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'Sky's the limit': a case study in fostering young children's creativity during STEM online learning experiences

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Abstract
Fostering young children's creativity is a desired outcome of STEM learning experiences. Such experiences often incorporate hands-on activities that encourage agency, curiosity, and experimentation. While educators generally have a good understanding of how to nurture creativity within a physical learning environment, less is known about creativity in an online context. Prior to the COVID-19 pandemic, little research focused on young children's online learning. During the pandemic, studies involving this age group focused upon the experiences and perceptions of emergency remote learning, rather than intentional online education strategies. This gap creates an opportunity to explore the potential of STEM online learning experiences to meaningfully engage young children in creative thinking. This article analyses key themes emerging from video and interview data obtained during a series of STEM shows and workshops delivered by Scitech to Year 1 children in regional Western Australia, framed by the *A-E of Children's Creativity Framework*. Findings illustrate how intentional online learning experiences can engage children creatively, and in turn supports a reframing of perceptions regarding the effectiveness of online delivery for young children.

Keywords Online learning · STEM · Creativity · Early childhood education

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Introduction

Quality STEM (Science, Technology, Engineering and Mathematics) learning experiences can effectively engage young children and foster their creativity (Murcia et al., 2020). Creativity has emerged as an essential twenty-first century skill, which can be nurtured through various learning experiences, including those that integrate STEM. Early years education has a significant impact on a young child's development and academic journey, and engagement in STEM can prepare them for discovering their world and exploring complex and abstract concepts (Burger, 2010; Lind, 1998; Tippett & Yanez Gonzalez, 2022; Wan et al., 2021). In this, the learning environment, including the classroom setting, pedagogical approaches and people, plays a crucial role in children's creative development (Beghetto & Kaufman, 2014; Henriksen et al., 2021; Richardson & Mishra, 2018). A comprehensive body of research describes requirements for encouraging children's creativity within physical classroom environments (Craft, 2010; Davies et al., 2013; DEEWR, 2009; Warner & Myers, 2009). However, strategies for fostering creativity online remains less explored (Maslin et al., 2023). Given the distinctive pedagogical skill set demanded by online learning, as opposed to face-to-face delivery, there is still much to learn (Sokal et al., 2020).

This study involves Year 1 children living in regional Western Australia (WA) who engaged in a series of synchronous STEM shows and workshops presented online by Scitech, a leading Science Discovery Centre located in metropolitan Perth. Specifically, the article addresses the following research question: *How do STEM online learning experiences foster young children's creativity?*

Literature review

Young children's creativity during STEM learning experiences

For over 70 years, creativity has enjoyed a research focus within education (Craft, 2005; Guilford, 1950; Hernández-Torrano & Ibrayeva, 2020) and is widely advocated as an essential twenty-first century skill (Donovan et al., 2014; Tok, 2021). Although an elusive and complex concept (Conradty & Bogner, 2018; Kupers et al., 2019), Murcia et al (2020) define creativity as "the ability to generate original ideas that are appropriate to the task at hand" (p. 1399). This definition incorporates the two core features of creativity generally agreed upon by researchers: originality (or novelty) and value (or appropriateness) (Runco & Jaeger, 2012).

