Beyond Paper Folding: Origami and Focused Play to Enhance Interdisciplinary Learning and Teaching in Universities.

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Abstract.

This paper presents a case study: a collaboration between an artist, a senior lecturer in engineering, and two faculty members from teaching and learning. It showcases how we, as a consortium are 1) using origami in university STEM teaching as a way of enhancing and promoting arts-based STEAM learning within the contexts of creativity, play, exploration, and learning from failure and 2) charting these processes within a broader interdisciplinary contribution to teaching and learning. As a result of our collaboration, we suggest a new shorthand of 'makerlearning' which captures both the physical maker elements underscored with a carefully considered pedagogy.

The process of applied making provides a space where the "*gap between disciplines…can be bridged*" (Troxler, 2017, p. 13). We are striving for a reframing of invention and innovation within and beyond educational context and contend that "*individuals are not creative, ideas are creative*" (Clapp, 2016, p. 3). Although our case study focuses on the discipline of engineering, we argue that makerlearning and artistic approaches to understanding complex concepts can be applied across disciplines and extend beyond the classroom into community and industry settings.

Keywords: Engineering; Origami; Robotics; Teaching and learning.

1. The Maker Movement.

The term making can be used to define the process where individuals play, make, experiment, and invent using no-tech to high-tech tools (Loertscher, 2012; Van Holm, 2015). The concept of making for the enhancement of teaching and learning has continued to gain momentum, with a particular focus on STEM education (Davies, 2017; Forest et al., 2014). Research suggests that making encourages and enhances multidisciplinary learning as hands-on approaches can foster personal curiosity within a supportive socio-cultural environment (Bilandzic, 2016; Clapp, 2016; Davies, 2017; Forest et al., 2014; Harris et al, 2017).

Makerspaces have been recognised as places to encourage innovation and entrepreneurship across all age groups and disciplines, and they have even been lauded as the catalyst of the next industrial revolution (Browder, Aldrich, & Bradley, 2019). The co-creational collaboration and idea-sharing evident in Makerspaces enable the discovery and fabrication of new and innovative outputs in far greater numbers than traditional settings (Browder, et al, 2019; Bergman & McMullen, 2020). These characteristics allow for novel methods of teaching and learning, with opportunities to present complex concepts, including in areas of STEM, in accessible and fun ways.

1.1 Why making as learning? Hands-on collaboration for inclusion and accessibility.

Facilitating a making as learning ethos in a university setting "*requires a profound revision of educational practice*" (Troxler, 2017, p. 28) including curriculum planning to allow for a variety in learning activities, new modes of assessment, and development of new learning outcomes (Troxler, 2017; Ross & Clapp, 2018). We suggest the term 'makerlearning' to encompass these concepts.

Makerlearning:

- Fosters collaborative exchanges by providing open spaces for staff and students to work together across disciplinary boundaries.
- Sparks creativity through providing spaces for informal learning and curiosity-driven explorations, via self-directed and collaborative learning models.
- Promotes horizontal connection-making between staff and students. No hierarchical preference is given to any specific department and projects can take form through a variety of media (low tech – high tech), keeping the space accessible, user-friendly, and achieving fluidity in a co-making environment.
- Promotes "*interdisciplinary and intercultural understanding, imbues willing participants with a passion for learning and a sense of wonder at the world, and instills a sense of 'can-do' spirit at tackling challenges ahead*" (Miodownik, 2014, p. 10).
- Enables partnerships with artists and members of the wider community to include

diverse perspectives and reflect the changing world around us.

- Facilitates experiential, active learning for students and staff who may not have an applied focus to their discipline or less opportunity to engage in learning through modeling, prototyping, etc.

Our makerlearning case study demonstrates the applied approach of origami in the context of teaching engineering.

For our collaborative case study, the engineer (G.H.) and artist (A.P.) had prior experience of one anothers' disciplinary and creative contexts. This ensured meaningful learning not only for the students, but for the authors themselves. The teaching and learning lecturers did not previously have subject or aesthetic knowledge pertaining to the application of origami but an understanding of approaches underscoring making as learning which enabled a common language for facilitation of learning. The precursor for this collaboration was a shared interest in origami as an approach to learning which transcends disciplinary boundaries.

1.2 Origami: A tool for teaching and makerlearning.

Origami is the art of folding a sheet of paper into various forms without stretching, cutting, or gluing other pieces of paper to it (Tachi, 2013). It derived its name from the Japanese words 'oru', which means 'to fold', and 'kami', which refers to 'paper' (Debnath & Fei, 2013). Originally, origami was developed more for artistic purposes, folding sheets of paper into various shapes, either in abstract forms or mimicking certain objects (Demaine, 2000).

