EESD2020 Submission 12: Art into Engineering: Demonstrating how Origami creativity can inform Robotics education

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Abstract

This paper discusses a teaching method in promoting students' learning and creativity in Robotics, which uses active Origami as a lab-based (design) tool to analyse and design robots. The 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. Learners/trainees have voted great compliments on the Origami-led course design. It shows that Origami is an effective tool and media to teach Robotics, and is suitable for teaching other Engineering topics such as structure and civil engineering.

1 Introduction

Robotics has become one of the hottest topics in research and industry, especially in the context of artificial intelligence and industry 4.0, which requires university for responsible education. Teaching robotics (such as ME6012-Advanced Robotics in UCC) contributes to the core-learning outcome of Mechanical Engineering degree. Robots typically consist of rigid links connected by kinematic joints such as revolute joints (hinges) and prismatic joints. There are two main tasks in robotics: Analysis and Design, which both require solid knowledge in mathematics and mechanics. An efficient way to help students master robotics knowledge is through a lab-based design project, where students can observe a physical motion on a robot prototype, and play with and analyze the motion toward designing a new robot for purposeful application. However, there is a great challenge in running the lab-based design project in an engineering class due to the limitation in learning space and cost even without mentioning health and safety issues.

Origami, as an ancient Japanese and/or Chinese art, is currently widely used for creating sculpture by artists (such as Pentek, 2020) and designing foldable structures/robots by engineers (Nishiyama, 2012; Zhakypov *et al*., 2018). Origami was also used for teaching geometry, thinking skills, fractions, problem solving, and fun science. Origami can be easily implemented by handcrafting creases from a piece of paper, which promotes creativity for teaching and research purpose. If we substitute the paper facets and creases (foldlines) with rigid links and revolute (R) joints, we can equate Origami and Robot. Using Origami we can enable a robotic analysis intuitively and inspire a new robot design. This is an efficient way to help students master robotics knowledge without the implementation issue in space and cost, which can also greatly inspire students' interest in a new learning space.

In order to demonstrate the equivalent relation between Origami and Robots, we use an Origami reverse fold as an example as shown in Fig. 1. The reverse fold is one of the basic folds in Origami, where three valley creases and one mountain crease intersect at one vertex. This is actually is a spherical robot with four R joints locating at the four foldlines. The kinematic constraint equation can be obtained as below based on the spatial vector loop (Fig. 1):

$$\boldsymbol{L}_1+\boldsymbol{L}_2+\boldsymbol{L}_3=\boldsymbol{L}_0 \tag{1}$$

where all vectors are with respect to the fixed frame system. Solving equation (1) requires the use of coordinate transformations and variable definitions, which are out of scope of this paper.

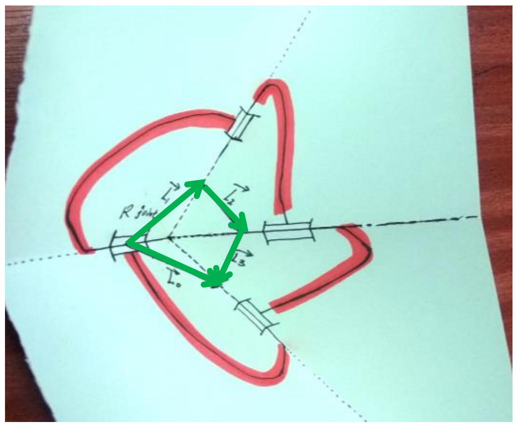


Figure 1: Reverse fold with kinematic mapping

With the similar motivation in combing Art and Robots (Herath and Kroos, 2016), this paper discusses the use of Origami in teaching robotics. Section 2 presented the Origami-led course design in detail, followed by feedbacks from trainees in Sec. 3 and reflections in Sec. 4. Conclusions are finally drawn in Sec. 5.