The importance of creativity as a crucial twenty-first century skill is underscored by its inclusion in international education policies and guidelines (Australian Government Department of Education, 2022; UNESCO, 2015). STEM learning experiences are reported as one way in which creativity can be fostered in young learners. The STEM acronym is frequently referred to in education as the partial or full integration of the separate disciplines of Science, Technology, Engineering and Mathematics, with a focus on twenty-first century competencies (Koul & Fisher, 2005; Timms et al., 2018). Over the past decade, there has been an increased emphasis on STEM education across all levels of schooling (Education Services Australia, 2018; Office of the Chief Scientist, 2013). Importantly, young children are naturally curious, creative and collaborative, all characteristics essential for effective STEM education (Banko, 2013; Glauert & Stylianidou, 2022), and early childhood education shares similar qualities to targeted STEM experiences in its emphasis on hands-on, inquiry-based learning approaches, and collaboration (Cremin et al., 2013; Wan et al., 2021). Similarly, teachers interviewed by McLean et al. (2021) identified skills such as questioning, investigating, communicating and using inquiry-based pedagogies as approaches to foster creativity during science lessons. Research has demonstrated a positive and permanent effect of STEM education on the creative development of young children (Üret & Ceylan, 2021) and a review of empirical studies into STEM education in early childhood reports activities falling broadly into four categories: programming robots, traditional engineering design, digital games and comprehensive approaches (Wan et al., 2021). Among the non-digital activities, a consistent theme has been the implementation of hands-on experiences using a range of physical materials (Aldemir & Kermani, 2017; Malone et al., 2018; Tank et al., 2018).

Young children and online learning

The emergence of online learning within the K-12 context derives from the early 1990s (Barbour et al., 2013; Clark, 2013) and is generally understood as learning that takes place over the internet (Maor et al., 2023). Online learning experiences are planned specifically for online delivery but research into young children and online learning remains limited (Maslin et al., 2023) resulting in a lack of evidence-based pedagogical strategies for early childhood educators. Research undertaken predominately during the COVID-19 pandemic points to the potential of active participation and agency in engaging children's creative thinking (Kalogeropoulos et al., 2021; Russo, 2021; Schwartz, 2012; Soltero-González & Gillanders, 2021) and aligns with the pillars of effective online pedagogy described by Archambault et al. (2022) which include: build relationships and community; incorporate active learning; leverage learner agency; embrace mastery learning, and; personalise the learning process. This was similarly supported by Ames et al. (2021) who found sending physical resources to primary-aged distance education learners to use during online science lessons to be effective for engagement. However, studies have also highlighted young children's inability to focus when online, extensive passive screen time and a lack of responsiveness from teachers (Dong et al., 2020; Inan, 2021; Uzun et al., 2021).

In contrast to the pre-determined and intentional nature of 'online learning', the experience of 'emergency remote teaching' marked a temporary shift to remote teaching methods that would otherwise be delivered face-to-face, and return to face-to-face once the crisis or emergency has passed (Barbour et al., 2020). This is a significant distinction, given that the term ‘online learning’ was used extensively in reference to the global educational response to the COVID-19 pandemic. During this time there was an inconsistent approach to online education, including synchronous versus asynchronous delivery, different activities, lesson frequencies and duration, as well as technology platforms (Hu et al., 2021; Kim et al., 2021; Munastiwi, 2020; Sharma et al., 2022; Yan et al., 2021) resulting in a complex understanding of what it means to participate in online learning, and no standardised approach for effective delivery, especially to young children.

Theoretical framework

The theoretical framework underpinning this study is the *A-E of Children’s Creativity* (Murcia et al., 2020). Drawing upon the Four Ps of Creativity (Rhodes, 1961), the framework outlines the role of the Product, the Person, the Place and the Process. At the Product level there are two key criteria, that the creative outcome is both original and fit-for-purpose. Products could be either physical (e.g. a picture) or abstract (e.g. an idea). At the Person level, Murcia et al. (2020) identify three perspectives on the child’s role in the creative activity: the child can be engaged by the educator’s creativity; the child can be involved in creative doing by following the educator’s example; and the child can be engaged in creative thinking through the generation of their own ideas. The Place elements and Process characteristics of the framework are outlined in Fig. 1 below. The framework has previously been used as a field of reference for analysing creativity in the context of children and digital technologies (Fielding & Murcia, 2022), making it an appropriate tool of analysis for this study.

