Developing spatial literacy through designing origami: advancing maker education pedagogy with maker études

Marten B. Westerhof, Technological University Dublin
marten.westerhof@tudublin.ie
Colm O'Kane, Technological University Dublin
colm.okane@tudublin.ie
Gavin Duffy, Technological University Dublin
gavin.duffy@tudublin.ie

ABSTRACT

Spatial literacy is crucial to success in STEAM-disciplines. Within these disciplines, spatial thinking manifests in a variety of ways, ranging from visualising how pieces of a solution might fit together to effectively communicating solutions to others through language, gestures, and graphic representations. Pedagogy for developing spatial literacy for children is still in its infancy, as training studies tend to focus on paper-and-pencil-based activities that resemble psychometric tests without explicit consideration for didactic approaches. Maker education offers children a design-based way of learning through a process of tinkering, designing, and building, with potential for creative output. In practice, educational maker activities generally tend to overemphasise prototyping tools and the development of the procedural knowledge required to use those tools. However, these hands-on learning activities could aid children to not only develop making skills, but also to attain spatial literacy. Although studies exist that identify spatial thinking during educational maker activities, no efforts have yet been made to design a maker activity that specifically aims to develop participants' spatial thinking holistically. This paper details a case study of the design and implementation of an origami workshop that aims to develop participants' spatial literacy. Origami, the art of folding sheets of paper into figures, is a process that requires frequent and varied use of spatial thinking. The workshop adopts the form of a 'maker étude', analogous to a musical étude, a satisfying exercise to practice and improve a particular technique so it can be applied creatively. The implementation of the origami maker étude in a public library makerspace in Amsterdam and its potential to support the development of spatial literacy are discussed. Finally, several suggestions are made for future research into the development of primary-school age children's spatial literacy in makerspaces.

Maker education, spatial literacy, origami, design-based learning, STEAM

1. INTRODUCTION

The ability to manipulate and transform mental representations of objects in space is an essential component of success in Science, Technology, Engineering, and Mathematics (STEM) disciplines (Wai et al., 2009). Spatial ability is malleable, with several studies highlighting the positive effect of pedagogically-sound training interventions on children's (Hawes et al., 2017; Lowrie et al., 2017) and adults' (Sorby, 2009) performance on psychometric tests. Training spatial ability is effective at the early stages of children's educational careers, when training can positively impact much of a child's educational career, and is particularly important for a cohort of children who have received much of their education online due to the COVID-19 pandemic (Lane & Sorby, 2022). However, the diverse forms of spatial thinking that are used in STEM disciplines are not covered by the psychometric construct of spatial ability (Atit et al., 2020), resulting in a reductionist understanding of spatial thinking. Furthermore, current educational efforts are often held back by the fact that training studies overemphasise the psychometric factors of spatial ability in the interventions (Bower & Liben, 2021), and rarely consider pedagogy explicitly (Adams et al., 2022). More holistic conceptualisations of spatial thinking within these disciplines are sparse, but several examples exist in work by Ramey and Uttal (2017) and Lane et al. (2019). Ramey and Uttal (2017) conceptualise spatial thinking within STEM not just as internal cognitive processes, but as 'repertoires of practice' that are mediated through context and supported by the use of tools, representations, and collaborations between participants. Spatial literacy is conceptualised as a set of skills one needs to engage in STEM disciplines, consisting of the ability to visualise, reason, and communicate about spatial concepts (Lane et al., 2019). Such conceptualisations of spatial thinking in STEM provide a better basis for designing didactically-sound interventions and its conceptualisation as a form of literacy gives a strong educational imperative. Zhu et al. (2023) conclude from an extensive analysis of the literature that spatially complex STEM problems could be useful for developing students' spatial thinking. In maker education, children learn in rich design-based learning settings through a process that emphasises tinkering, designing, and building. Maker education could thus be a powerful medium for developing spatial literacy by providing children with spatially complex STEAM (STEM + Art) activities to practice their spatial visualisation, reasoning, and communication skills. Maker education also provides room for the extensive manipulation of objects in space e.g., by creating three-dimensional representations of ideas, which is crucial for children to learn to visualise and reason about spatial concepts (Yang et al., 2020). This paper details the development and pilot case study of the implementation of a theoretically informed origami workshop that aims to support the development of primary school-age children's spatial literacy and discusses the workshop's feasibility within the context of public makerspaces in Amsterdam.