2 Origami-Led Course Design

The Origami-led course is delivered by a team, which consist of an Origami artist (second author of this paper) and a Mechanical Engineer (first author of this paper). It includes three parts. Part I is a 2-hour lecture mainly on the introduction and theory of Origami (by the artist) as well as engineering applications and the kinematic mapping between Robotics and Origami (by the engineer) (Fig. 2). This lecture was held in a traditional lecture room in UCC, ending with a warm-up of simple folding. Part II is a two-session intensive hands-on workshop of Origami (Fig. 3), which was delivered by the artist. Both sessions were held in National Sculpture Factory (NSF) in Cork, with each session lasting 2.5 hours. The first session workshop is on the individual training on several basic Origami folds such as Miura fold and Waterbomb fold. The folds were implemented on 90g A4 papers. After the first-session hands-on training, students were able to repeat the basic folds. In the second session workshop for Part II, students were split into teams working on folding big-size papers (Fig. 4). All teams starting from the same foundation folds aimed to create different Origami designs in the end. Each team was required to use at least two different folds in their final finish using their creativity with innovation in consideration. The prototypes completed by each team are shown in Fig. 4(a), (b) and (c) and all prototypes connected together is shown in Fig. 4(d).

Part III is an individual Origami-based project as continuous assessment (CA) in the Advanced Robotics module. The CA work's requirements are shown as below, based on which the outputs of one student can be indicated in Figs. 5 and 6.

- Conducting a literature review on the "Design of Robots inspired by Origami".
- Repeating an existing robot design (or creating a new design) using Origami technologies.
- Analysing kinematics of the design.
- A 5000-word (or equivalent including figures) report is required for submission to Canvas.
- CA is composed of writing a report (20 marks) and giving an oral presentation (10 marks). The oral presentation taking 15 minutes of each student is the concise explanation of the written report. Students are also required to bring a printed poster and an Origami piece for engaging with public audiences/peers.

Figure 2: Course Part I

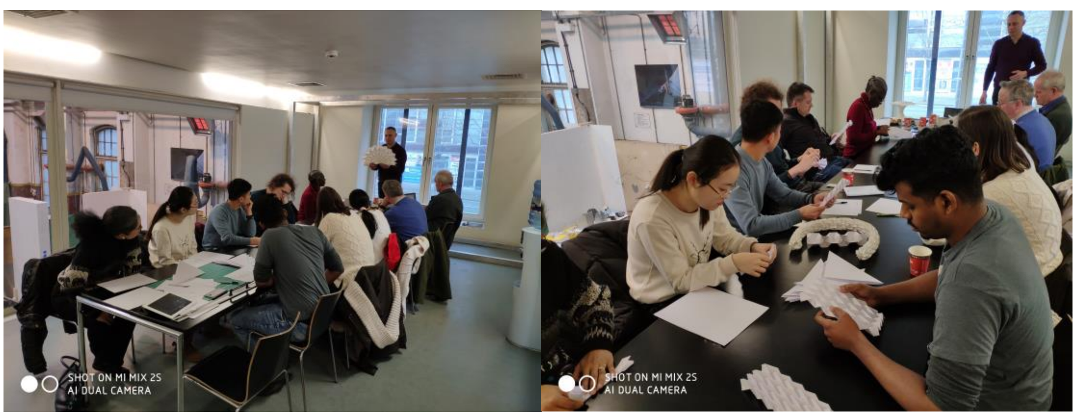


Figure 3: Course Part II 1st session (L: folding demonstration; R: students working on Miura folding)

3 Feedbacks from Trainees

There are 11 trainees attending the first-session hands-on workshop, including 4 UCC academic staffs (two from Architecture, one from Business Information Systems and one from Digital Humanities, 4 PhD students and 3 master students. 82% trainees voted "excellent" for the overall quality of the Origami course and 18% voted "very good" (Fig. 7).

The positive and encouraging comments written on evaluation forms from trainees are summarized below.