Origami as a teaching and learning tool is a materials-led approach, guided by a skilled artist in the field. Participants working with the physicality of folded paper discover its versatility by being introduced to a number of repeated rigid origami folds such as those in the images below.[1] (Images courtesy of Pentek, with permission).

[1] All images courtesy of Pentek. They are reproduced with the artists' permission.

Image 1: Alex Pentek. Implicate and Explicate Order. 2019. (Detail). Image: Shane O'Driscoll.
Image 2: Alex Pentek. The Intimacy of Distance. 2011. (Detail). Image: Alex Pentek.

Image 1

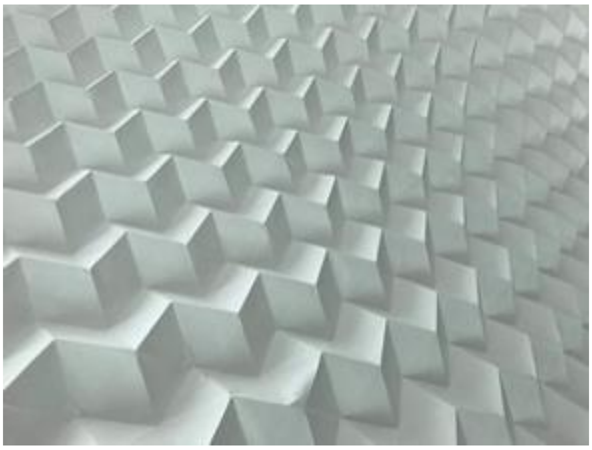
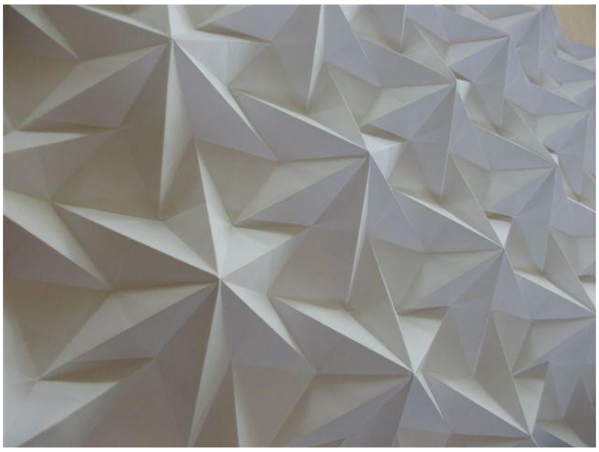


Image 2



The complex geometries in folds such as those pictured above (Miura and the collaborating artist's own star fold), in addition to others such as the Waterbomb and Koshi-Miura, can easily be applied to a range of robotics/engineering applications such as the creation of original compliant/bi-stable mechanisms and other articulated forms. The versatile geometry of deployable rigid origami is governed by a number of proven mathematical axioms that allow for more in-depth analysis after playing and experimenting with a working paper model. Furthermore, working with paper causes skin moisture to soften the paper after a certain time, creating a limited window of opportunity to work on a specific area before the paper is affected. This demands a holistic, methodological approach that can also be beneficial to researching other materials, where specific tasks are seen in context with the broad, overall aims of design.

Rigid origami as an art form can be appreciated in the following images created by the collaborating artist.

Image 3: Alex Pentek. *Implicate & Explicate Order*. 2019. (Detail). Image credit: Zillah Ni Loideoin..

Image 4: Alex Pentek. Folded Space. 2018. Image credit: The Voyage Out.

Image 3

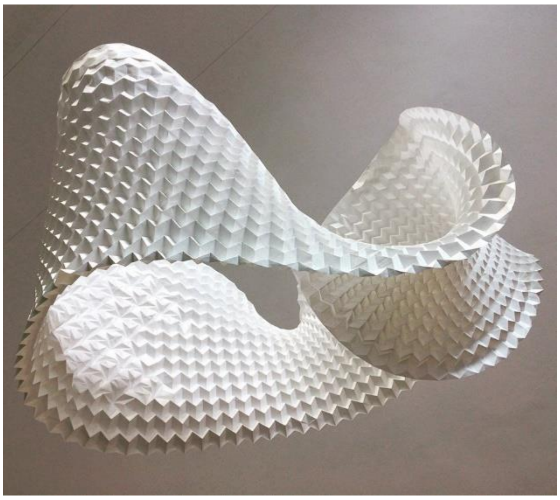
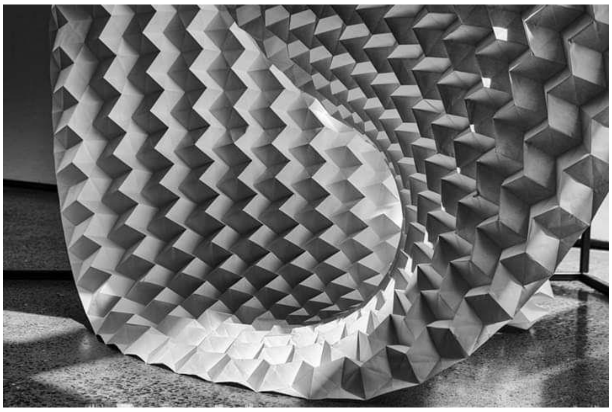