2. LITERATURE REVIEW

2.1. Spatial thinking in origami

Origami is the Japanese name for the art of folding paper into figures. Due to widespread attention and innovation in origami over the course of the 20th century, it has sparked new applications in STEM-disciplines such as aeronautics, micro-engineering, and architecture (Meloni et al., 2021). Origami is also extensively used for educational purposes and, for example, its use in teaching

mathematics is well-developed, as illustrated by books such 'Project Origami: Activities for Exploring Mathematics' by Thomas Hull (2013). Folding origami requires visualising of and reasoning with spatial concepts, e.g., in translating verbal and graphic instructions onto the paper, and rotating, inverting, and visualising how a sequence of folds results in a completed model (Taylor & Tenbrink, 2013). A 2014 study from Turkey describes the effect of a series of origami activities that were embedded in mathematics classes on the spatial thinking of 9–12-year-old students and found that it had a statistically significant effect on the students' spatial visualisation and spatial orientation test scores (Cakmak et al., 2014). Findings by Taylor and Tenbrink (2013) suggest that spatial training that includes vocabulary for spatial concepts, such as those found in origami, may help to build spatial thinking, as they found that the use of 'new spatial terms' correlated with success in origami related tasks. An origami and paper engineering programme for elementary school-age children resulted in gains in the participating children's spatial thinking, and it was found that the engagement increased, particularly 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).

2.2. Pedagogical considerations for the makerspace

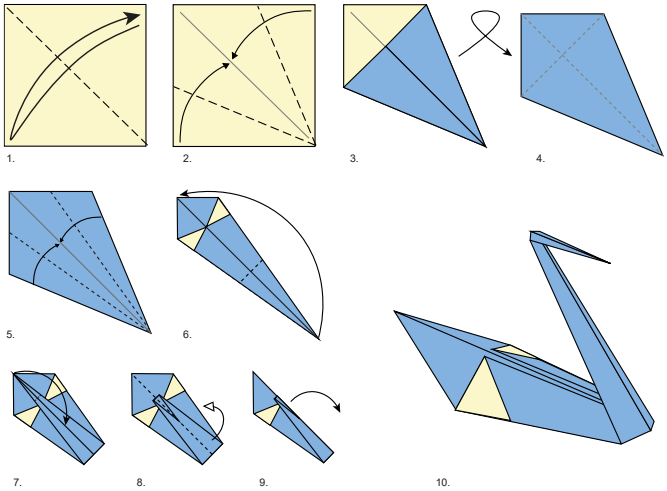
Within makerspace settings, activities generally revolve around a playful process of iterative problem solving in open-ended design tasks (Blikstein, 2018). The context of this project is within the makerspaces of the *Openbare Bibliotheek Amsterdam* (OBA), the public library of Amsterdam, The Netherlands. In these makerspaces, coaches offer both in-school and after-school programmes consisting of weekly afternoon-long workshops. Over the course of such a programme, children make e.g., their own stuffed animals or automata using prototyping tools such as laser cutters, 3D-printers, and sewing machines. These educational maker activities tend to be rather result-oriented, as coaches focus on helping children create something they are proud of, but as a consequence lose out on the potential to scaffold the children's learning processes. This is illustrated by Pijls et al. (2022), who found that the makerspace coaches in the OBA hardly mentioned evaluating the children's activities and work during these workshops. To advance the pedagogy of the activities in public library makerspaces in Amsterdam, a conceptual format was developed to design activities that are more learning-oriented, with specific emphasis on spatial literacy. Inspiration was taken from the musical 'étude', which is a composition that explores a technical problem in a musically coherent and aesthetically satisfying way (The Editors of Encylopaedia Britannica, 2011). An étude is thus a tool to further a specific technical skill through a cohesive exercise that is aesthetically pleasing, gives a sense of accomplishment after completion, and teaches techniques that can be used for creative expression and improvisation. These principles were transposed to an origami maker étude, consisting of a two hour-long workshop in which children first practice origami techniques and then creatively apply these newly acquired skills to create a novel design.

2.3. Origami maker étude for developing spatial literacy

The workshop's structure follows the format of the activities in the OBA makerspaces and its contents were informed by studies of origami activities that have shown to improve psychometrically assessed spatial ability and to facilitate the use of spatial language (Cakmak et al., 2014; Taylor & Hutton, 2013; Tenbrink & Taylor, 2015). In the first half, a brief plenary

introduction to origami techniques is given, followed by step-by-step instructions for traditional origamis such as the relatively easy swan and more complex crane models. These instructions are illustrated through diagrams and symbols, standardised in the Yoshizawa-Harbin-Randlett system, which show the linear sequence of transformations the paper needs to go through to recreate the final design (Lang, 2012). For about 45 minutes, the children explore how to fold classic origami designs using instructions on a handout, while they discuss and help each other.