PLACE: Elements of an enabling environment

Resources	***Communication***	***Socio-Emotional Climate***
• Intentional provocations • Stimulating materials • Adequate materials for everyone • Time for creative exploration	• Intentional learning conversations • Hearing and valuing children’s ideas • Open inquiry questioning • Facilitating dialogic conversations	• Stress and pressure free environment • Non-prescriptive • Non-judgemental • Allowed to make mistakes

PROCESS: Characteristics of children’s creative thinking

Agency	***Being Curious***	***Connecting***	***Daring***	***Experimenting***
• Displaying self-determination • Finding relevance and personal meaning • Having a purpose • Acting with autonomy • Demonstrating personal choice and freedom • Choosing to adjust and be agile	• Questioning • Wondering • Imagining • Exploring • Discovering • Engaging in ‘what if’ thinking	• Making connections • Seeing patterns in ideas • Reflecting on what is and what could be • Sharing with others • Combining ideas to form something new • Seeing different points of view	• Willing to be different • Persisting when things get difficult • Learning from failure (resilience) • Tolerating uncertainty • Challenging assumptions • Putting ideas into action	• Trying out new ideas • Playing with possibilities Investigating • Tinkering and adapting ideas • Using materials differently Solving problems

Fig. 1 An adapted version of the *A-E of Children’s Creativity* framework

Methods

Research design

This study is part of a larger project within the ARC Centre of Excellence for the Digital Child. A qualitative, multiple case study approach was employed, with three children each serving as a case (Merriam, 1998).

Scitech, a leading Science Discovery Centre, located in metropolitan Perth was a key partner in this study. Their existing education outreach includes theatre shows, science incursions and STEM workshops, all typically conducted face-to-face. Their regional and remote outreach team aim to visit each town once every 3–5 years. For the purposes of this study, Scitech adapted a selection of their existing content for synchronous online delivery and used Microsoft Teams to connect with a class of Year 1–3 children located in a regional WA town 700 km from Perth. Scitech provided materials for the classroom teacher prior to the sessions, and the teacher then accessed Microsoft Teams using her laptop, which was connected to a classroom television. During the online sessions, a Scitech facilitator assumed the role of primary educator while the classroom teacher remained present with the children. She adopted a supporting role, assisting with re-directing the children's focus, organising groups and assisting with fine motor skills. During the hands-on activities, the case study children remained in the classroom under the Scitech facilitator's guidance, positioned close to the television, while the remainder of the class were relocated under the supervision of the classroom teacher. The researcher remained in the classroom with the case children.

Participants

Ethical approval to conduct the research was granted through Curtin University's Human Research Ethics Approval process and Catholic Education Western Australia's research process, and pseudonyms have been used to protect all participant identities.

The three case study children comprised of two girls and one boy: Beth, Mandy and Timothy. Initially, an introductory letter and participant information sheet was provided to the families of all children in Years 1–3 at the participating primary school, and case children were selected based upon their willingness to contribute and engage with all Scitech's activities and elements of the research data collection process. Informed consent was provided for the case children, as well as the remainder who were involved as 'incidental' participants. The Year 1 classroom teacher, Miss Bird and the Scitech Facilitator, Katie were both interviewed for this study and provided consent accordingly, and Table 1 presents an overview of each participant.

Table 1 An overview of study participants

Beth	Mandy	Timothy	Miss Bird	Katie
Beth is a female in Year 1. She is an imaginative, high-achieving child who enjoys arts and crafts	Mandy is a female in Year 1. She is a mature and articulate child, who enjoys learning	Timothy is a male in Year 1. He is a bubbly and enthusiastic child, who enjoys building things	Miss Bird is the Year 1 classroom teacher. She is in her first year of teaching	Katie is a Scitech facilitator. She has been working at Scitech for four years

Data collection and analysis

Interview data

The use of children's voices in this article is considered important for revealing previously undiscovered themes and perspectives. Each child was interviewed following their involvement in the Science shows and workshops. Short video compilations were presented to the children during their interviews to help stimulate recall and the use of the participant adult voices were included to provide additional perspectives.

