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Promoting Engineering To K12 Students Through Spatially Challenging Making And Outreach Activities

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Workshop: Promoting Engineering to K12 students through Spatially Challenging Making and Outreach Activities

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ABSTRACT

Outreach activities are an important and valuable approach to promoting engineering education and careers to young people. They provide an excellent way to show that engineering can be fun, challenging and rewarding. With some careful thinking, they can also be used to promote and develop spatial ability, a cognitive ability that is very important to engineering. The purpose of this workshop is to demonstrate examples of outreach activities that are the result of such careful thinking. Those who attend this workshop will be able to:

1. Explain why and how spatial ability is so important to success in engineering education
2. Summarise findings from research on gender and SES differences in spatial ability
3. List some key features of hands-on outreach activities that require spatial thinking
4. Find and explain a lesson plan or set of instructions to run a spatial outreach activity
5. Suggest ideas for how they could adopt spatial thinking into their outreach activities

1 INTRODUCTION

Along with verbal and mathematical abilities, spatial ability is a primary factor of intelligence. Large scale longitudinal studies (e.g., Wai, Lubinski, and Benbow 2009) have shown spatial ability to be a more important than mathematical ability in influencing the selection of engineering as a career for young people. This has at least two implications for outreach activities that have an engineering content or theme. First, young people with low spatial ability may struggle at a cognitive level to engage with and succeed in these activities and may not find them to be as fun, challenging and rewarding as the instructors assume. If paired with a high spatial ability child who easily grasps the process and quickly completes the activity, a low spatial ability child may feel incompetent. The outreach activity may backfire and teach these low spatial children they are not suited to engineering. Second, outreach activities can be designed with the knowledge that participants will have varying levels of spatial ability. Extra supports/alternative paths can be provided to those with low spatial ability and/or activities can be designed to promote the development of this ability if even to a small extent. Promoting spatial ability development could be very empowering in other ways including transfer to improved performance in mathematics and other Science, Technolgoy, Engineering and Mathematics (STEM) subjects that are foundational to engineering. Those who provide engineering outreach activities should be aware of how spatially demanding their activities are and make sure all children, including those with low spatial ability children can engage successfully and even develop their spatial ability to some extent.

2 WORKSHOP

2.1 Workshop Design

In this workshop, we present a range of hands-on activities that can be used to both promote engineering education and careers to young people and expose them to spatially challenging activities, thereby achieving more through an outreach activity. The target age group for the workshop is 8- to 12-year-olds but a wider range of age groups was discussed during the workshop.

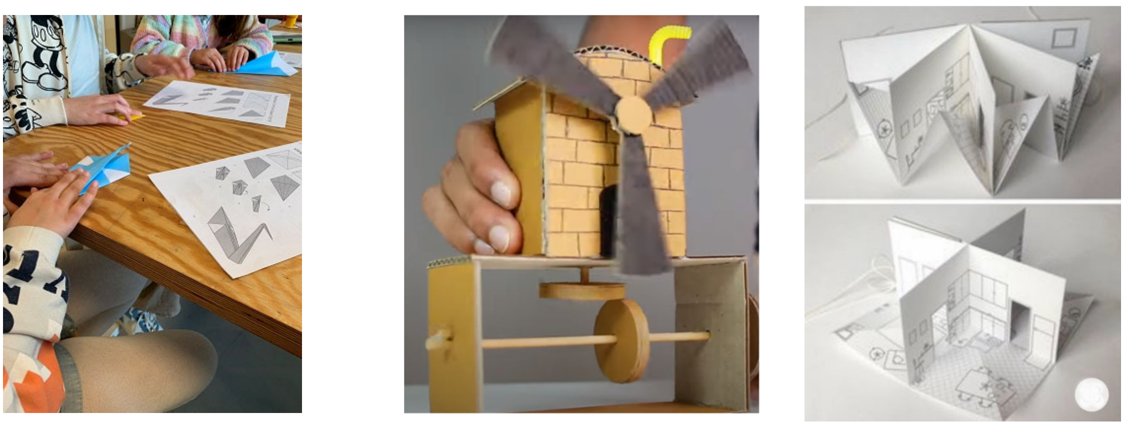
The workshop began with a short outline of why spatial ability is so important to achievement in engineering education with reference to several research studies on the topic. Attendees were then asked to form groups and engage with one of three different outreach activities that have been designed to expose children to engineering and to challenge them to exercise their spatial ability. These activities involve design thinking, problem-solving, 2D and 3D visualization and making and have been informed by an extensive review of the literature on this topic.