Image 4



By engaging with origami as an artform, whose geometry and economy of line contain a certain aesthetic, students can make exciting discoveries and the creation of new complex articulated forms of their own. This helps to inform and inspire the design process in successful advanced robotic and engineering design. The most economic and successful solution is also often more elegant and visually pleasing. Evidence of this can easily be found in the natural world and is known as bio-mimetic design. In addition to eliciting an intuitive and almost eidetic way of thinking through imagery, the subject of art also brings much more to an engineering program that will often focus on a series of very specific tasks.

Since time immemorial the word ‘art’ has long been associated with skill. Because of this association, in its broadest definition the art of a subject can also mean the total skill or gestalt of that subject (Read, 2014). In a safe workspace that allows materials-led design to occur, this holistic ethos encourages a dynamic approach to the art of robotic engineering design/education; encompassing the entire program while remaining open to inspiration from outside fields of knowledge and expertise. Art is therefore an invaluable resource in this engineering program (Hao & Pentek, 2020).

On a practical level, the endless variations that rigid origami can offer are often surprising and difficult to predict without prior experimentation. Bringing this knowledge into other fields and disciplines leads the student intuitively towards discovering novel innovative approaches of their own (Liang, Hao, Olszewski & Pentek, 2021). Drawing on ideas such as the philosophy of design and theory of inventive problem solving (TRIZ) (Mindtools, 2020), we have chosen to introduce the discipline of origami to robotic education to bring playfulness and innovation into the design process by mixing these two areas. If this playfulness is combined with a specific real-world task in the workspace (such as grasping, lifting or moving), it may allow the physical properties of the paper material to interact with the environment of the workspace. As well as encouraging innovation, this level of interaction could lead to increased successful robotic design outcomes by incorporating a passive dynamic approach, where the cognitive/design process needed to accomplish a task is directly extended into the workspace environment (Hao & Pentek, 2020; Clark & Chalmers, 1998; Collins & Ruina, 2005).

Origami encompasses an entire disciplinary program while remaining open to inspiration from outside fields of knowledge and expertise – as our applied case study below highlights.

1.3 Makerlearning case study: Application of origami to the specific discipline of engineering.

Enabling complex 3D structures from a 2D plane simply by folding, Origami has attracted attention from various areas such as architecture (Buri & Weinand, 2008; Sorguç, Hagiwara, & Selcuk, 2009; Thrall & Quaglia, 2014) mathematics (Hull, 2012; Hull, 1994; Santangelo, 2020) and engineering (Liang, Olszewski, Pentek & Hao, 2021; Hao & Pentek, 2021; Edmondson et al., 2013).

Our own Origami-led course design involves a lecturer team composed of an Origami artist and a Mechanical Engineer. It includes three parts: Part I is the introduction and theory of Origami as well as engineering application and the kinematic mapping between Robotics and Origami; Part II is the intensive hands-on training of Origami folding; and Part III is an Origami-based project as continuous assessment in the Advanced Robotics module. A direct experience-led approach forms the basis of this module where the behaviour of complex rigid Origami surfaces cannot easily be predicted in Part I. By introducing a number of rigid Origami crease patterns in Part II these can then be practically applied by the students to a broad range of design applications, allowing them to explore their new ideas independently and intuitively in Part III.

Our application of origami as makerlearning worked as a way of translating concepts in Kinematics and of investigating Statics. If we substitute the paper facets and folds with rigid links and revolute joints, we can equate Origami and Robot, so that students can access and play with the kinematic analysis intuitively via the medium of paper.

Origami promotes both Analysis and Design in Robotics. Using paper as an inexpensive media, students can easily replicate an existing kinematic model and robotic concept to facilitate their analysis. In addition, folding paper allows an effective materials-led design process of discovery for the students. Origami can enable students to simultaneously sketch and make working, articulated models from paper for new designs.