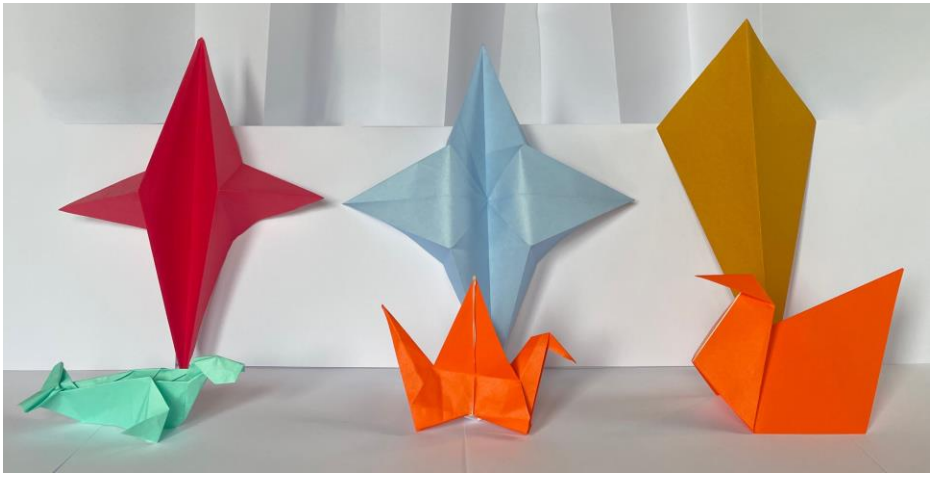
Figure 1.
Origami Instructions for the swan model



This is followed by a plenary discussion in which the children share their experiences of folding. After a short lemonade break the children exploratorily design a novel origami for another 45 minutes to an hour. This workshop section 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.

The workshop facilitator then explains that many classic origami designs were made by manipulating the flaps on these bases e.g., to resemble different animals. The children are first split into small groups of 3 - 4 and tasked with thinking of animals that they could create from each of the bases. After coming up with several possible designs, they transform one of the classic bases using 'detail folds' (Lang, 2012), in a process analogous to music improvisation, where techniques are creatively applied after having practised them. Finally, the children present their designs to each other, and are tasked with recognising the bases in the origami designs folded by their peers. The children then organise the designs based on different aspects such as orientation, what they represent, simplicity, complexity, etc., and discuss which designs they liked most or found surprising.

Figure 2.
From left to right: a fish, bird, and kite base with respective design examples in front.



3. METHODOLOGY

This paper describes a case study of the implementation of the origami workshop in the context of an OBA makerspace, with specific interest in its feasibility and potential to support the development of spatial literacy of participants through practice. Whereas most workshops are hosted by the makerspaces, in this case the first author acted as workshop host. The first author had observed several workshops and discussed their didactic approaches with the coaches at several stages during the iterative process of developing the origami workshop. The workshop replaced the regular programming of the makerspace. The goal of the case study was principally centred on the workshop's feasibility and pedagogical qualities. Data were collected through observations and photographs and analysed by the first author. 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.

3.1. 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 primary school-age children all regularly attend the after-school workshops on Wednesday afternoons. The two older boys originally came to finish a 3D print that they had started during an in-school programme earlier that day but decided to join the workshop. The two makerspace coaches had dynamic roles, in which they worked on origami designs themselves, supported the child participants in their origami folding, and helped the first author to host the workshop.

4. RESULTS

When the children had arrived, they were asked to sit down around a table in the centre of the room. The first author introduced himself, the structure of the workshop, and asked the children several questions about their experiences with origami. After some basic origami techniques were explained, such as valley and mountain folds and the importance of folding neatly, the children received handouts with folding instructions. All children succeeded in folding the swan from the instructions, but most of them needed help with deciphering the diagrams, with several children waiting for the facilitator to explain each step to them. Two girls decided that they would fold swans in all available colours. When asked by the first author if they would also like to try folding the crane, a more challenging model, they responded no, and both girls spent most of the workshop folding a rainbow of origami swans. Two boys, who had indicated at the start that they would prefer to work on their own projects rather than folding origamis, quickly and independently finished their swans, and then grabbed their laptops, 3D modelling in TinkerCAD and playing video games for the remainder of the workshop. After having finished the swan, most other children tried to fold origamis from the instructions. One boy asked for help from the first author to help him fold the fish and bird base from the instructions in the handout and managed to recreate one of the examples designed by the facilitator from the fish base independently. After about 45 minutes, all children had stopped folding origamis and the makerspace coaches organised a lemonade break for the children.

Figure 3.
Folding swans from instructions during the first half of the workshop.