In total, eight semi-structured interviews were analysed as part of this study. The interview questions focused on engagement, creativity and strategies from each of the STEM learning experiences and all interviews were audio recorded and subsequently transcribed. Initial thematic analysis was conducted using an inductive approach to identify emerging themes, followed by a deductive analysis utilising the *A-E of Children's Creativity* framework.

Video data

Each Scitech session was video recorded, and multimodal video analysis carried out (Jewitt & Mackley, 2019). Again, this process began inductively with episodes defined by the nature of the communication. Episodes where moments of creativity were observed were chosen for deeper analysis against the *A-E of Children's Creativity* framework. These episodes were also coded for the focus strategies that Katie employed while the children were creatively engaged. V-Note Pro analysis software was used to assist with the analysis. An overview of the codes is presented in Table 2.

Findings

The findings are reported in two parts. Firstly, as the context of the Scitech sessions is relevant to the findings, a comprehensive summary of the seven STEM activities is accompanied by photographs for context. Then, the experiences of participants are reported via interview data and short dialogues observed during the sessions. The second part is structured under four themes: *intersection between online delivery and physical resources; focus strategies that encouraged creativity; the intentionality of activities;* and *challenges*.

Overview of sessions

See Table 3.

Table 2 Overview of video codes

	Examples
Phase 1 codes: communication type	
Dialogic (between Katie and children)	Answering questions; sharing ideas
Children-only Communication	Sharing predictions with child next to them
No Communication to others on screen	Children working on investigations while talking to classmates
Scitech-only Communication	Katie conducting demonstrations or giving instructions
Adult-adult Communication	Katie asking Miss Bird to choose a child to answer a question
Phase 2 codes: creative moments	
Material-based > Making	Children making DIY Shakers
Material-based > Experimenting	Children experimenting with slime
Ideas-based > Predicting	Predicting what is in the cups
Ideas-based > Problem solving	Children sharing solutions to character's problem during puppet show
Phase 3 codes: focus strategies	
Show me	"Beth, can you show me how you got your cup to make a sound?"
Questioning	"What do you think is going to happen if I do XYZ?"
Task setting	"Have a think to yourself and then whisper to person next to you. You have 10 s… go!"
Responding to children's queries and comments	"You're looking for the plastic tube? It's the one next to the ruler"; "Oh yeah, that's very bendy"
Extrinsic Motivators	"You are doing a really good job"
Silence (time to focus)	Children investigating, Katie quietly watching

The intersection of online delivery and physical resources encouraged creativity

Emphasised across the interviews was the participants' enthusiasm for the online learning experiences, with each speaking of their enjoyment for the shows and workshops. Regarding the nature of the sessions and their potential for creativity, Katie reflected:

> I think given what we do, there's a lot of opportunity to foster creativity in the online environment. And there's certain activities which 100% would do a great job of that. Something like setting a task with a certain amount of materials and seeing how children solve that problem and be able to share that online would be a really great way of fostering creativity. I feel the sky's the limit when it comes to fostering creativity through online engagement and the online medium.

