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Making pedagogy for spatial literacy: a case study of an origami workshop in an after-school makerspace

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Abstract
Spatial skills are crucial to STEM disciplines and involve a variety of cognitive processes and skills related to visualising, reasoning and communicating about spatial relations. Particularly in the primary school years, attaining 'spatial literacy' gives children a valuable set of skills and knowledge that can aid them in successful participation in STEM subjects. However, it is poorly understood what constitutes spatial literacy for primary school age children. Furthermore, research into pedagogy for spatial skills is limited, with training interventions often resembling psychometric tests. Therefore, it is pertinent to explore which spatial skills and knowledge are most important for primary school age children to develop and how pedagogy could look to help children to attain spatial literacy. Maker education provides an integrated and design-based approach to learning in which children could practise spatial skills and knowledge by applying it in a creative way. Origami provides a particularly interesting medium to explore these questions as it has previously been used successfully to train psychometrically assessed spatial skills. This paper details a 'research through design' case study of the development of a theoretically informed origami workshop and its implementation in a makerspace during an after-school makerspace programme. The origami workshop and its pedagogical qualities are described and the implementation of the origami workshop in an after-school makerspace is analysed in light of spatial literacy. These findings are discussed and contextualised with insights from the literature. Finally, several recommendations for further research on spatial literacy for primary school age children, specifically in the context of maker education, are made.

Keywords
Spatial skills, spatial literacy, maker education, origami, STEM learning

Introduction

The Importance of Spatial Skills

Spatial thinking is an umbrella term for a set of abilities and skills that are the product of a complex interplay of sensory, cognitive, and motor processes, which are pervasive throughout our everyday lives (Maresch & Sorby, 2021). As a consequence, spatial thinking is not like a subject onto itself, but rather an important skill across myriad disciplines, and it is a particularly essential component of success in Science, Technology, Engineering, and Mathematics (STEM) disciplines (Wai et al., 2009). Most of the literature on spatial thinking, particularly that showing its relevance to education, is characterised by use of the psychometric construct of spatial ability. Spatial ability is defined as the ability to manipulate and transform mental representations of objects in space. Myriad studies have highlighted the positive effect of training interventions on children's (Hawes et al., 2017; Lowrie et al., 2017) and adults' (Sorby,

2009) performance on psychometric tests. However, there is a significant gap between this body of literature and educational practice (Hawes et al., 2017). For example, training studies, often written from a developmental psychology perspective, rarely consider pedagogy explicitly (Adams et al., 2022). Therefore, spatial literacy is a crucial addition to the literature, particularly from an educational perspective, although it has only received a limited amount of attention in the literature. The authors of the 'Learning to Think Spatially' report describe spatial literacy as *'constituting proficiency in terms of spatial knowledge, spatial ways of thinking and acting, and spatial capabilities'* (National Academies Press (U.S.), 2006, p. 18). Since the report, spatial literacy has been conceptualised as an amalgam of skills in three overlapping domains – visualisation, reasoning, and communication (Lane et al., 2019). Conceptualising spatial thinking and its associated skills as a form of literacy holds a normative implication, but the norms for what one should be able to do with and know about space, representation, and reasoning remain unclear, particularly regarding what is required from children for them to successfully partake in STEM-related learning.

Exploring spatial literacy through origami in maker education

This paper details a case study that describes the design and analyses the implementation of an origami maker workshop in such a makerspace of the *Openbare Bibliotheek Amsterdam* (OBA) [translation: Amsterdam Public Library], the public library of Amsterdam in the Netherlands, in early 2023. Within museums and libraries, across Europe, South-East Asia, and the United States, makerspaces have been established where supervised and structured educational activities are offered (Bevan, 2017; Peppler et al., 2016). Generally, in these makerspaces, maker educators aim to provide primary and secondary school aged children of diverse demographics with educational programmes change in topic from week to week or over longer periods (Bevan, 2017; DiGiacomo & Gutiérrez, 2016). In maker education activities, children learn in rich design-based learning settings through a process that emphasises tinkering, designing, and building (Schad & Jones, 2020). Making activities might involve crafts such as sewing and woodworking, and often make use of (digital) technologies for manufacturing and design such as laser cutters, 3D printers, CNC machines, and microcontrollers (Martin, 2015). In general, maker education and the process of learning in makerspaces differs from classroom education in many ways, emphasising a creative and integrated process of making that involves the use of technology, collaboration, and the sharing of knowledge and skills (Pijls et al., 2022).