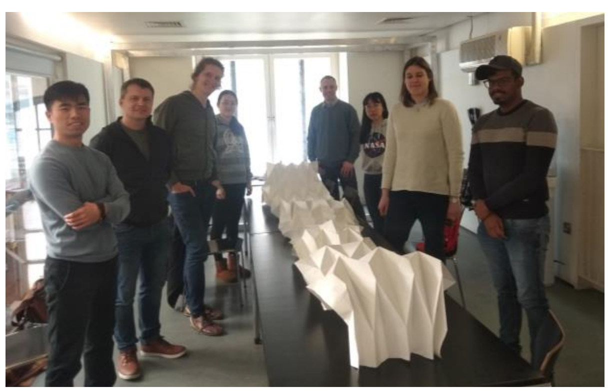
❖ Question: Does the Origami workshop help your understanding of Robotics Knowledge? If so, why?
"Yes, different types of folds and knots represent different joints. It is handy to have Origami to build a rough prototype out of paper"; "Yes, was a new way to see robots and could inspire the design of new kinds of robots"; "Not directly but I can see the relation"; "Yes, Origami also contains a lot of joints, that is the similarity with traditional mechanical design"; "Yes, bringing one simple revolute joint to complex shapes is very insightful"; "Yes, this certain part of robotics, specifically to have unique solution via intelligent mechanics instead of programming and for unique atoric"

❖ Question: Does the Origami inspire design of new robots? How?
"It is interesting to see how all the different pack of paper behave as we are working on one fold (joint)"; "Origami could be a good inspiration for new robots"; "I think it can do that but it will take time to become familiar with how it works"; "Very relevant to deployment and packing of dynamic, flexible and transportable structures"; "Yes, Robots are not limited to certain kinds of forms. All Origami structures can be utilised in certain way as robots"; "Yes, free shapes is very inspiring"; "I can imagine its use in creating emergency shelters"; "Yes, by enabling unique actoric"

❖ Question: How do you comment on the new Learning Space comparing to the traditional one?
"Interesting and Promising. New approach equips me with a skill of transform ideas into paper whenever I want"; "The learning space is more practical and in this way it is possible to experiment personally what I want"; "Excellent"; "Practical work is very useful and encouraged in my own teaching"; "I love the new learning place. It makes more excited on new knowledge"; "Yes, it opens up more creative thought"; "Workshop gives a better understanding especially when it is hands-on and to see a finished product-good entertainment." "Very nice space"; "The sculpture facility is amazing learning space for creative hands on work."

❖ Question: Any other comments for the lecturer/content?
"Excellent way of teaching"; "Really appreciate the enthusiasm and the patience"; "Content was perfect"; "Hope this content can be opened to architecture and engineering students as well"; "Very interesting with lots of possible applications"

(a) Team I design prototype (b) Team II design prototype (c) Team III design prototype



