A STEAM X D WORKSHOP FOR PRE-UNIVERSITY STUDENTS: PREPARING STUDENTS FOR TRANSDISCIPLINARY APPLICATIONS

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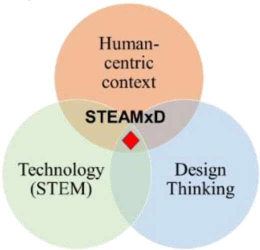
ABSTRACT
In this work, we introduce the Singapore University of Technology and Design (SUTD)'s STEAM x D (STEAM = Science, Technology, Engineering, Arts and Mathematics, and D = Design Thinking) multidisciplinary collaborative workshop, which was carried out for a total of 46 participating high school students (16-18-years old, 30% female). In this 5-day workshop, the students collaborated in teams of 4 to 5 members and interacted with 10 SUTD faculty members from several disciplines, 11 SUTD undergraduate helpers, and students from the Multi Rotor club to solve a design challenge. As part of our daVinci@SUTD immersion programme, which seeks to inspire youth in human-centred design and innovation that are grounded in STEM education fused with the understanding of Humanities, Arts, and Social Sciences to serve greater societal needs, students used a systems approach complemented with human-centric, design thinking, and technology-based elements, which prepared the students for a transdisciplinary application of competences. In general, survey feedback showed high levels of student engagement, awareness of using engineering, technology, and design thinking to solve real-life problems, and an overall students found the workshop useful. Design thinking was used to bridge the societal context (humanities, arts and social science) of real-life problems to the engineering and technological solutions through an interdisciplinary systems approach. This work will benefit those interested in transdisciplinary education, engineering design education, and those interested into finding principles for amalgamating faculty from different disciplines to work together into a meaningful and impactful project that prepares students towards a transdisciplinary application.

Keywords: Design Education, STEAM, workshop, interdisciplinary, multidisciplinary, transdisciplinary

1 INTRODUCTION
The SUTD curriculum places its emphasis on design-based projects focusing on active and hands-on learning [1] – [10]: starting from Freshmore year (defined as the first 3 terms - 2 terms in freshmen and 1 term in sophomore) to pillar years (terms 4 to 8), and finally ending with a 2-term long capstone (industry related) project (terms 7 and 8). This unique Big D framework empowers students to learn beyond the normal textbook knowledge and encourages a hands-on independent active, hands-on learning culture, ultimately leading to transdisciplinary application during a capstone project.
The STEAM workshop (STEAM = Science, Technology, Engineering, Arts and Mathematics, and D = Design Thinking) was structured as a designette [11] [12][13] wherein participants were provided with a design brief containing an opportunity statement, workshop narrative, deliverables, rubrics, and metrics. Students applied a design systems approach, which included: human-centric context, technology (STEM), and design thinking. The human-centric design developed a narrative of the workshop to highlight the humanistic component of the design challenge. The technological component ensured the transferring of abilities through a series of sessions to enable the participants to prototype appropriate solutions, while design thinking provided design tools to the to find potential solutions, but, most

importantly, bridged the other two components to drive the workshop towards a collaborative outcome, see Fig.1 (left).



	AM (9:00 am – 12 pm)	PM (2 pm – 5:00 pm)
Day 1	**Session 1: Societal Context** Workshop narrative, Humanities session, introduction to the Design Brief.	**Session 2: Design Thinking** Project design brief and design thinking activities.
Day 2	**Session 3: Physical World of Drones Session** Drone assembly, flight dynamics, forces at play.	**Session 4: Coding world of Drones Session** Block-based visual programming and learning to fly a drone.
Day 3	**Session 5: Space-age Fabrication Technologies** Training on using Automaker Fusion360 and Cura to prepare printing file.	**Session 6: Makers Space** 3D printing exercise and laboratory tours.
Day 4	**Session 7: Math & Analysis of Drones** Modelling and optimization of task (flight path) through the Traveling Salesperson (TSP) problem.	**Session 8: Experimental Design** Challenge preparation (Storyboard + prototyping + drone practice)
Day 5	**Session 9: Final Test Run:** Last minute preparations for competition and storyboard pitch.	**Session 10: Design Challenge Day** Drone competition + storyboard pitch.