After the break, the first author asked the children about their experiences during the first half of the workshop, such as what they noticed while they were folding. The second half of the workshop was introduced by explaining how classic origami bases, such as the kite, fish, and bird can be used to design novel origami that represent animals by performing detail folds on the flaps. The children were then asked to start the process of doodling, but several of them grabbed their laptop instead of trying this step. Rather than bring them back to doodling, one of the makerspace hosts quickly looked up an instructional video for making an origami elephant, which she displayed on

the large TV-screen in the makerspace. The children followed the steps in the video, which was paused every now and then so they could catch up. Some of the children noticed that this elephant origami was designed from the bird base too, which they had folded earlier in the workshop. The boy who had recreated one of the examples earlier, noticed that an intermediate step of the elephant looked like a dinosaur, which he decided would be his final design as he preferred over the elephant. The presentation moment at the end was skipped, as the workshop had surpassed the scheduled time, and most children were being collected by parents. Before they left, two children independently asked the first author if they could take home the instructions and some origami paper to continue at home. One girl said: 'I love origami!'.

Figure 4.
Folding elephants from a video and trying to design novel origami from one of the bases.

5. DISCUSSION

5.1. Discussion of the workshop

Most of the children engaged with origami independently for about 30 to 45 minutes before they lost attention. In this period, the children freely explored the instructions that were given in the handout, but most children did require help from the facilitator. The workshop introduction should more clearly explain how to read diagrams and teach correct folding techniques through several examples. Additionally, more differentiation in difficulty is required from the start to mitigate the children losing interest from the activity either being too difficult or too easy. For example, providing instructions for other models that are more difficult than the swan, but less difficult than the crane could help to achieve this. The structure of the workshop was intended to scaffold the children's practice with origami techniques, each section being a step that built on the previous and leading up to an original design. However, the results from the pilot indicate that this structure was too linear and therefore untenable within this context. For example, too many moments seemed to require a shift from individual work to group-based instruction and vice versa, taking children out of their own processes. As a consequence, the workshop's structure failed to effectively scaffold the children's idea generation in the second half of the workshop. Instead of

several short instruction moments spread throughout the workshop, one plenary brainstorm immediately after the break could help to support the children in coming up with what they want to make. The use of an instructional video from a first-person perspective helped many children who struggled, but the use of the video by the makerspace coach did undermine the process of constructing novel origami through doodling. Due to a lack of time, the presentation moment that was part of the original structure of the workshop did not take place. However, a conclusion to the workshop through a collective celebration of the children's creations is not only an effective way to bring the workshop to a close, but also an important step in consolidating learning through a reflection on the process and ups and downs the children experienced.

5.2. Discussion of the role of spatial literacy

The children's degree of success in following origami instructions varied greatly, as some kids were able to fold independently and successfully while others required extensive assistance, which could indicate that the individual levels of spatial literacy played an important role in the participants' success in the workshop. For example, most children found it much easier to follow the first-person perspective instructions in the video, which could be explained by the video requiring less visualising, reasoning, and perspective taking compared to translating the 2D diagrammatic instructions in the handouts into actions. During the second half of the workshop, which requires children to creatively apply their newly acquired origami techniques, some children demonstrated an ability to creatively see new things in intermediate steps origami, e.g., by changing its orientation. These findings illustrate the importance of one's ability to visualise, reason, and communicate about spatial concepts, i.e., being spatially literate (Lane et al., 2019), as well as the ability to translate spatial thinking into actions that are mediated through tools and materials (Ramey & Uttal, 2017). For children to attain spatial literacy through maker education, it is pertinent for educators to understand how they can support the wide variety of spatial practices that emerge in maker education contexts and how they can scaffold children's abilities to visualise, reason, and communicate about spatial concepts and relations. Through the theoretical lens of spatial literacy and spatial practices, an activity such as the one described provides a medium through which the interactions between participants and educators can be studied as they emerge based on different elements of activities and contexts.

5.3. Conclusion

This paper described the design and implementation of a workshop that follows the principles of a maker étude in which primary school-age participants learn to creatively apply origami techniques, with the specific aim of developing spatial literacy. Observations from the pilot 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. Through a future study, the making process of a number of children could be analysed for the diverse forms of spatial practices that emerge from maker education activities and how educators support these diverse practices within their makerspaces. This would provide a valuable step towards a better understanding of how children of primary school-age could develop spatial literacy 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.