(d) All designs connected together

Figure 4: Course Part II 2nd session

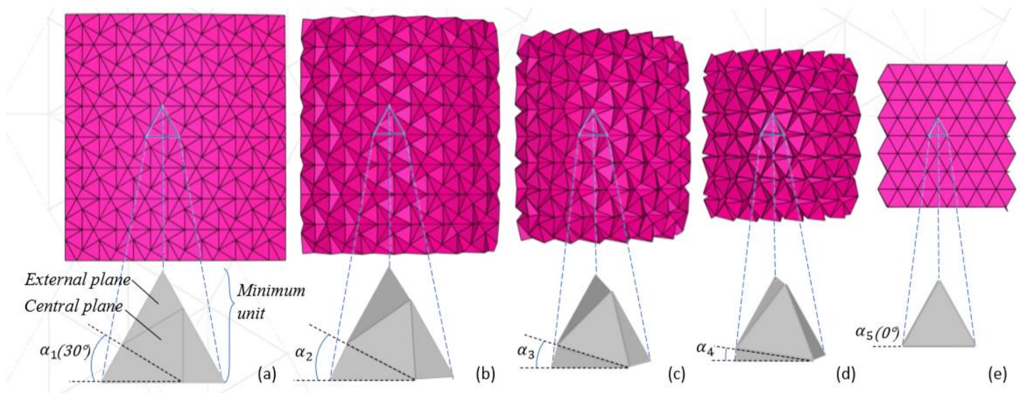


Figure 5: Course Part III: inspiration by the Resch Triangular Tessellation

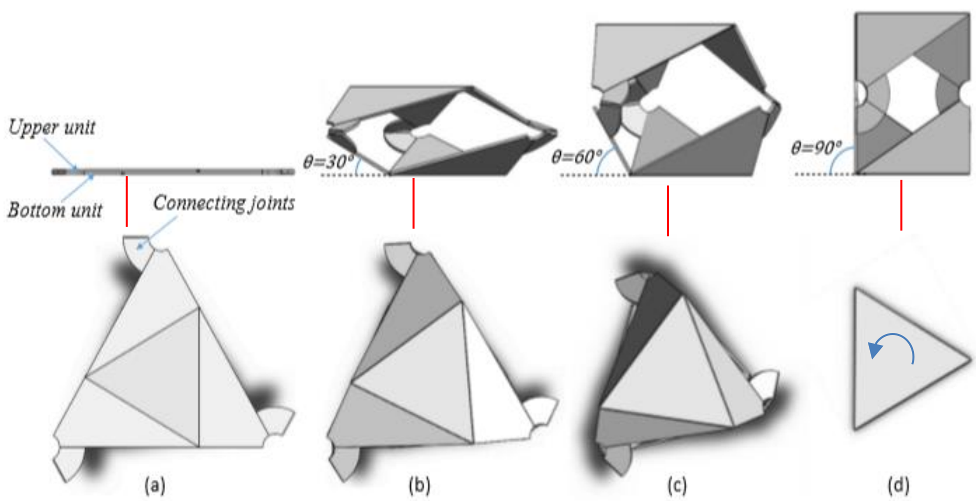


Figure 6: Course Part III: design of a twisting robot by connecting two Origami units

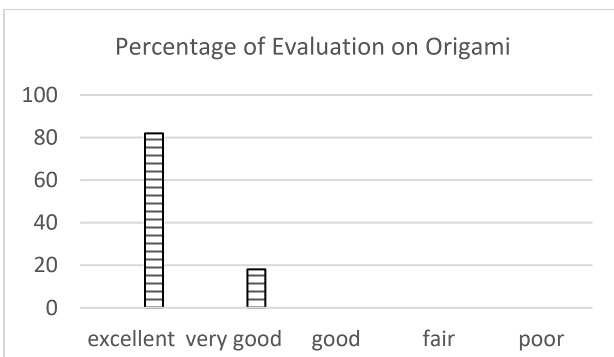


Figure 7: Evaluation from trainees

After completing the second-session hands-on workshop, further comments received from several trainees by email as follows:

➢ *"But I wanted to thank you for organising such an imaginative, original and very effective workshop. I learned a lot and thoroughly enjoyed it. My research area at the moment is on interdisciplinary,* *in particular arts and STEM collaborations (as you can see from the publication on my signature below) and I would like to keep on this list if possible please, and to continue attending other events on the subject that you may have."*

- *"Thank you making effort to introduce me into Origami. It was insightful and informative to see how something as simple as a paper transform into something that has interesting abilities. I am looking forward to explore more into Origami and how the techniques are used in robotics and mechanical engineering."*
- *"Thanks for organizing this inspiring and interesting workshop. I have learned lots of Origami techniques as well as stimulated my imagination from it. What's more, it's closely linked to my project, and I can not wait to apply the Origami in it. At last, thanks for Alex patiently teaching, hope I will have chances to get involve in this kind of workshop."*
- *"The Origami Workshop was interesting, and it has given me an overview of what can be built with Origami. There were also practical experiences in folding papers, and that experiences increased the student involvement and understanding. At the beginning was a bit challenging understanding how the folds have to be done, but at the end the result was impressive. In the last lesson, we were split in groups to figure out our Origami structure and solicited to be creative. It was a good way to work together and share ideas. Before taking this workshop, I thought that Origami is only about paper folding aimed to create something to play. I had never thought about the relationship between Origami and robotics application. This workshop showed me Origami from a new and very interesting prospective."*
- *"Many thanks for organizing the Origami workshops, which we found very interesting, and the final exercise working at larger scale in mixed teams very stimulating. We often refer to Origami in our teaching of both architecture and engineering students, and feel there is an untapped potential interest for such workshops to be offered to students in both schools."*
- *"It was a unique experience to have some hands on training with Origami folding patterns. While I find the folding of specific (animal) shapes, as it is most often taught in books, has little applications to engineering, I found it very fascinating to do some easy folds, that patterned over a sheet of paper, would greatly modify he mechanical properties of this paper. Therefore I found this course a much better introduction into Origami methods for engineers than most books about Origami I read in the past. Unfortunately I wasn't at the first lecture and can't say much about this. But one question that remained in my head was how different Origami pattern change the material properties and cause flexibility or stiffness in certain directions as well as create compliant mechanism in the structure. I would be happy to have an overview of some of the most used Origami patterns and their respective effects. On top of that I found the workshop well organized and where fascinated by the National Sculpture Factory, which I only have ever seen from the outside"*

From the above feedbacks, we can learn that students have greatly appreciated the Origami course that has changed their way in thinking about Origami and Robotic as well as stimulating new robot designs. Students also commended the new learning space using Origami in the National Sculpture Factory for robotics education.