The creation of Origami structures is also a valuable approach for continuous assessment for students. There are no boundaries, limitless imagination possibilities and the process of trial and error; the dynamism of this is in stark contrast to traditional assessment methods such as a written exam. The students were also learning at the same time about the aesthetics and art of origami in a creative sense; learning which transcends disciplinary boundaries.

2. Evidence of Student Learning.

Feedback was sought via anonymous surveys from participants in the teaching and learning workshop and from engineering students. The feedback was intended purely for developmental purposes in order for the workshop facilitators to adapt the delivery approach in future sessions. For this reason, ethical clearance was not sought and direct quotes will not be provided here, however the following provides a summary of the learning reported by participants in both the engineering focused and teaching and learning workshops.

Engineering students:

11 participants attended this hands-on workshop, including four academic staff, 4 PhD students and 3 Masters students.

The students reported that the sessions enabled them to understand how origami is a multi-faceted activity which allowed them to think more about the relationship between its practice and disciplinary applications. Students also reported a sense of experiencing something unique through a simple piece of paper.

Teaching and learning workshop participants:

This workshop was attended by 9 participants who were academics from across the university, and came from disciplines of Business Information Systems, Engineering, Dentistry, Food Science, Geography, Law, Chemistry and Architecture.

Participants reported that the opportunity to engage with a tactile practice using paper was a unique opportunity to step away from the day-to-day demands of screen-heavy research and virtual teaching during the height of lockdown. The swap from teacher to learner also enabled lecturers insight into their students' worlds in learning something new from scratch.

3. Conclusion.

The practice of makerlearning can provide a contextual playground to encourage and combine creative thinking and innovative research methods, by using a direct experience and materials-led approach. Learning through Making is creative and playful; yet playfulness and the process of play are not often words associated with educational contexts beyond early years. However, the processes of play are often inextricably linked to innovative design through experimentation that is relevant for all ages. We argue that the language of creativity and play needs to be brought into all levels of interdisciplinary learning, such as is starting to emerge with the development of STEAM approaches. We define play as self and peer-guided exploration and design (Dousay, 2018) where creativity can be explored and developed as "*participatory and socially distributed process*" (Clapp, 2016, p. 21). Furthermore, through its "*antithetical stance to the heavily cognitively biased and linguistic forms of education, making creates ways of interacting with professional practice that exceed the possibilities that language alone offers*" (Troxler, 2017, p. 10). Therefore, we propose that makerlearning, such as teaching engineering through the discipline of origami, provides an innovative and inclusive platform for non-linguistic modes of research into education, creating opportunities for people from a variety of language, cultural and educational backgrounds to engage in postgraduate-level learning (Troxler, 2017). Research also suggests that the co-creational environment enabled by making which is underscored by art effectively enables better knowledge transfer and deeper understanding of complex concepts by providing hands-on, creative exploration (Bevan & Dillon, 2010; Gutwill & Allen, 2012; Sheridan et al., 2014).

As per this case study, we argue makerlearning has huge potential to drive changes to traditional and out-dated modes of teaching in higher education. Many questions now remain for us regarding play, pedagogy, place and space for makerlearning.

The concept, nature and nurturing of play, we feel, has been lost in higher education. Our hope is that practices like ours bring play to the fore and highlight how deep learning can be underscored by play-based approaches to higher education. We wish to bring forward the language and ethos of ‘playful learning’, playful curiosity and experimentation through makerspaces in the university setting, as we have seen first-hand how positively students respond to this kind of approach to learning.

Our future work will also focus on developing clearly articulated outcomes and aims for learning within makerspaces. We intend to explore how to conceptualise assessment within practice-based contexts for the benefits of all learners, to leverage the rich interdisciplinary sites of makerspaces in order to inspire educators to create learning opportunities for their students with these spaces and look at which tools might be developed to help educators design their curriculum to include makerlearning.

Finally, we see huge scope for how makerspaces and makerlearning can bridge non-academic/community spaces engage with universities to develop meaningful and informative research strands, how maker projects work as prototypes for industry connections and how skills such emotional resilience and teamwork/collaboration skills be enacted and ‘unhidden’ within makerlearning approaches.

For our future practice and collaborative endevours, we look forward to seeing what kind of magic happens in interdisciplinary learning when we focus less on traditional modes of higher education delivery and more on learning through process, experimentation and, dare we say, joy. As a consortium we continue to be curious and excited about the potential for makerlearning in higher education.

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