Table 3 Overview of sessions

Session	Summary	Materials	Duration (HH:MM)	Communication	Creative moments	Focus strategies
Science is Spectacular!	30-min chemistry demonstrations and experiments	N/A	00:30	Children-only Dialogic Scitech-only	Predicting Problem solving	Questioning Task setting
Mini volcanos See Fig. 2	Teacher-led activity where children created their own volcanos. Followed on from *Science is Spectacular!* show. Materials and instructions prepared by Scitech	Baking soda, detergent, canisters, pipettes, vinegar	00:15	Children-only Dialogic Teacher-only	Experimenting	Responding Silence Task setting
Bend, Twist, Stretch, Squash	Children investigated items to see if they can be changed by physical force. They also followed directions to make slime	*BTSS* Balloon, Cloth, Elastic band, Metal spoon, Plastic tube, Playdough, Pipe cleaner, Ruler, Sponge, Stone, Tennis ball, Wood *Slime* Coloured water (red and blue), Psyllium husk, Zip-lock bags	01:03	Adult-adult Dialogic None on screen Scitech-only	Experimenting Predicting Problem solving	Extrinsic motivator Questioning Responding Show me Silence Task setting
Sound Cups See Fig. 3	Children explored how sound travels through vibrations. They were then challenged to create a 'telephone' using cups and string	Paperclips, paper cups, String	01:00	Adult-adult Children-only Dialogic None on screen Scitech-only	Experimenting Predicting Problem solving	Extrinsic motivator Questioning Responding Silence Show me Task setting
What's in the Cup? See Fig. 4	Children participated in a scientific investigation, making predictions about the different sounds concealed within cups	Bottle tops, cups, masking tape, pasta, paperclips Pebbles, Pom-poms, Rice, Rubber bands, Sand	01:10	Adult-adult Children-only Dialogic None on screen Scitech-only	Experimenting Predicting Problem solving	Extrinsic motivator Questioning Responding Silence Task setting

Table 3 (continued)

Session	Summary	Materials	Duration (HH:MM)	Communication	Creative moments	Focus strategies
DIY shakers	Children designed and created their own musical instrument ("maker shaker") using materials provided by Scitech	Cardboard, tubes, elastic bands, paper, pasta, pens, pipe cleaners, rice	00:58	Adult-adult Dialogic None on screen Scitech-only	Making Problem solving	Extrinsic motivator Questioning Responding Silence Show me Task setting
Quiet as a Mouse Puppet Show See Fig. 5	Interactive puppet show involved children using their own DIY shakers and testing instruments to help music-loving mouse, Racket	DIY shakers, instruments from Music Room	00:30	Adult-adult Children-only Dialogic None on screen Scitech-only	Experimenting Predicting Problem solving	Questioning Silence Task setting

Fig. 2 Mini volcanos

Fig. 3 Telephone cups

Fig. 4 What's in the Cup investigation

Fig. 5 Quiet as a mouse puppet show

Participation during the shows

All three children spoke positively about the two shows. For Timothy, being able to use his own DIY shaker was the highlight of the *Quiet as a Mouse* show. Miss Bird also reflected:

> It was a lot of fun for them to be able to interact [with the show], using things they had made…I definitely could see they were loving it, getting to make a bit of noise [laughs].

Katie described how Scitech strategically designed the shows to be as interactive as possible. Speaking of *Quiet as a Mouse*:

> By asking them to describe sounds and trying to get them to find a way to communicate sounds that their DIY shaker made… It was kind of a 'show-workshoppy' kind of thing, it did lean a bit more on the workshop side than normal [theatre delivery]. The reason for that was making sure the children weren't sitting for 30 minutes staring at a screen watching me do a whole show.

Agency

Reflecting specifically on the *Mini Volcano* activity, Miss Bird explained:

> I think it added lots of value. Having their own opportunity to take what they learnt from that first *Science is Spectacular!* show, and do an experiment was great. They loved it. They were very, very engaged.

Highlighting the connection between the children's offline and online learning is the following exchange between Katie and the class the following day:

- Katie: *First, I want to know how you went with your volcano activity yesterday. Did you like that one?*
- Class: *Yes!*
- Katie: *Remember yesterday in our show we were talking about our observations and using our senses, and then using words to tell people about our discovery. So, does anyone want to share what happened with your experiment?* [hands go up] *Awesome, Miss Bird, I'll get you to choose someone for me.*
- Timothy: *It was so fun that it exploded so high!*
- Katie: *Yeah, how high did we get? Was it so high it went over your heads* [gesturing]?
- Class: *No!* [laughing]
- Timothy: *Just this high* [gestures with hands]
- Katie: *Oh sweet, so it went up and bubbled over, that is super-duper. Well, I'm glad you had that experience doing some experimenting because we are going to keep on experimenting today.*

Agency and connecting

The children were given opportunities to take ownership over their learning, by making decisions during experiments and making activities. In reflecting on her design process during the DIY shaker activity, Beth said:

> I made a bunny [out of my shaker]. The pipe cleaner gave me an idea, so I folded it around [the tube] and I kind of twisted and scrunched it and pulled to make a little bunny tail.