6. REFERENCES

Adams, J., Resnick, I., & Lowrie, T. (2022). Supporting senior high-school students' measurement and geometry performance: Does spatial training transfer to mathematics achievement? *Mathematics Education Research Journal*. https://doi.org/10.1007/s13394-022-00416-y

Atit, K., Uttal, D. H., & Stieff, M. (2020). Situating space: Using a discipline-focused lens to examine spatial thinking skills. *Cognitive Research: Principles and Implications*, *5*(1), 19. https://doi.org/10.1186/s41235-020-00210-z

Blikstein, P. (2018). Maker Movement in Education: History and Prospects. In M. J. de Vries (Ed.), *Handbook of Technology Education* (pp. 419–437). Springer International Publishing. https://doi.org/10.1007/978-3-319-44687-5_33

Cakmak, S., Isiksal, M., & Koc, Y. (2014). Investigating Effect of Origami-Based Instruction on Elementary Students' Spatial Skills and Perceptions. *The Journal of Educational Research*, *107*(1), 59–68. https://doi.org/10.1080/00220671.2012.753861

Hawes, Z. C. K., Moss, J., Caswell, B., Naqvi, S., & MacKinnon, S. (2017). Enhancing Children's Spatial and Numerical Skills through a Dynamic Spatial Approach to Early Geometry Instruction: Effects of a 32-Week Intervention. *Cognition and Instruction*, *35*(3), 236–264. https://doi.org/10.1080/07370008.2017.1323902

Hull, T. (2013). *Project origami: Activities for exploring mathematics* (Second edition). CRC Press.

Lane, D., Lynch, R., & McGarr, O. (2019). Problematizing spatial literacy within the school curriculum. *International Journal of Technology and Design Education*, *29*(4), 685–700. https://doi.org/10.1007/s10798-018-9467-y

Lane, D., & Sorby, S. A. (2022). Bridging the gap: Blending spatial skills instruction into a technology teacher preparation programme. *International Journal of Technology and Design Education*, *32*(4), 2195–2215. https://doi.org/10.1007/s10798-021-09691-5

Lang, R. J. (2012). *Origami Design Secrets*. 770.

Lowrie, T., Logan, T., & Ramful, A. (2017). Visuospatial training improves elementary students' mathematics performance. *British Journal of Educational Psychology*, *87*(2), 170–186. https://doi.org/10.1111/bjep.12142

Meloni, M., Cai, J., Zhang, Q., Sang-Hoon Lee, D., Li, M., Ma, R., Parashkevov, T. E., & Feng, J. (2021). Engineering Origami: A Comprehensive Review of Recent Applications, Design Methods, and Tools. *Advanced Science*, *8*(13), 2000636. https://doi.org/10.1002/advs.202000636

Pijls, M., van Eijck, T., Kragten, M., & Bredeweg, B. (2022). Activities and Experiences of Children and Makerspace Coaches During After-School and School Programs in a Public Library Makerspace. *Journal for STEM Education Research*, *5*(2), 163–186. https://doi.org/10.1007/s41979-022-00070-w

Ramey, K. E., & Uttal, D. H. (2017). Making Sense of Space: Distributed Spatial Sensemaking in a Middle School Summer Engineering Camp. *Journal of the Learning Sciences*, *26*(2), 277–319. https://doi.org/10.1080/10508406.2016.1277226

Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education*, *31*(3), 459–480. https://doi.org/10.1080/09500690802595839

Taylor, H. A., & Hutton, A. (2013). Think3d!: Training Spatial Thinking Fundamental to STEM Education. *COGNITION AND INSTRUCTION*, *31*(4), 434–455. https://doi.org/10.1080/07370008.2013.828727

Taylor, H. A., & Tenbrink, T. (2013). The spatial thinking of origami: Evidence from think-aloud protocols. *Cognitive Processing*, *14*(2), 189–191. https://doi.org/10.1007/s10339-013-0540-x

Tenbrink, T., & Taylor, H. A. (2015). Conceptual Transformation and Cognitive Processes in Origami Paper Folding. *The Journal of Problem Solving*, *8*(1). https://doi.org/10.7771/1932-6246.1154

The Editors of Encylopaedia Britannica. (2011). Étude. In *Encyclopedia Britannica*. https://www.britannica.com/art/etude-music

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, *101*(4), 817–835. https://doi.org/10.1037/a0016127

Wong, B. (2022, November). *Origami design class* [Playlist of videos]. YouTube. https://www.youtube.com/playlist?list=PL6CCJHQcukwXKpuGuBkVaVx4WgItD4WO9

Zhu, C., Leung, C. O.-Y., Lagoudaki, E., Velho, M., Segura-Caballero, N., Jolles, D., Duffy, G., Maresch, G., Pagkratidou, M., & Klapwijk, R. (2023). Fostering spatial ability development in and for authentic STEM learning. *Frontiers in Education*, *8*, 1138607. https://doi.org/10.3389/feduc.2023.1138607