Maker education is often framed as a way to improve motivation and learning in specific content areas (Schad & Jones, 2020) and to instil a positive attitude towards STEM-disciplines that helps participants to realise that they too can engage in scientific endeavours (Blikstein, 2013). Furthermore, Zhu et al. (2023) conclude from an extensive analysis of the literature that spatially complex STEM problems provide a context in which children can effectively practise their spatial skills. Maker education could thus be a powerful medium for developing spatial literacy by providing children with spatially complex STEM activities to practice their spatial skills. The primary school age children (usually 8-12 years old) who participate in the after-school programmes are at a stage of their school careers in which they are faced with important choices regarding their future (educational) careers and consequently, they would greatly benefit from becoming spatially literate (Hawes et al., 2022). Origami – the Japanese name for the art of folding paper into figures – provides an interesting medium to address elements of spatial literacy through maker education, as several studies have shown the positive effects of origami activities on measures of spatial thinking (Boakes, 2009; Cakmak et al., 2014; Serrano Anazco & Zurn-Birkhimer, 2020). In an earlier conference paper, the development of this origami workshop and its implementation in the context of an after-school activity in a makerspace were detailed (Westerhof, O'Kane & Duffy, 2023). In this paper, the implementation of the workshop is analysed in light of spatial literacy and these findings discussed and contextualised within the literature on spatial literacy, discussing how spatial literacy may be best conceptualised, particularly for primary school age children within integrated STEM-settings such as maker education.

Literature review

Individual development of spatial thinking

The greatest developments in individual spatial thinking skills occur from about age 3-15 years, with intrinsic and extrinsic spatial thinking skills developing at different stages of childhood (Maresch & Sorby, 2021). Spatial thinking skills relating to *intrinsic* transformations, involve changing the rotation and orientation of objects, scaling objects, cutting or folding etc., and those relating to *extrinsic* transformations, involve imagining and visualising objects from another perspective as an observer and moving in relation to other objects (Newcombe & Frick, 2010). Intrinsic skills most rapidly develop at around 6-8 years of age, whereas extrinsic skills show the greatest development between ages 8-10 (Hodgkiss et al., 2021). Furthermore, it is crucial for children to extensively manipulate objects in space e.g., by creating three-dimensional representations of ideas to learn to visualise and reason about spatial concepts (Yang et al., 2020). This is of particular relevance to a cohort of children who have received much of their education online due to the COVID-19 pandemic (Lane & Sorby, 2022). Spatial thinking skills keep developing considerably until about 14 years of age, when the natural development has mostly completed, but spatial thinking skills remain malleable in adulthood (Maresch & Sorby, 2021). However, there is a significant gap in translating the insights from the educational and cognitive literature into pedagogy (Bufasi et al., 2024). For example, education for spatial thinking is often restricted by the fact that the psychometric factors of spatial ability are overemphasised in interventions (Bower & Liben, 2021). This is problematic, as the psychometric construct of spatial ability is far from comprehensive with regards to the cognitive processes used by STEM experts (Atit et al., 2020), and these processes are only part of what makes up spatial thinking in practice.

Spatial Literacy

What one needs to know and be able to do in relation to spatial thinking has been conceptualised as spatial literacy (National Academies Press (U.S.), 2006). Literacy can perhaps best be conceptualised as a state in which one has attained a certain level of knowledge and skills and can apply them when appropriate. As Grossner & Janelle (2014) explain, although not everyone becomes an accomplished writer, most people can become proficient enough in reading and writing to participate in society in a meaningful and fulfilling way, which is no different with regard to spatial literacy. In practical terms, spatial thinking is perhaps best understood operationally – as an amalgamation of three elements: concepts of space, tools of representation, and processes of reasoning (National Academies Press (U.S.), 2006). Several studies have further developed the concept of spatial literacy over the past decades. An important contribution can be found in the work of Moore-Russo et al. (2013), who argue that to be spatially literate, one must be able to: (1) visualise spatial objects, (2) reason about properties of and relationships between spatial objects, and (3) send and receive communication about spatial objects and relationships. The process of visualising a spatial object can involve an object that is physically present, allowing one to manipulate the object and to assess its properties from different perspectives, while it can also involve the same processes with no object present at all, with the processes purely taking part in 'the mind's eye', spatial reasoning involves manipulating this internal representation of an object to visualise changes to the object or analyse it, and the communication domain relates to exchange of information about these through e.g., sketches, computer models, physical models, or gestures (Lane & Sorby, 2022).