Focus strategies of 'questioning' and 'responding' encouraged creative thinking

Being curious

Reflecting on the strategies Katie employed to encourage the children's creative thinking, Miss Bird said:

> I think Katie asked a lot of open-ended questions, which really got the children thinking. It wasn't just a 'yes' or 'no', it was, 'well, I thought this…' I also thought Katie was very good at taking answers. Even if they weren't always exactly aligned with the question, she would kind of bring it back in. She would find a way to connect it, which was great.

An example of a class discussion Katie facilitated after the children finished experimenting with their sound cups:

- Katie: *I want to know what you thought about the noises your cup made.*
- Child 1: *It sounded like rain falling on a tin roof*
- Katie: *That's a great way to describe it. Anyone else?*
- Child 2: *It kind of sounded like something dragging on the floor*

- Katie: *Oh yeah, so something banging on the floor. Ok well, I've got a string and paperclip like we had inside of our cup, but if I rub this* [demonstrates] *I don't get the same noises. So, why can't I hear it here but I can hear it when I put the cup on top? Does anyone have any ideas why?*
- Child 3: *Because the cup is harder than the string, that's why.*
- Katie: *Pretty good theory there. What our cup is doing is actually making the noise louder* [picks up a slinky]. *I want you to try and guess what kind of sound a slinky might make. I have my big amplifier here so hopefully we can hear it. I'll give you ten seconds to make your guess.*
- [Children turn to one another and begin making their predictions].

Connecting

Miss Bird described the impact of Katie's questioning on Beth's creative thinking:

> She put her hand up a lot, which was really great… she was very engaged in the experiments and investigations, which for Beth isn't very different... But I did feel like she was thinking a bit more deeply about things, and asking those questions.

Beth herself described the elephant toothpaste eruption, "[Katie] *went to do another activity and then elephant toothpaste, like caterpillars came out.*" Mandy also made the connection that it looked like *"snot"*.

Intentionality of activities supported creative thinking

Being curious

Speaking of the *Bend, Twist, Stretch and Squash* activity, Miss Bird described how the intentional nature of the activity encouraged the children to be curious:

> I really liked that it was very hands-on and they got to explore …The children were doing things you wouldn't expect with some of the items. You wouldn't think that the tennis ball would twist, but they'd have a go anyway… [Mandy] was a bit more patient with these activities, because I feel like sometimes [in class], she's kind of like, 'I just want to do it now.' Whereas with Katie she was very engaged in whatever they were learning about.
>
> Reflecting on *Bend, Twist, Stretch and Squash*, Mandy said:
>
> I liked the playdough. And umm they put a spoon and ruler there, it was quite silly, because you can't do anything with them…I didn't know that before I started experimenting.

Challenges impacting creative opportunities

Time constraints

When asked to reflect on any limitations in the way activities supported children's creativity, Miss Bird commented:

> [*Bend, Twist, Stretch and Squash*] I wonder if they could go out and actually bend and twist other things in the classroom, not just the things they were given on the … They did have those extension questions that we could use, but I guess it's just having the time… [*Sound Cups*] When we did the telephones, we spent quite a lot of time trying to make the telephones with the children, because it wasn't easy for them to do independently…By the time we made them, we didn't have much time left to experiment. But we did say we would put them out for Investigation Time, so we still get to use them.

Resource constraints

When asked to reflect on any limitations in the way activities supported children's creativity, Katie reflected:

> I think there were slightly less creative opportunities [during workshop activities] mostly because of the resourcing—needing to send a box and not having infinite craft supplies [laughs] did limit that a little bit.

