A TRANSDISCIPLINARY STEAM X D WORKSHOP ON AI RESCUE ROBOTICS FOR PRE-UNIVERSITY STUDENTS

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ABSTRACT
We apply the *STEAMxD* (STEAM = Science, Technology, Engineering, Arts and Mathematics, and D = Design Thinking) transdisciplinary framework to a different set of disciplines (i.e. Humanities, Artificial Intelligence (A.I.) and engineering), in a 5-day workshop which was carried out for a total of 95 participating high school students (16-18 years old) with the intention to validate our transdisciplinary training approach by applying a *STEAMxD* framework [1]. The students worked in teams of 5 students along 9 faculty instructors from different disciplines, and 10 undergraduate helpers, to solve a design challenge using a systems approach complemented with human-centric, design thinking, and A.I. elements. In general, survey feedback showed high levels of student engagement, awareness of using A.I., engineering, and design thinking to address real-life problems. Overall, the students found the workshop useful and insightful, validating the *STEAMxD* framework as an approach using design thinking to bridge the *social-ethical context* of real-world problems to engineering and technological solutions through transdisciplinary design and a systems approach. Specifically, we were able to construct a *socio-ethical context* for robotics through a human-machine interaction scenario and A.I. image recognition training that was showcased through a design competition comprised of a storyboard pitch and an AI-equipped rescue robot challenge. This work will benefit those interested in transdisciplinary education, engineering design education, and those interested in forming strong faculty teams from different disciplines to work together into meaningful and impactful projects that prepare students in transdisciplinary design.

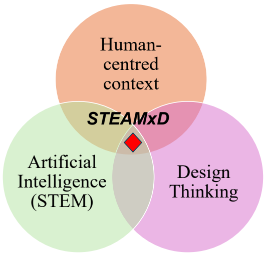
Keywords: STEAM, STEAMxD, design education, transdisciplinary education, human-centric, artificial intelligence

1 WORKSHOP BACKGROUND

Since we had developed a transdisciplinary design training workshop successfully for pre-university students in areas of *Medical Supplies* and *Drones*, we set forth to determine if the *STEAMxD* framework can be also applied to the topics of *Artificial Intelligence* and *Rescue Robotics*. As a result, a *STEAMxD* workshop (STEAM = Science, Technology, Engineering, Arts, and Mathematics, with D = Design Thinking) was organized as a designette [2-3], wherein students employed a design systems approach, incorporating a human-centric context, A.I. (STEM), and design thinking [2]. The narrative for the workshop, emphasizing the ethical aspect of the design challenge, was created with the help of social science. The A.I. component facilitated the transfer of skills through a series of workshop sessions, enabling participants to prototype suitable solutions. Design thinking, crucially, provided tools and methods to drive potential solutions and bridged the other two components, guiding the workshop towards a collaborative outcome [2-8], see Fig. 1 (left).

2 WORKSHOP METHODOLOGY

The use of design thinking methodologies has been receiving significant attention in education as a powerful framework for fostering creativity, collaboration, and problem-solving skills among students [9]. Design thinking helps students develop a deep understanding of complex problems and generate innovative solutions and is particularly valuable in education as it prepares students to tackle real-world challenges, adapt to change, and think critically and creatively across disciplines. Unlike traditional problem-solving, which follows a linear and structured approach, design thinking revolves around a human-centric innovation process, leading to enhanced solutions.



AI Rescue Robots Workshop Programme

	AM (9:00 am – 12:00 pm)	PM (2:00 pm to 4:30 pm)
Day 1	**Welcome + Humanities** External speakers followed by the Humanities session, design brief and workshop narrative.	**Design Thinking** Introduction of design thinking activities (e.g., storyboard, assembly, etc.).
Day 2	**Space-age Fabrication Technologies** Automaker Fusion360 + Cura Workshop to prepare 3D printing files.	**Makers Space** Fab Lab tour + 3D printing exercise, DManD and Dyson Labs tour.
Day 3	**Robot Assembly and Driving** Design and assemble of robots with the appropriate mobility and learn to drive to overcome terrain obstacles.	**Introduction to A.I. Principles** Introduction of A.I. concepts to train a robot to identify disaster victims amongst the rubble.
Day 4	**A.I. Image Recognition Training** Training neural networks to recognize human, animal, and object images under various disaster conditions.	**Self-Immersion Design** Challenge prep., including storyboard, A.I. training, and 3D prototyping.
Day 5	**Final Test Run** Practice at driving through disaster zone and finalize storyboard.	**Design Challenge:** A.I.-equipped rescue robot competition, storyboard pitch, and prize ceremony.