A lot of skills involving spatial thinking involve knowledge that is used to structure the data and sensory information we get into relevant understandings of spatial phenomena. Many of these spatial concepts are important or inherently tied to a particular discipline, which involve complex, conceptual structures of how space is described and explained within it, as illustrated by the striking accounts of spatial thinking in fields ranging from geology to astronomy in the 'Learning to Think Spatially' report (National Academies Press (U.S.), 2006). However, one does not need to master all the specialised spatial approaches that expert surgeons, geologists, architects or mechanical engineers need to become spatially literate. What is pervasive throughout STEM disciplines is referred to by Newcombe (2018) as 'spatialisation' – the use of symbol systems to think and reason about space, for example spatial language, gesture, maps, and diagrams. Although these are often discipline-specific, they can be tied together by their use of the universal properties of space and spatial data such as symmetry, reflection, orientation, and rotation, dimensionality, continuity, and proximity and separation (National Academies Press (U.S.), 2006). These concepts, and the ability to reason with and apply them, can be seen as the universal and fundamental building blocks of spatial thinking in many disciplines, hence they are required knowledge that can be seen as an integral part of spatial literacy (Grossner & Janelle, 2014). In addition to the three domains of spatial skills that together form spatial literacy, there is also a domain of spatial knowledge – a familiarity with a diverse set of concepts – which informs the extent to which the spatial skills in the three previously mentioned domains can be applied. However, the norms and structure of the knowledge and skills that make someone spatially literate are poorly defined. Consequently, it remains unclear what knowledge and skills pedagogical interventions should help students to attain spatial literacy and how this can best be facilitated.

Spatial thinking in origami

The literature on pedagogy for spatial literacy is rather limited, but recent work points to elements such as constructivist pedagogy and utilising hands-on materials like tangrams and blocks as effective approaches to training spatial skills (Bufasi et al., 2024). Further, origami is well-studied in relation to training spatial skills, making it a promising medium to explore which spatial skills and knowledge are pertinent to origami, how those relate to a spatial literacy within after-school maker activities, and how they can be scaffolded. A 2014 study from Turkey reports a statistically significant effect of the origami-based instruction on the spatial visualisation (η^2=.10) and spatial orientation (η^2=.29) scores of 9–12-year-old students (Cakmak et al., 2014). Fujiki & Nishihara (2023) found that the scores on the Paper Folding Test and Surface Development Test were significantly correlated to self-reported ability of individuals to perform origami from instructions (Fujiki & Nishihara, 2023). These tests are measures of intrinsic spatial thinking skills, for which an important qualitative, empirically confirmed, distinction can be made between those relating to 'rigid transformations' and 'non-rigid transformations' (Harris et al., 2013). Harris et al. (2013) found that the ability to predict non-rigid transformation, e.g., how shapes change when a piece of paper is folded, emerges in children of about 5.5 years old. Furthermore, the effects of origami training on elementary school age children are not limited to increases in the visualisation domain of spatial literacy, but also effectuates improvements in engagement and motivation (Cakmak et al., 2014; Taylor & Hutton, 2013). Some studies find a particularly strong increase in engagement from girls, which may make origami a good medium to help close the gender-based performance differences observed on some tests of spatial ability (Taylor & Hutton, 2013). Furthermore, because of the rich spatial vocabulary and concepts used within origami (Taylor & Tenbrink, 2013), it could also provide a valuable medium for children to familiarise themselves with spatial concepts. Because of the rich potential of origami as a pedagogical medium to develop spatial skills in diverse ways, it is an opportune medium to explore how it relates to the larger content and structure of spatial literacy for primary school age children.

Making pedagogy for spatial literacy with origami

One of the fundamental pedagogical approaches in maker education is referred to as 'tinkering', through which children exploratorily practise skills and construct an understanding of what they work with (Resnick & Rosenbaum, 2013). Whereas some activities have a strong emphasis on interest-driven and play-based exploration with tools to facilitate personalised constructive, explorative and collaborative learning (Hsu et al., 2017; Martin, 2015), other activities provide learners with concrete goals, tools, and steps towards realising those goals, with creative freedom in certain aspects of the project (Bevan, 2017). Particularly activities that require technical skills or that are under time constraints are often planned and pre-structured by educators to scaffold children's learning (Blikstein, 2018). Moreover, as Pijls et al. (2023) note, the role of educators is crucial in supporting children to gain confidence in their abilities, to overcome their anxieties, and to embrace times of frustration. This crucial role for maker educators extends to other elements such as mitigating gender-based stereotypes and associations with materials and tools that could affect both participation and learning in maker activities (Bevan, 2017). However, there is a strong need for more detailed analyses of what learning can occur in educational makerspace settings (Bevan et al., 2015). Similarly, Pijls et al. (2022) conclude that informal learning settings such as library makerspaces would benefit from integrating insights from the cognitive and learning sciences to help to show how informal learning settings such as makerspaces allow for unique learning opportunities.