2.2 Significance for engineering education and attractiveness of the workshop topic

The workshop seeks to build on previous work that has been done on engineering outreach by adding spatial ability as a new element in designing and delivering outreach activities. In addition to thinking of outreach activities as fun, challenging and rewarding, we seek to include spatial ability as a key component so instructors ensure children with low spatial ability have a positive experience and even try to use the activities to promote development of this key ability.

2.3 Target audience, participant knowledge required, target numbers of participants and restrictions on size if appropriate.

Aimed at anyone who is or may be in a position to run or participate in an engineering outreach activity, the workshop requires little prior knowledge other than an understanding of what outreach is and that hands-on activities are a way to promote engineering to children. Given the limited time for the workshop, examples of completed artefacts were demonstrated rather than asking participants to make the artefacts themselves. No upper limit on numbers of attendees was imposed.



(a) Origami (b) Carboard Automata (c) Folded House

Figure 1. Examples of outreach activities that have a spatial ability focus.

2.4 Enhancement of knowledge and dialogue on the workshop topic

Spatial ability has been shown to consist of different factors, rather than being a single construct (e.g., Schneider and McGrew 2012). Mental rotation, spatial visualization and spatial orientation are factors that can be tested and developed through hands-on activities. Shown in Figure 1 (a), Origami requires paper folding and spatial visualization to see 3D shapes emerge from 2D patterns; it brings in a design theme or challenge. Cardboard Automata, shown in Figure 1 (b), has rotating wheels, cams and pulleys that require mental rotation and mechanical reasoning, both aspects of spatial ability. As a topic it can be easily connected to engineering. The Folded House, shown in Figure 1 (c), challenges participants to think in advance how a 2D pattern will become a 3D object; it has an architectural theme but can be adapted to other themes or contexts.

These different possibilities – Origami, Cardboard Automata and Folded House - were presented to those who attended the workshop. All were asked to join one of three groups, based on their personal preference for an activity. Within groups, members collaborated with each other to brainstorm a lesson plan for the activity. Each group then critically evaluated their lesson plans with regard to:

1. Creativity
    a. What is the potential for creativity development?
    b. At the start of the activity, should children be provided with finished artefacts or not?
    c. What is required to ensure creativity is not avoided?
    d. How can creativity be included in this activity?
2. Age
    a. What age group could you use this with?
3. STEM
    a. To what extent to which it will promote STEM.
    b. How do you see these promoting STEM or how can the STEM connection be emphasized?

Each group was then asked to report back on this evaluation.

3 RESULTS

3.1 Origami

Two lecturers from TU Dublin's civil engineering department participated in the origami part of the workshop. Most of the time was spent on a discussion on how the workshop could be adapted to their own teaching practice. Although the original origami activity was designed for children of late primary school-age, the participants noted a resemblance between the origami activity and the activities used in introductory courses for first-year university students. For example, the activity could be adapted for structural engineering courses to replace the well-known ‘spaghetti bridge’ activity, by having the students use modular origami parts instead of spaghetti. Adapting it to resemble subject-related material more closely could help to answer the ‘why?’ question that many students need as motivation, when the motivation that their spatial thinking skills will benefit from such an activity could be too abstract. This was the main concern that the participants had with the origami workshop: how can it be made explicit that this relates to STEM? Another approach the participants suggested was to adapt the activity to focus more on reverse engineering existing models in a group, which could also aid the students to learn how to collaborate. In conclusion, the participants found that with some adaptations, the origami activity could be an interesting way to introduce fresh first year students to fundamental spatial aspects of STEM practice, such as reading diagrams and visualising multiple transformations to an object, help them to think about creative problem-solving as a structured process they can learn, and finally be a good way to help the fresh students to make friends and practice collaboration.

3.2 Cardboard Automata

Six educators from universities across Europe and the UK participated in the Cardboard Automata workshop activity. The participants were asked to critically evaluate the activity with regards to prescribed criteria: creativity development, suitable age, and the promotion of STEM.