Discussion

The aim of this paper was to investigate how STEM online learning experiences can foster young children's creativity. Each participant spoke of how they enjoyed the sessions delivered online by Scitech, with the classroom teacher noting several instances of the children demonstrating creative thinking.

Of particular importance was the intersection between the online and offline learning environments, in terms of active learning and creative thinking. While the children watched and listened to Katie on the television, there were also regular opportunities to participate with their own voices and hands. This resulted in four types of creative moments: making, experimenting, predicting and problem solving. Having the agency to investigate and create on their own fostered creative outputs such as Beth's bunny-inspired DIY shaker, and the working telephone cups. During each of these activities, Katie actively watched the children through the screen, and provided verbal feedback. These examples highlight the potential of online learning to foster creative thinking, by intentionally providing opportunities for children to become active learners and aligns with effective online pedagogy as described by Archambault et al. (2022) and Ames et al. (2021), as well as incidental findings that emerged during the COVID-19 pandemic regarding positive outcomes when children were given agency (Kalogeropoulos et al., 2021; Russo, 2021). However, this study provides unique insights by specifically focusing on the intentional development of creative thinking in young children.

The structured, intentional nature of the investigative activities supported the children's creative thinking. For example, *Bend, Twist, Stretch and Squash* involved children manipulating eight items and recording their findings. There was intentionality in both the design of the activity and the way children engaged with the materials. While guided by Katie, the nature of the task provided scope for agency as each child instigated their investigation. This activity could be regarded as somewhat prescriptive, at odds with the play-based learning approach so often advocated in early years (Bubikova-Moan et al., 2019; Danniels & Pyle, 2018). However, these activities were adapted from Scitech's existing schedule of workshops, and align with an example offered to educators in the Early Years Learning Framework to "intentionally scaffold children's understandings, including description of strategies for approaching problems" (Australian Government Department of Education, 2022, p. 53) designed to help children develop learning and thinking skills such as problem solving and inquiry. Miss Bird remarked on how all three children, in different ways, demonstrated impressive levels of curiosity, exploration and deep thinking while engaged in Katie's activities. She remarked specifically on how the activities appeared to encourage children who otherwise tended to rush, to slow down and engage with each task at a deeper level. This could be attributed to the way the activities scaffolded the creative thinking process, by providing the scope of investigation and modelling how to carry out the activities before giving the children independent exploration time. This was supported by Katie's strategies for online delivery, in which she visually and verbally set the tasks, gave the children 'quiet time' to investigate at their desks and was present to respond to questions as they arose. Accordingly, it illustrates the need to consider the balance between open-ended and intentional learning opportunities and demonstrates how a combination of structured activities can support creative development.

Some strategies known to be effective in fostering creativity within a traditional classroom environment also appeared effective within the online learning environment, such as questioning. Questioning is reported as an effective technique in promoting children's creative thinking and problem-solving skills (Cremin et al., 2018; Murcia et al., 2020). Katie was observed questioning the children numerous times throughout each session, both as a class during group discussions as well as individually during the small group work activities. Miss Bird commented on the effectiveness of Katie's questioning, and the way the children responded by thinking deeply about her questions. Questioning encouraged dialogic conversations during each session, where children's voices were not only heard but their ideas valued and responded to (Sedova et al., 2019). This suggests well-established pedagogical principles and strategies could serve well in an online learning context, potentially facilitating a smoother transition for existing STEM educators aiming to foster creativity through online delivery. It should also be acknowledged that the synchronous nature of the Microsoft Teams sessions facilitated real-time interaction and responsiveness, and the use of the television ensured all children could see Katie and her demonstrations.