Research Questions

In summary, although it has become clear why it is necessary to support the development of spatial thinking, the 'what' remains rather vague – it is unclear what the structure of spatial literacy for primary school age children in maker education is, which skills and knowledge need to be developed and how pedagogy for spatial literacy may look. This leads to the following research questions:

1. What does a maker education workshop look like, in which primary school age children can learn, tinker with, and creatively apply origami techniques?
2. How is spatial literacy relevant for primary school age participants while they participate in this origami workshop in the context of an after-school makerspace?

Methodology

Procedure

An ‘intensive’ case study approach (Danermark et al., 2019) was taken, to explore, through an in-depth analysis of several sources of qualitative data, which spatial skills and knowledge manifest in a specific activity and how they are relevant to the larger structure of spatial literacy. The case study is rooted in a ‘research through design’ process, which can be characterised as when design activities play a formative role in the generation of knowledge, for example reframing a design problem and iteratively developing and evaluating prototypes to address the complex situation in which the problem occurs (Stappers & Giaccardi, 2017). As Stappers and Giaccardi (2017) explain, such a design artifact can create the possibility for people to engage in interactions that were not possible before the design came into existence, making novel interactions observable. The research through design process and the design artifact themselves are thus part of the core epistemological strategy through which the researcher comes to new insights. As part of this research through design process, the first author engaged in ethnographic data collection methods. First, he observed several workshops from the regular after-school programme in the maker space and then discussed the format and the didactic approaches taken by the coaches in those workshops to aid the iterative process of developing the origami workshop. These insights were then used to design the workshop detailed as the first part of the results. Next, the implementation of the origami workshop during an after-school programme in a makerspace at the public library of Amsterdam was investigated. Observational data were collected through observation notes and photographs, and after the workshop was done, the first author wrote up a narrative description of the workshop. Finally, a week after the workshop, an informal debriefing with the coaches took place to reflect on and discuss the implementation and structure of the workshop, during which the first author took notes. These data were then analysed by the first author.

Participants

The workshop was attended by 12 children of primary school age, six girls and eight boys, and two boys in the first year of secondary school. The origami workshop replaced the workshop in the regular programme of after-school workshops. The first author acted as workshop host instead of the two makerspace coaches, who instead took on dynamic roles, working on origami themselves, supporting the child participants in their origami folding, and helping the first author to host the workshop as they saw fit.

Results

Design of the origami maker workshop

A two hour-long origami workshop was designed that lets children tinker with basic origami techniques and skills, which they then creatively apply to come up with original origami designs. The first half of the workshop started with a brief plenary introduction to origami instructions and folding. Origami instructions show the linear sequence of transformations the paper needs to go through to recreate a final design, illustrated through diagrams and symbols in standardised in the Yoshizawa-Harbin-Randlett system (Lang, 2012). The participants then receive step by step instructions for several simple origami models on a handout. For about 45 minutes, the children explore how to fold classic origami designs using instructions on a handout (Figure 1), while they discuss and help each other. This is followed by a plenary discussion in which the children share their experiences of making origami.