Figure 1. STEAM x D lies at the interface of the human-centric context, technology, and design thinking (left). The workshop is created on a contextual reality, driven by Design Thinking, and implemented through STEM. Daily programme timetable (right)

According to a study by Dr Graham [14], the engagement of STEM to youth should be before university. Thus, a pre-university, a 5-days collaborative STEAM x Design Workshop was formulated and conducted in earlier January 2022 for 46 students (16-18 years ago) [15]. The 5-days programme was designed with a weekend (2 days) as an intermission for the purposes of providing reflection time for the students as shown in Fig 1 (right). Each day was separated into 2 segments (AM and PM) for the purpose of providing abilities-transferring training sessions. The participants were introduced to a design brief wherein the workshop was titled “Covid-19 Vaccine Cargo Airdropped to an Isolated Village Using Drones.” In addition, participants were introduced to a workshop scenario where they took the role of SUTD entrepreneurs (TECH NGO) undergoing a series of training sessions to rapidly acquire competencies needed to deploy a comprehensive cargo delivery service to remote areas. Finally, participants developed a problem scenario which included deliverables for day 5: (1) a drone challenge with its metrics, and (2) a storyboard 3-min pitch with its rubrics.

2 THE DESIGN WORKSHOP PROGRAMME

2.1 Day 1 AM Session 1: Socio-historical Context

SUTD’s STEAM x Design pedagogy foregrounds the importance of human-centred design. In the workshop, we highlighted its importance by introducing a session on equitable design run by faculty members from the Humanities Arts and Social Sciences (HASS) cluster. HASS’ main learning objective was to enhance the ability of the students to (1) identify and analyse socio-historical contexts of the drone service and (2) ensure equitable access to medical supplies. To that end, the session introduced two key principles: equity and empathy through interactive discussions and hands-on exercises. Using the World Health Organization (WHO) and World Bank databases, students first examined the correlation between Covid-19 vaccination rates and per capita GDP of Singapore, Nigeria, and India, to quantitatively explore global inequities in vaccination. Each group was then assigned a particular location for drone delivery in either Nigeria’s Kaduna State or India’s Himachal Pradesh. Students then went over academic journals and newspaper articles to gather more information about their locations, including challenges faced by historically marginalized communities in these areas. Specific challenges included vaccine scepticism, religious-based opposition to the use of vaccines, and a history of marginalization from medical services. Their exploratory research culminated in the *persona* exercise, where students developed a user profile to concretize their understanding of the specific cultural context and needs of communities in the location assigned for their drone delivery service. Based on this user profile, the students were then ready to begin work on their storyboard during the Design Thinking session in the afternoon session.

2.2 Day 1 PM Session 2: Design Thinking Tools/Methods

Students were introduced to the UK design council’s framework for innovation: the *double diamond* design thinking framework (discover, define, develop, deliver) as a guiding tool to the workshop deliverables. The discovery and define components of the design thinking process were finalized during this session through a series of tools/methods, such as *affinity matrix*, *storyboard, morphological matrix and c-sketch.* The session culminated in a redefinition of the problem statement from the design brief. By the end of the day, students had a clear idea of the deliverables expected for Day 5: a storyboard pitch and a drone challenge. A sample of the student working on the storyboard is shown in Fig. 2 (left).

Figure 2. Students working on their storyboard during their design thinking session in day 1 (right), and training session on VB programming of the drones in day 2

2.3 Day 2 AM Session 3: Physics World of Drones

Students learnt about the forces and torques that control the flight behaviours and dynamics of a simple quadrotor drone, and how to control the balance of these forces to make the drone fly in the air the way we desire. After introducing the basics of flight and how a multi rotor achieves controlled flight by actively regulating the speed and thrust of each of the 4 motors, the students moved on to flying an actual multirotor drone using a specialized controller (a stick controller). This specialized controller contains 2 joysticks that are controlled by the index and thumbs of each hand to allow independent motion of the drone in the altitude, yaw, roll and pitch axes. Since controlling all 4 motions at once is quite challenging for a beginner (it is akin to learning to ride a bike - learners must simultaneously balance as well as coordinate their arms and legs), we started off with just control of 1 direction (vertical up and down) and getting students familiar with altitude control (left stick). Once students were familiar, they then combined the altitude (left stick) control with the lateral motion (right stick) of the drone. Once students were able to do so, they then followed a pre-defined obstacle course and practiced their piloting skills.

2.4 Day 2 PM Session 4: Coding World of Drones

Once the students have mastered manual piloting of the drone, the next step was to program the drone to fly autonomously. Such an operation requires programming skillset from the students. To allow students who are new to programming as well as provide an avenue for more experienced students with programming background to leverage on each other, we elected to employ Visual Block Programming (VBP) to introduce the basic mechanics of programming and relate these concepts to an easily relatable 3D positional control of the drone. VBP is a kind of programming language that lets user create programs by manipulating program elements graphically rather than specifying them textually. It allows rapid programming with visual expressions, spatial arrangements of text and graphic symbols, such that it is synthesized in a manner that makes sense to humans (as opposed to text-based which ‘forces’ the programmer to think like a computer) as shown in Fig. 2 (right).