Initially the group actively explored the working examples of automata and reviewed a sample lesson plan and a detailed instruction booklet that were provided. The automata examples provided were developed by a range of age cohorts from ages 8 to 10 and 17 to 80 years in primary and tertiary levels. The participants feedback initially focused on the adaptability of the activity making it suitable for all ages even as young as 4 years old with the flexibility of increasing and decreasing its complexity to suit multiple learning styles and abilities. The participants discussed the flexibility of the activity agreeing the ‘narrative’ or creative aspect of the automata made space for educators to focus and adapt the activity to different scenarios and learning outcomes. Debate surrounded the provision of working examples both in terms of impacting creativity and motivation however it was agreed that examples of the working mechanisms and cam wheels was essential especially for younger cohorts. Participants also discussed the benefit of an instructional video played on a loop for younger children to enable independent engagement and problem-solving.

One of the main concerns centred around which aspect of the activity would capture children’s interest the most: the creative narrative above or the mechanical reasoning below (a central feature of the research project). It was noted that the children could spend most of the activity developing their favourite part and questions were raised as to how to emphasise the mechanical reasoning as the main learning goal. Would creative learners focus only on the narrative and vice versa? This became a key consideration with participants agreeing that the role of the teacher was key in providing clear instruction and managing the staged approach to the activity.

In conclusion, the participants found the automata to be an actively enjoyable ‘hands on’ project for engaging learners of all ages in STEM activities. With additional education supports in terms of ‘how to’ videos and explicit mechanism instructions especially for younger children participants agreed the activity would be suitable to all ages and could easily integrate into primary, secondary, and tertiary classroom environments and curricula. Participants also found the flexibility of the activity important enabling educators to relate learning to real-life mechanical systems, the potential to introduce technology, and emphasised the importance of creative problem-solving aspect of the activity.

3.3 Folded House

Five educators from institutions across Europe, the UK and the USA participated in the Folded House workshop activity. These participants were also asked to critically evaluate the activity with regards to prescribed criteria: creativity development, suitable age, and the promotion of STEM.

The group were provided with finished working examples of the activity, cutouts for active engagement and a set of printed instructions. The main discussion point centred on how easily the activity could be adapted to suit all disciplines within their own teaching practices (for example: build a lab and learn lab equipment in the context of chemistry education, design an exhibition space instead of a house in the context of general design). Participants found the activity could be made either very simple or more complex to suit learning outcomes or topics across multiple fields.

The folded house activity was designed to engage learners in 2D to 3D transformations and the participants agreed the learners would need the instructional sheet provided and working examples to engage successfully with the activity though 'hands on, minds on' theories of design learning.

Like the Origami Workshop, the participants suggested a reverse engineered approach to the folded house activity. Introducing technology, it was suggested that second and third level students could use CAD to work out the starting point or net of the house through hands on interaction with a finished house example.

In conclusion, the participants found that the activity could be developed to suit a broad age range from primary through to tertiary levels with increased complexities to suit older age cohorts. It was agreed the activity was flexible and could easily be adapted into their own teaching practices. The participants noted the relevance of the activity with particular focus on developing spatial cognition important to STEM disciplines including architecture, engineering, and chemistry.

4 SUMMARY

All three activities were considered to be suitable activities for promoting or exposing children (and adult learners) to STEM. Adaptations are needed depending on the skill level, mostly determined by age, of the audience and these adaptations can be easily implemented by e.g. providing a video to guide construction or a partially completed artefact. An interesting finding from the discussions was the potential for these activities to be integrated into existing STEM higher education courses such as using origami to demonstrate structural concepts to engineers or the folded house to create a pre-lab learning activity for chemistry students. The activities will now be adapted based on this feedback and delivered to children as part of the next phase of this research work.

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REFERENCES

Schneider, W. Joel, and Kevin S. McGrew. 2012. 'The Cattell-Horn-Carroll Model of Intelligence'. In *Contemporary Intellectual Assessment: Theories, Tests, and Issues., 3rd Ed.*, edited by Dawn P. Flanagan and Patti L. Harrison, 99–144. New York, NY: The Guilford Press.

Wai, Jonathan, David Lubinski, and Camilla P Benbow. 2009. 'Spatial Ability for STEM Domains: Aligning over 50 Years of Cumulative Psychological Knowledge Solidifies Its Importance'. *Journal of Educational Psychology* 101 (4): 817.