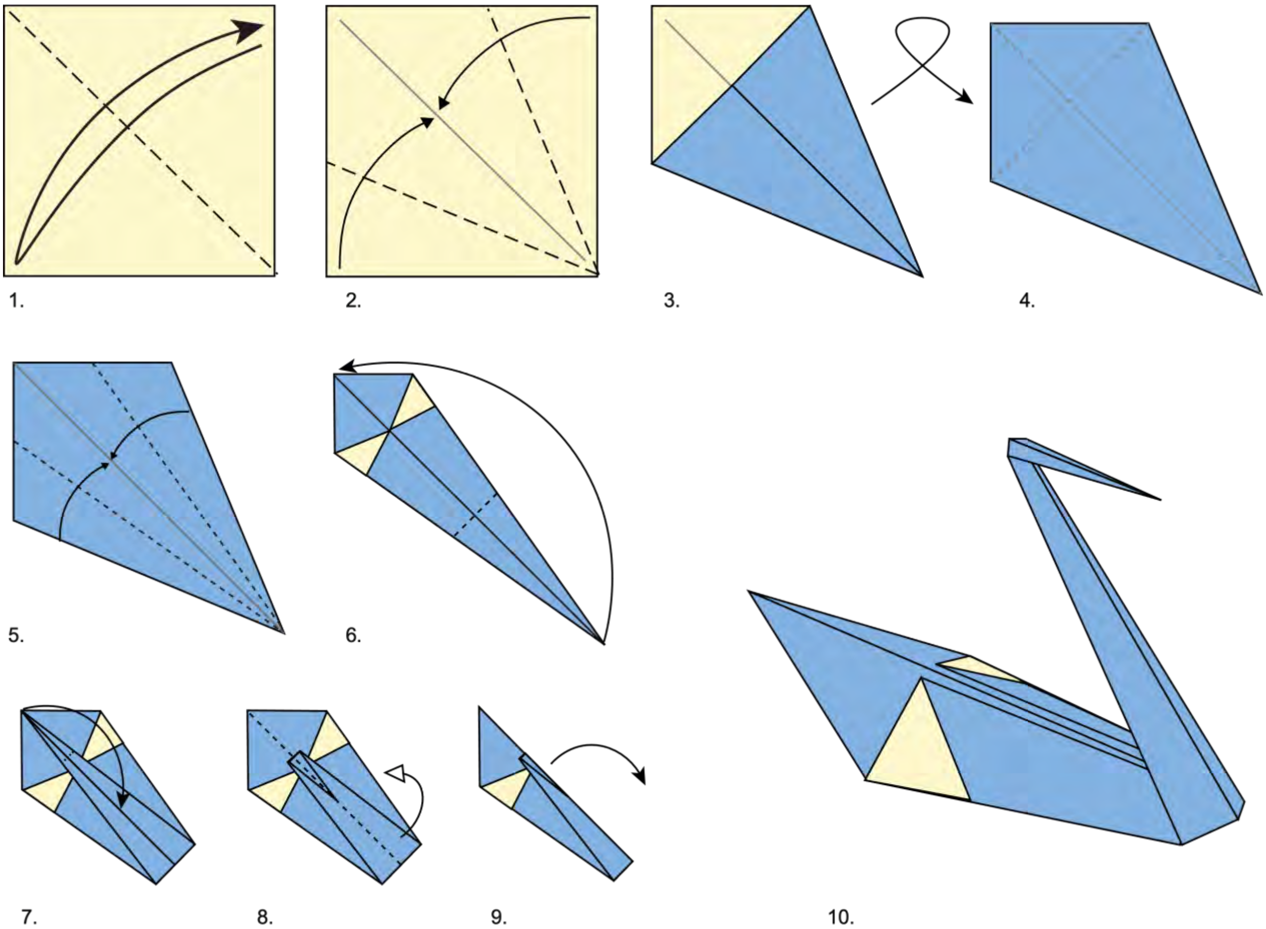

Figure 1. Origami instructions for the swan model

The second half of the workshop was informed by Chapter 4 of the book ‘Origami Design Secrets’ by Robert Lang (2012), and a course on YouTube by Brandon Wong (2022) based on the book by Lang. The children are introduced to three ‘classic’ origami bases (Lang, 2012) – the fish, bird, and kite – and shown several different origami designs based on each (Figure 2). These geometric forms can resemble an abstracted version of desired subject that has the same general shape or number of flaps (Lang, 2012). A flap is a region of paper that can be manipulated relatively independently from the rest of the model, which can be folded to represent, for example, an appendage.

To recreate an animal, one can try to find a base of which the number of flaps corresponds with the number of appendages of that animal. For example, a fish base consists of two large flaps, which can be used to shape the head and tail, and two small flaps, which can represent the pectoral fins. The children are then tasked to design their own (fantasy) animal using one of the bases and the techniques learned in the first half of the workshop. This process is described as ‘doodling’ (Robinson, 2004, p. 38) – analogous to tinkering – where folding techniques are exploratorily and creatively applied to come to new ideas.