2.5 Day 3 AM Session 5 and PM Session 6: CAD for Additive Manufacturing

One of the challenges given the students was to fly the drone with a payload (a lightweight yet soft spherical ball) to mimic the delivery of a vaccine cargo to a designated location. To achieve the challenge, students needed to design via software and use 3D printing to fabricate a simple container that can hold the spherical ball yet allow for an easy drop-off of the payload. We took this opportunity to introduce computer-aided design (CAD) using Fusion360 software to design and model a simple bowl-shape container as shown in Fig. 3. Students experienced a typical workflow of modelling in Fusion360 and learned different basic functions, such as extrude, evolve, mirror symmetry, constraints, and fillet. Specifically, we emphasized parametric modeling as it provided flexibility for design modification and improvement later. Finally, we made use of Ultimaker Cura software to convert a .stl format 3D file to a g-code format file for 3D printing in the next session. In this session, students used a AnyCubic i3 Mega-S FDM 3D Printer in our SUTD Fabrication Lab (Fab Lab) to print their payload container. We also arranged a lab tour to the Fab Lab and the SUTD Digital Manufacturing and Design (DManD) Centre to broaden students’ horizons on numerous possibilities of 3D printing in industry and research in various applications, manufacturing processes, and fast prototyping.

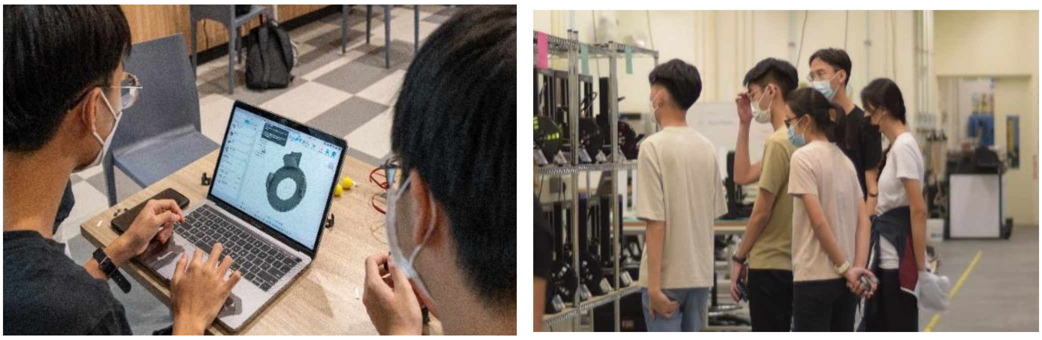


Figure 3. Training session on CAD drawing using Fusion360 (left) and students experiencing the 3D printing facility in the SUTD FabLab (right) in Day 3

2.6 Day 4 AM Session 7: Math Analysis of Optimal Fly Path

Following the lessons on how to fly a drone using VBP in Day 3, the students learnt how to design the route of the drones by re-casting the problem as a Traveling Salesman Problem (TSP). The key objective of the session was to teach students how to minimize the time taken for each flight path since each drone was only able to fly for a limited amount of time. Students were exposed to various strategies to find the most optimal path and were shown examples of how the TSP problem is applicable to many other applications, such as in manufacturing processes and in scheduling. As a simplest example, students were taught the brute force method to exhaust all possibilities to find the most optimal path. As a scaffolding exercise, students were first asked to calculate the number of ways for a journey with n vertices to complete the trip, and this was related on their prior knowledge on permutation and combination that they have learnt in school. The instructors then provided the students with a mock example containing 4 vertices and they were tasked to compute the shortest path. Through these two discussions, we introduced the idea of computational complexity, allowing students to appreciate that the difficulty of the brute force approach scales rapidly with the number of vertices. After demonstrating the tedium in solving the problem by hand, as part of a hands-on activity, students were taught how to generate the most optimal path using Microsoft Excel Solver, as well as to visualize the optimal path automatically on a generated graph within Excel.

2.7 Day 4 PM Session 8 and Day 5 AM Session 9: Experimental Design

In these sessions, students had the flexibility to organize their time and efforts according to their priorities and needs.