4 Reflections

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.

- ***Reflection on Creativity in Design***. Engineering design classically begins at the drawing phase to be then refined and practically informed by the creation of a 3D working model. The time and related costs of this linear process means that it can be greatly limited by the availability of resources: By comparison, this program shows that origami can provide a new exciting, inexpensive and quick method to simultaneously sketch and make working articulated models from paper. This is an attribute associated with sustainability in engineering education. From a creative perspective it allows an effective materials-led design process of discovery for the student. While the discipline of origami uses humble materials such as paper, it is by no means simplistic. The mathematically proven axioms and geometry within origami provide an infinitely complex platform to stimulate students' creative thinking and problem solving on multiple levels, while simultaneously recording students' individual progress within the module.

This has already yielded successful results in the individual origami-based robotic project (Part III), where new origami inspired robots were created (Fig. 6). Used as an educational tool, origami promotes individual creative thinking but it also successfully allows groups of students to think creatively as a team (Part II). By working on a large scale students had to work together and collectively draw on their experience of origami patterns to creatively solve new technical challenges. These teams then finally collaborated to create a single deployable structure from their unique fold designs (Fig. 3d). This demonstrates origami as a medium that allows students to practice communication skills within groups and also between groups to be part of a larger and more complex creative design team.

- ***Reflection on Playfulness and Innovation in Design***. Innovation is the key to successful design and educational strategy. Two ways in which innovation can occur are through playfulness and by mixing different areas of knowledge and expertise. It has been our aim to nurture a comfortable, playful and inspiring environment by moving out of the traditional Robotics Engineering learning space that can sometimes be overwhelming for the students into the fresh creative surroundings of the NSF. We have chosen to introduce the discipline of origami to robotic education as it brings playfulness into the design process and mixes both of these disciplines. If this playfulness is combined with a specific real world task in the work space (such as grasping, lifting or moving), it may allow the physical properties of the paper material to interact with the environment of the workspace. This level of interaction could in some cases allow greater parity between the design task and the workspace environment, leading to increased successful robotic design by a passive dynamic approach (Collins, 2005).

- ***Reflection on the Value of Art in Engineering Programmes***. Origami is a recognized art form whose geometry and economy of line contain a certain aesthetic. By introducing students to these aesthetics and techniques it allows them to make exciting discoveries and create new complex articulated forms of their own. This helps to inform and inspire the design process in successful advanced robotic 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 in 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, 1948). 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. For the above reasons, art is an invaluable resource in this engineering program.

- ***Reflection on Other Considerations***. (i) A competent and experienced lecturer/tutor team is important to make the practical origami aspect of this program successful (Part I & Part II). As this course combines the communication of in depth knowledge from an origami artist and an engineer in robotics, a mutual understanding between these areas of expertise is essential. This cross disciplinary approach has allowed the maximum learning outcome for students. (ii) If this educational model is adapted for other engineering topics such as structure/ architecture, a theoretical mapping of the relation between origami and the engineering topic as the key should be designed appropriately in advance. (iii) The current Origami course is embedded into a 5- credit robotics module. In order to make an impact and spread this teaching method to a broad community, a full 5-credit Origami course would need to be established. (iv) In order to ensure that the tutor can provide essential close guidance to each individual there is a limit to the number of trainees for the practical workshop. In our Origami workshop, we set the maximum number to be 12 to match a 2-person tutor team.

5 Conclusions

By introducing Origami into Robotics education, we have demonstrated that Origami is an effective tool and media to teach Robotics and that Origami can be adapted to teach other Engineering topics such as structure and civil engineering. Origami is a sustainable media in promoting creation towards innovation. In the near future, we will show the final design products from students' CA projects.

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