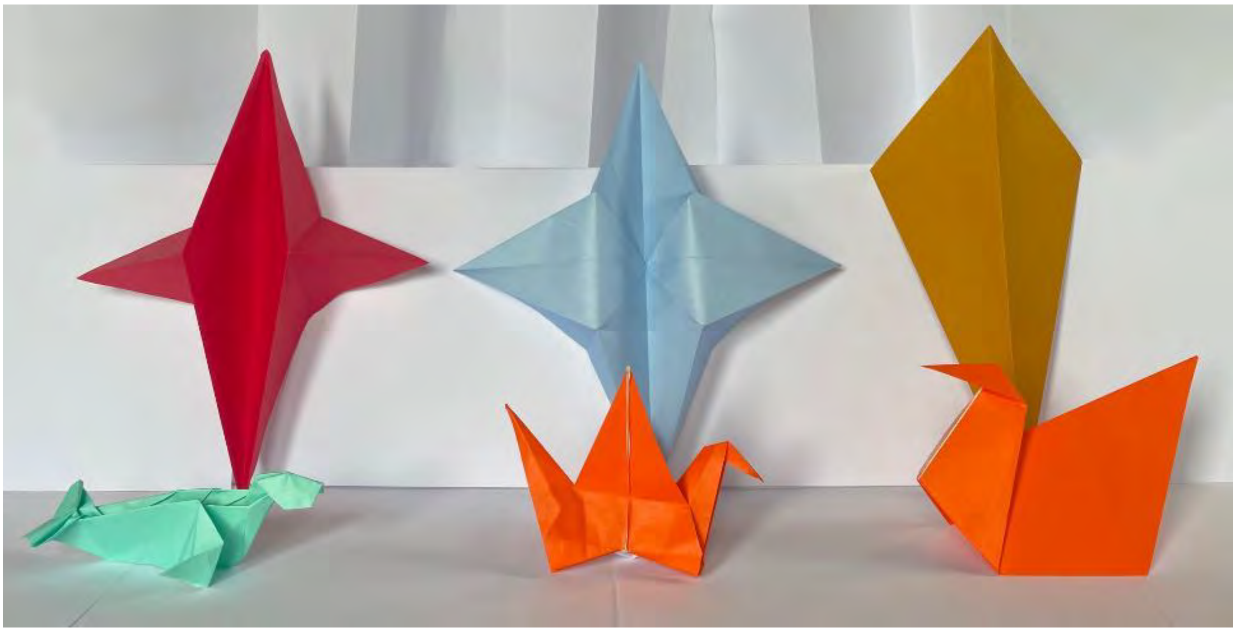

Figure 2. From left to right: a fish, bird, and kite base with examples of designs based on each

Implementation of the origami maker workshop

Individual differences in spatial literacy

In the first half of the workshop, all children engaged with the origami instructions, but their degree of success in following the origami instructions varied greatly. This is illustrated by how many children continuously called upon the researcher for help while they explored the origami instructions, as shown for example in Figure 3. Some of the children waited for the facilitator to explain each step to them, while a small number of children seemed to give up entirely and asked if they could do something on the computer instead. This was contrasted by the two boys who had indicated at the start that they would prefer to work on their own projects in the makerspace, who independently and very quickly finished their swans after the plenary introduction. They then opened laptops to work on their own projects, which involved part 3D-modelling in TinkerCAD and a more significant part playing video games. It thus became apparent that some children were able to fold independently and successfully while others required extensive assistance, but also that individuals reacted to their success or struggle in folding the origami models from the instructions in qualitatively different ways. For example, when during the second half of the workshop the researcher explained how classic origami bases can be used to design novel origami, the children were asked to start the process of doodling to come up with an original design. However, this task appeared to be too daunting, as most children, except one or two, started doing other things in the makerspace.

Figure 3. Three children folding the swan model.

Video circumvents the need for diagrams

In response to the difficulties that were faced by the children while they tried to come up with novel designs, one of the makerspace coaches looked up an instructional video for making an origami elephant, which she displayed on the large TV-screen in the makerspace. The video helped in regaining the attention of many of the children, particularly the children who had previously struggled with the instructions. The children all followed the steps in the video, which was paused periodically by the coach so all children could catch up. Most children seemed to find it much easier to follow the first-person perspective instructions in the video than translating 2D diagrammatic instructions in the handouts into actions. However, instead of trying to apply their newly practised techniques to create a novel origami design, the children were again recreating an existing model of an elephant (Figure 4). However, now they did not have to decipher diagrammatic instructions.