Having enough time for young children to explore and be creative is an essential component of STEM learning experiences (DeJarnette, 2018; Murcia et al., 2020). Miss Bird reflected on time limitations during the sessions, but that they were going to continue exploring the Scitech resources during their own class Investigation Time. However, this challenge is not exclusive to the online learning environment. In their systematic literature review into STEM education, Wan et al. (2021) reported time constraints to be the most frequently cited challenge. Similarly, having a range of stimulating materials is important for encouraging creativity (Murcia et al., 2020) and this constraint was raised by Katie. Again, it should be noted that access to STEM resources is also an issue in face-to-face classrooms settings (Jamil et al., 2018; Park et al., 2017). In future online deliveries, this could be overcome by Scitech providing an 'additional materials' list for teachers, as well as encouraging children to explore the immediate environment for extra materials to investigate.

The findings from this study contrasts with perceptions that arose during the COVID-19 pandemic that online learning is boring and passive (Dong et al., 2020; Inan, 2021) and raises the importance of context. This study set out to explore the potential of intentional online delivery in which children participate in STEM outreach activities while physically in a classroom. This is a starkly different context to children engaging in emergency remote learning at home through a hybrid of synchronous and asynchronous activities.

Conclusion

This article has explored how STEM online learning experiences can foster young children's creativity. It has reported on a series of synchronous shows and workshops delivered by Scitech to Year 1 children located in a regional town 700 km from Perth, via Microsoft Teams. Given limitations of time and resources preventing more frequent face-to-face delivery, the purpose of this study was to explore the potential for increasing Scitech's connection with regional and remote schools through online delivery to complement their outreach services. The experience was enjoyed by all participants but critical to its success was Scitech providing materials to the class so the children could actively engage in hands-on activities under Katie's guidance. This made the pre-session preparation for Miss Bird easy, given the materials were clearly packaged for each workshop activity. The clearly defined roles of Katie and Miss Bird enhanced the intersection between online and offline, with the children engaging with Katie as the primary educator while simultaneously receiving support from Miss Bird in the classroom. Further, Katie's effective use of communication strategies such as questioning encouraged children's creative thinking and problem-solving. Interestingly, rather than being limiting, the structured and scaffolded approach to investigative activities was found to encourage children's creativity as they slowed down and thought deeply about possibilities, while exploring STEM concepts. While the constraints of time and resources were raised, these are not unique challenges to online delivery. Further, these challenges have the potential to be minimised by providing classroom teachers with a list of suggested additional materials, as well as encouraging them to allow extra investigation time following the online sessions. These two strategies would provide children with a wider range of stimulating materials and additional time for creative exploration. This study has demonstrated how the *A-E of Children's Creativity Framework* can be used by researchers or educators to evaluate children's creativity during STEM activities by providing guidance on what process characteristics to look for and what elements need to be present.

Initially, five children volunteered to participate as case studies but due to unforeseen circumstances two were unable to participate for the duration of the study. As case studies are characterised by their detailed insight into smaller numbers of individuals, the number of cases provided adequate level of analysis for this study (Ward & Delamont, 2020). While this may limit the ability to draw broader conclusions about the implementation of STEM online learning experiences for young children, it can offer opportunities for transferability. By providing a detailed summary of the online STEM learning experiences, other educators can determine the extent to which these conclusions could apply to their own contexts. Additionally, the study did not explicitly explore the impact of online learning experiences for children with learning difficulties. Future research could explore how STEM online learning experiences can effectively cater to the needs of a diverse range of learners. The study has also attempted to reframe perceptions around the effectiveness of 'online learning' by acknowledging the nuances that exist within online contexts. It is therefore recommended that academics and media differentiate between intentional 'online learning' and ad-hoc 'emergency remote learning' when discussing the opportunities and limitations of online delivery. Importantly however, the findings illustrate the potential for synchronous online delivery of STEM to foster meaningful creative learning opportunities in young children, an important avenue in the pursuit of advancing STEM education (Education Services Australia, 2018; Office of the Chief Scientist, 2013).

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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