.

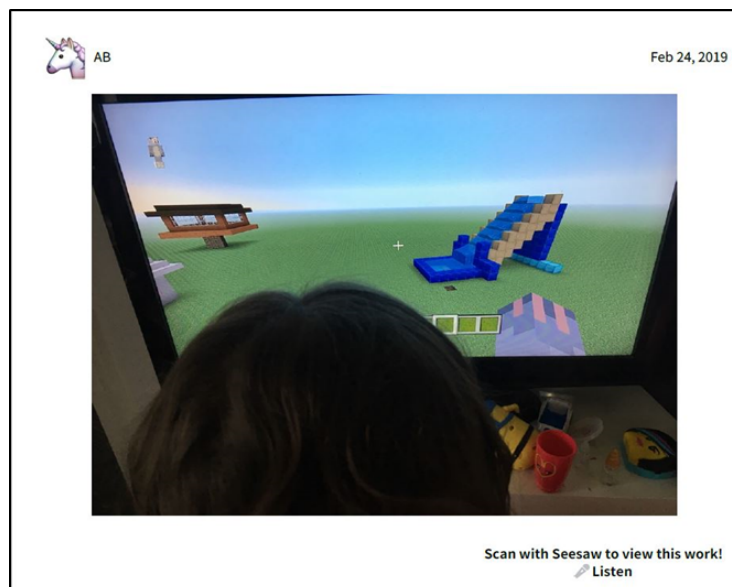


FIGURE 1B - PUPIL WORK SAMPLE WHICH MEETS “ABOVE AVERAGE” CRITERIA

In Figure 1b, the pupil has created both digital and physical models. They have communicated their work using a photograph, which they have verbally annotated

clearly and articulately. They have also added their own design features to the digital model, adding water thus turning their marble run into a water slide.

5. Discussion: critical reflection on the learning experience

During the process of planning, teaching and assessing the learning experience, I drew from Brookfield's concept of "critical lenses" (1995; 2017), with a focus on reflecting through the lenses of self, literature and my pupil participants. I also drew from the work of Schön (1987), in particular his concepts of reflection-in-action and reflection-on-action. I kept field notes during the activities and as earlier mentioned, I used Jolly's STEM Design Framework (2017) to design a reflective checklist to support my reflections on the learning experience. However, while offering an insight into how the pupils interacted with learning experience, the checklist did not depict the whole story of what rich learning took place for me during the learning experience. However, it did offer a useful starting point.

I wished to identify what learning had taken place for me in a sharper way, to allow me to refine my STEM practice going forward. Following consideration of the STEM Framework (Jolly, 2017), I conducted an inductive thematic analysis on my field notes (Braun & Clarke, 2006), which allowed me to engage in further critical reflection on my practice. I have summarized the identified themes according to three broad areas: What went well, what I found challenging and what I found surprising. This allowed me to consider suggestions as to the "why" underlying my perceptions of certain aspects of the experience, using the reflective lenses of self, literature and the participants to dig deeper (Brookfield, 2017).

5.1. What went well

Upon analysis of my field notes, I identified pupils' demonstration of curiosity, creativity and engagement as positive outcomes. Reflecting on existing literature, I noted that there may have been several reasons for this. Firstly, the activities during the learning experience were linked to pupils' interests. This was in line with constructionist principles, which highlight the importance of learning which involves meaningful artefacts (Papert, 1991). Secondly, the pupils also got the opportunity to explore the materials for themselves, rather than observing a teacher demonstration. Thirdly, it appeared to me that the pupils were given an appropriate level of challenge within their ZPD (Vygotsky, 1987). Finally, the selected activities were open-ended in nature, allowing pupils to express their creativity with no one "right" solution to the task. I also felt the children's enjoyment linked to Csikszentmihalyi's notion of "flow" (1975), where children were engaged in so-called hard fun.

5.2. What was challenging

While positive outcomes were identified during the process of critical reflection, my analysis also revealed some challenges during the learning experience. Firstly,

the difficulty I perceived in creating opportunities for teamwork amongst the pupils. When reflecting on this challenge through the lens of existing literature, I noted that the level of social maturity of the pupils may have meant that some pupils found it difficult to work with others. Some pupils showed a preference for working individually rather than working with another child to build a design. I felt this resonated with Piaget's (1964) work, which suggests that children's social development in terms of their capabilities to interact meaningfully with peers beyond parallel play at age 5 can vary. This also suggests that while socially constructed learning makes sense in theory, these principles are challenging to enact in the practical realities of a classroom. Designing inclusive experiences which aim to offer children meaningful opportunities to work and learn together requires careful planning and consideration on the part of the educator, particularly in the choice and set-up of tasks and experiences.