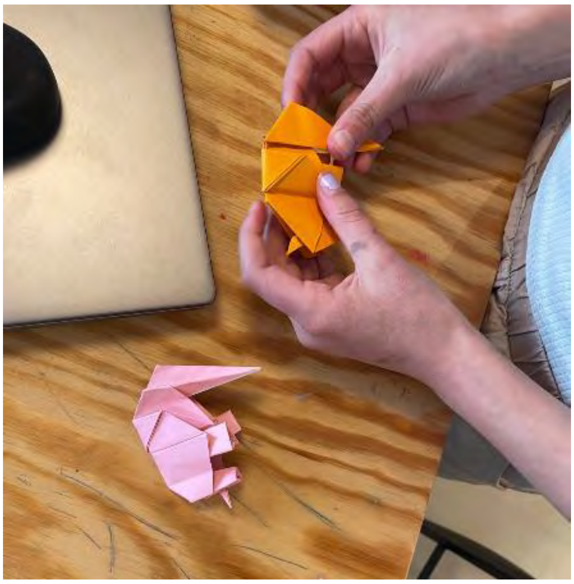

Figure 4. Folding elephants from a video

Spatial creativity comes in different shapes and sizes

While the children were following the instructions for folding the elephant, two of the children noticed independently of each other that this elephant origami was designed from the bird base, which they had folded earlier in the workshop. While folding the elephant from the video, a boy thought that an intermediate step of the elephant looked like a dinosaur, which he preferred over the elephant (Figure 5). This boy had previously independently recreated one of the examples designed from the fish base by the facilitator, showing an ability to harness his spatial thinking skills creatively and analytically.

Figure 5. A boy doodling to come to a new design.

In the first half, two girls had decided that they would fold the swan in all available colours. When asked by the researcher if they would also like to try folding the crane, a more challenging model, they responded no, and both girls spent a significant period of the workshop folding the swan model from all the available colours (Figure 6). In contrast to the previously mentioned boy, these girls perhaps did not engage with a spatially challenging task after the initial challenge of deciphering the instructions, but they did show a playful commitment to making a creative series. Before they left, one of the girls who made a rainbow of swans and the boy who had recreated one of the examples both asked if they could take home the handout and a few sheets of origami paper to continue making origamis at home. As the girl left, she said: “I love origami!”. Although in this case the activity failed to engage the girls in a more spatially challenging task, it does show an important benefit of open-ended creative tasks – allowing each child to find an angle to the activity that is personally meaningful and fulfilling, setting them up for later independent learning.

Figure 6. A participant displaying her creations.

Discussion

Spatial literacy: spatial skills, knowledge – and beliefs

Previous research on the effects of origami instruction in relation to spatial thinking has not only shown the positive effects on measures of spatial ability, but also has pointed to the positive effects on the motivation of girls. Similarly, in the limited sample we observed in this specific case, most of the girls actively engaged in origami. Potentially, origami could be a valuable medium for engaging children in spatial skills. This is particularly pertinent because there is a large body of research on the effects of stereotypes and self-beliefs on spatial thinking, which points towards the strong negative effects of gender-based stereotypes and self-concepts such as spatial anxiety, which negatively influence how children engage with spatial problems (Burte et al., 2020; Lennon-Maslin et al., 2023). An important question is whether the children who did not engage with the 'spatially challenging' elements of the workshop, such as the girls who spent most of the workshop recreating the same model, would benefit from more explicit spatial training. However, further research is necessary to investigate individual levels of spatial literacy in relation to how the children engage with the workshop to be able to make any further conclusions.

Further, this also raises the question how self-beliefs should be conceptualised in relation to whether an individual can be considered 'spatially literate'. In the 'Learning to Think Spatially' report (National Academies Press (U.S.), 2006), one of the characteristics of a spatially literate individual is considered to be having the habit of mind to think spatially – knowing where, when, how, and why to think spatially. Therefore, a prerequisite is that an individual has a healthy level of self-efficacy regarding their spatial skills and knowledge, as only then will they engage with and practise the application of those skills when the situation calls for it. This begs the question whether self-beliefs should be considered an integral part of the conceptualisation of spatial literacy, as from an educational standpoint they are important elements to be addressed.

Diagrams: a barrier or enabler to understanding space?