2.8 Day 5 PM Session 10: Drone and Storyboard Pitch Challenges

The exciting final challenge arrived for the students on Day 5 of the STEAM x D Workshop. The drone challenge required all teams to integrate and combine all the skills learnt during the sessions to complete the challenge task that was related to the overall theme of vaccine delivery using drones. To start, each team had to first modify and retrofit the drones provided to carry up to 2 vaccine payloads, which were achieved by using computer-aided design (CAD) and 3D printing technologies (from Day 3). As per the scenario, to minimize transmission of the virus, this aerial delivery had to be done without human pilots and the flying mission needed to be fully autonomous and attained through VBP programming in an optimized path (from Day 2 and Day 4). Each team needed to utilize the onboard 8x8 LED screen to inform the local population (who may not understand written language) that the team was non-hostile and was carrying medical supplies (from Day 1). Each team operated in a 12 x 7 m^2 region that was separated into 1 m^2 grids. Every team was assigned 5 random coordinates. One of them will be the home coordinate (where the team is home based) and the 4 other coordinates are where the team's drone needed to traverse. The order of the coordinates had to be optimized by minimizing the total travelling distance (TSP from Math in Day 4). At each of these 4 coordinates, the drone was required to carry out specific tasks (e.g., technological demonstrations, such as: land and take-off, 360-degree visual scanning, LED illumination, and payload release). These tasks must be fully automated and can only be carried out through programming using VBP (programming). The overall scoring was dictated by how precise the drones were able to reach each of the coordinates in the correct sequence as well as carry out the correct task at each coordinate. Teams were allowed unlimited tries within a 12-minute window and each team scored points by executing the correct task at the correct waypoint (see Fig. 4 (left)). Teamwork was critical as all these tasks were required to be carried out concurrently. As there were 2 teams flying within the same zone, teams needed to also communicate with each other to deconflict the flight zone.

Students in each group were given 3 minutes to give a storyboard pitch to convince the judges that they had the best systems-approach solution to deliver Covid-19 vaccines to rural villages. Each group was assessed based on their cultural sensitivity, geographical considerations, understanding of technology, logistics planning, clarity of message, and their unique selling point (USP). There were five judges, each with a different background (academic and industry) and disciplines (Social science, Physics, and Chemical Engineering).

Figure 4. A team executing their design fly path for a given set of coordinates (left), and a team during their 3-min storyboard pitch on day 5 (right)

3 WORKSHOP SUMMARY

Overall, here are some salient points, which are summarized in Fig 5.

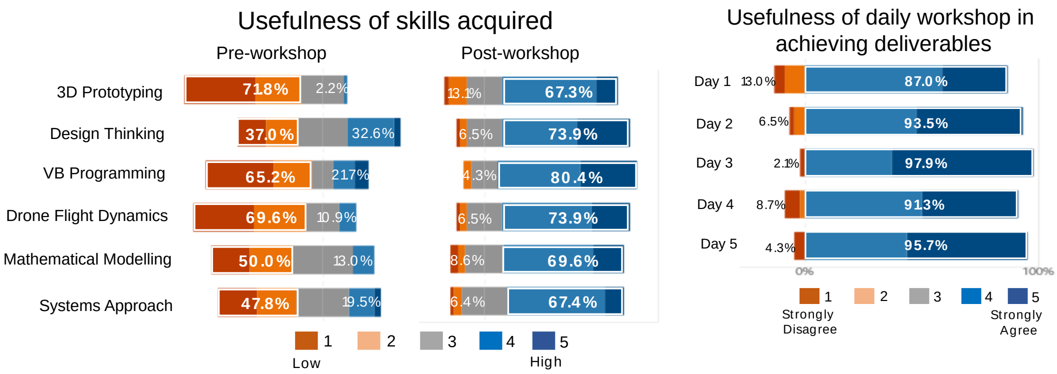


Figure 5. Student feedback on usefulness of skills acquired (left), and usefulness of daily workshops in achieving the deliverables on day 5 (right). Areas of improvement are the Design Thinking session and the emphasis on the Systems Approach.

All (100%) students agree that the workshop allowed them to experience, learn and apply human-centred design, technology, and engineering to solve real-world problems. Majority of students (> 80%) are more likely to consider undergraduate studies in engineering or technological design after this workshop experience. The students enjoy the most *Hands-on learning*, *Teamwork* and *Socio-historical context* of the workshop. All skills taught were found to be valuable (67-80%). The hand-on sessions are viewed extremely positive especially the 3D printing session on day 3 and the Design Challenge on day 5. And all sessions were found to be relevant in achieving the deliverable tasks on day 5. Overall, we believe that this unique 5-day collaborative workshop represents a unique opportunity to equip students with competencies required for a transdisciplinary application in a real-life context, wherein students are expected to problem solve in a different contextual setting. Furthermore, bringing faculty members to work together across their disciplines (Humanities, Design, Physics, Engineering, Mathematics) to create a workshop which larger than its parts was a novelty.

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