5.3. What was surprising

The third major theme which I identified during my thematic analysis of my field notes pertained to unexpected and unanticipated occurrences during the learning experience. The first example of unexpected occurrences pertained to pupils' creativity, in that I had not anticipated the sheer variety of marble run designs that the pupils would come up with. For example, Figure 2 shows a flat plane Lego© maze-type model designed by one of the pupils.

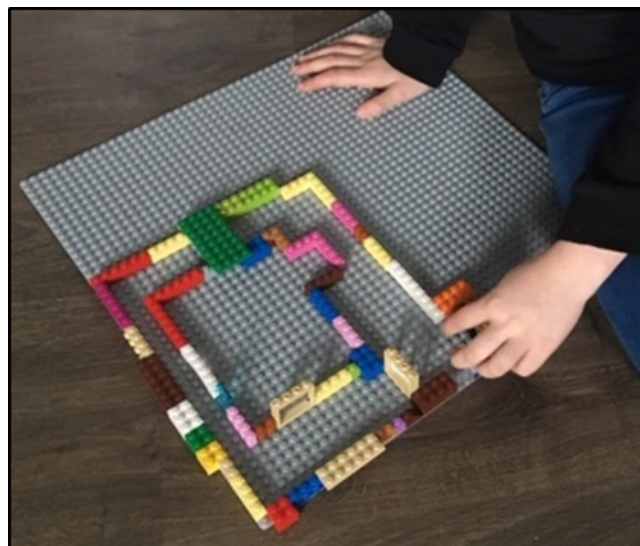


FIGURE 2 - PUPIL WORK SAMPLE (LEGO© MAZE DESIGN)

For me, this showed that my own assumptions coloured my expectations of pupils' creativity. This reminded me of the work of Roche (2007), who points out

the importance of hunting out and addressing our own assumptions when seeking to develop our practice.

The second unexpected occurrence related to my expectations in relation to the level of sophistication of pupil designs. As earlier explained, I had deliberately chosen to omit the “plan” section in my learning experience design as I was drawing from Roberts’ (2016) model. However, while engaging in what Schön (1987) describes as reflection-in-action, I felt compelled to respond to unfolding events during the course of the lesson. During the child-led free play segment of the lesson, one of the learners mentioned that the marble run reminded her of a rollercoaster they had built at home in Minecraft. In line with constructionist principles which advocate utilizing objects of interest to learners (Beisser, 2005; Papert, 1991), I felt this would be a good opportunity to build on this pupils’ interest and prior knowledge, and asked them if they would like to make a plan of their marble run in Minecraft. Their work was shown earlier in Figure 1b. I felt my interaction with and response to this pupil resonated with the work of Sarama and Clements (2009) and Bruner (1964). Both describe the learning trajectories of children, and how with teacher scaffolding, pupils can progress with communicating their conceptual understanding from concrete to pictorial representation.

5.4. Implications for practice

In terms of my future practice, this experience has highlighted the need to create more opportunities for children to learn from each other during STEM activities. Through carefully choosing engaging, inclusive and stimulating tasks which lend themselves to discussion. Furthermore, encouraging pupils to work together on a collaborative project, rather than an individually (as was the case in this learning experience) would also support development of pupils’ collaboration and teamwork skills which form an essential aspect of STEM literacy.

Engaging in the process of planning, teaching, assessing and reflecting on this learning experience has highlighted the need for me to re-examine my own assumptions and expectations around what I understand as inclusive, creative open-ended tasks. I plan to begin developing a bank of possible open-ended STEM tasks which I could draw from in designing future STEM learning experiences. In line with constructionist principles, the pupils’ engagement with this experience allowed me to see the value of using truly open-ended tasks to tap into children’s strengths and interests and using these as a springboard for deeper learning in STEM.

6. Broader implications and limitations

Based on the author’s exploratory experience as reported in the present paper, the use of the Bridge 21 model along with playful pedagogical approaches appear to be effective in developing young pupils’ STEM literacy. However, this paper acknowledges the limitation that it is based on an individual’s subjective experience

with a small group of pupils within the Irish primary school context. Therefore, further exploration of such pedagogical approaches in a variety of contexts with a large sample size would be useful in order to ascertain the effectiveness of such approaches more broadly. While the main purpose of this endeavour was to inform the author's own professional practice in STEM, the approaches described may be of interest to educators in other contexts and jurisdictions who are interested in developing learners' STEM literacy.

Conclusion

This paper presented an account and critical reflection relating to the author's recent experience of using a theory-based innovative constructionist pedagogy as part of an exploratory 21st century STEM learning experience with a small group of young learners in an Irish primary school setting. The aim of the learning experience was to develop pupil participants' STEM Literacy using a series of playful STEM-based tasks. The paper has highlighted the potential of such constructionist-founded pedagogies to build the foundations of STEM literacy, even from a young age.

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