One of the main observations that informed the analysis related to the use of an instructional video during the workshop. This video showed a first-person perspective of two hands folding an origami elephant, and many of the children who had stopped working on anything origami-related were drawn back into the workshop again. Within many STEM and non-STEM disciplines, diagrams play a crucial role but the skills and knowledge that are required to engage them are often neglected (National Academies Press (U.S.), 2006). Diagrams are used to structure spatial information, but often do not directly show function or behaviour, which need to be inferred (Heiser & Tversky, 2002). This is often scaffolded through 'extra-pictorial devices' such as lines and arrows to convey e.g., transformations that need to be inferred (Heiser & Tversky, 2002) – similar to how the origami instructions in this activity were illustrated in the Yoshizawa-Harbin-Randlett system (Lang, 2012). In the case of the origami workshop, the reason many children were drawn back in by the video might have been because it was easier for them to follow a video which shows the correct procedure from the same perspective as they themselves view their hands, circumventing the need to interpret diagrams. Folding origami from diagrammatic instructions requires a variety of spatial skills during the translation of diagrammatic instructions into transformations of the paper, which involves a process of visualising and reversing, rotating, turning over and inverting models (Taylor & Tenbrink, 2013). Initial individual levels in spatial skill can have a strong influence on whether students correctly interpret diagrams (Kozhevnikov et al., 2002). For example, spatial thinking plays a decisive role in accurate problem representation in mathematics (Duffy et al., 2020). Structured practice with spatial diagrams – involving spatial representations and transformation of spatial information – could facilitate significant benefits with regards to participants' spatial literacy (National Academies Press (U.S.), 2006). This is one of the crucial things that the maker workshop can help teach, particularly when actively scaffolded by educators. Therefore, the video might have appeared to the educator as an appropriate didactic approach to regain the children's attention, but in the light of spatial literacy, may have taken away the opportunity to practise valuable skills related to interpreting diagrams.

Rubrics: making spatial literacy assessable

In this specific case study, it was explored how maker education provides a valuable context in which children can develop a wide range of spatial skills in a context where educators can help to structure these skills. It became apparent that knowledge of spatial concepts is a requirement for engaging with spatial skills, as these concepts are integral to how the spatial information is structured. In this workshop, spatial concepts such as symmetry, reflections, and fractions were integral parts of the origami design task. Furthermore, origami provides the opportunity to engage with rich spatial language (Taylor & Hutton, 2013), which is well known to play an important role in developing children's spatial thinking (Newcombe, 2018). In addition, self-beliefs regarding spatial thinking may play a crucial in how children (are able to) partake in activities that require spatial skills. For children to attain spatial literacy, educators need to understand how they can support children's spatial skills, knowledge, and self-concept through the wide variety of spatial challenges that emerge in the context of maker education activities.

That raises the crucial question of what the norms are for spatial literacy for primary school age children in relation to those skills. Another apparent challenge to defining spatial literacy relates to the extent to which student learning of spatial knowledge and spatial skills relate to a specific area of expertise and thus how those skills and that knowledge can be transferred to another area of expertise or be applied in general. Secondly, for educators to support children in their development of those skills, it is crucial to have pedagogical strategies and tools such as rubrics to help them to assess individual children's development on those norms. Perhaps it is impossible to define a comprehensive list of spatial skills that are relevant, but future research could define the spatial skills present in maker education to be able to define which spatial skills and knowledge are crucial within maker education settings and how educators can identify their use and potential extent among participants to better support their development. Furthermore, such rubrics would allow for measuring the impact of an intervention such as the one described here, to further elucidate and potentially quantify the impact. Furthermore, this would allow for the effect on such scales to be measured based on engagement in such a workshop, allowing for research designs with larger generalisability. Because of the crucial role the maker educators have in providing adequate scaffolding and support for children to develop their spatial literacy, further research could benefit from involving the views of experienced maker educators in relation to what they consider relevant spatial skills and how children apply these, which can help to develop a better-defined understanding of spatial literacy within the context of maker education activities.

Conclusion

This case study detailed the design and implementation of an origami workshop, in which primary school age participants learn to creatively apply origami techniques, which was analysed through the lens of spatial literacy. Observations from the study indicate that a well-designed and implemented workshop can be used to elicit a variety of spatial practices, providing a valuable medium to investigate how activities and educators may support the development of spatial literacy within makerspaces. Spatial literacy is an amalgam of skills and knowledge that is influenced by self-beliefs. Diagrams are a spatial tool that can elicit spatial skills but may work as a barrier for students who are not spatially literate. Therefore, it is crucial to understand which skills and knowledge are crucial to attaining 'domain-general spatial literacy'. Through a future study, the making process of several children could be analysed for the diverse forms of spatial practices that are required in diverse maker education activities and how educators support these practices within their makerspaces. This would provide a valuable step towards a better understanding of what should be considered spatial literacy for primary school age children, how primary school age children could develop spatial skills during design-based maker activities and how educators can support them in harnessing this set of crucial skills while working on projects that are important and engaging to them.

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