Figure 1. STEAMxD lies at the interface of the human-centric context, Artificial Intelligence (Science & Technology), and design thinking (left). Daily programme timetable (right)

The workshop is created in a socio-ethical context, driven by Design Thinking, and implemented through STEM. This concept aligns well with transdisciplinary education as design thinking can integrate arts, sciences, technology, engineering into a larger whole from its components, enhancing learning outcomes in these fields [10]. It has been argued that the engagement of STEM to youth should be before university [11]. Thus, a pre-university (16-18 years ago) collaborative *STEAMxD* workshop was formulated and conducted in January 2023 and January 2024 for a total of 95 students. As shown in Fig. 1 (right), each day was separated into 2 sessions (AM and PM) wherein the students were introduced to a design brief titled "Rescue Operation at a Disaster Area Using Robots Equipped with A.I. Image Recognition Technology" and to a *workshop scenario* where they seized the role of SUTD entrepreneurs (TECH NGO) undergoing a series of training sessions to rapidly acquire competencies needed to deploy search-and-rescue teams at a disaster site. Finally, students received information on the workshop deliverables for day 5: (1) A.I. Rescue Operation challenge with its metrics, and (2) a storyboard 3-min pitch with its rubrics.

3 WORKSHOP PROGRAMME

3.1 Day 1 AM Session 1: Socio-ethical context

The deployment of rescue robots, especially during an emergency, requires ethical deliberations. Ethical decisions to be made before the deployment of rescue robots are who to prioritize and who or what to deprioritize, and in a multi-site disaster setting, which site to focus on first and which site to focus on later. Different choices or strategies of rescue entail different risks to the victims and the robot and accompanying human rescuers. The stakes are real. In this session, students tackled a thought experiment, titled: '*The Prioritization Problem*', which mirrors the design brief. The primary aim of this thought experiment is to prime the students for more advanced ethical reasoning during the A.I. rescue operation challenge in day 5, such that they can 'transfer' the learning from this ethics session to inform their subsequent deliberations. In this thought experiment, a landslide has occurred and there are multiple casualties, which are unevenly distributed across the disaster zone, each characterized by a different risk profile. In the thought experiment, the first responder is an autonomous rescue robot that has been programmed to make hard choices on site: should the robot focus on the four kids huddled around an unconscious adult potentially hazardous boulder and fallen trees, or seek to map out the main site of the landslide, which is likely to have trapped many more people? Should the robot abide by the rule of helping the most vulnerable, the riskiest, or the most likely number of victims near the main site of the landslide? Importantly, every movement the rescue robot makes across the disaster area renders the site even more unstable, and recommending an optimal course to help different groups of victims is paramount. Students are then asked to justify why they have selected certain courses for the robot. In rendering their ethical deliberation explicit, students are then primed to undertake a similar line of reasoning throughout the duration of the workshop.

3.2 Day 1 PM Session 2: Design Thinking Methods and Tools

After introducing the students to ethical considerations, students were introduced to the *Double Diamond Design Thinking Framework* [12]. Afterwards, students were guided to complete 3 activities in the remaining 2 hours. In activity 1, each team was tasked to create 2 to 3 victim *personas* in a disaster area described in the design brief. In activity 2, each team was to choose one of the *personas* and generate a *problem scenario* and a corresponding *activity scenario.* A *problem scenario* is a narrative of current practice and user experience while an *activity scenario* describes how the *problem scenario* can be transformed with the use of social robotics technology. Each team went on to develop the *information scenario* and corresponding *interaction scenario.* The "Scenario-Based Design for Human-Robot Interaction" was developed by Y. Wang, inspired by the Scenario-Based Design framework proposed by John M. Carroll and Mary B. Rosson for Human-Computer Interaction projects [13]. This activity allowed students to evaluate user needs and to generate useful functions and properties to be designed for the A.I. robot for the rescue mission. In activity 3, each team was given the freedom to build a low-fi prototype using Lego bricks, Playdoh, and craft materials such as pipe cleaners, ice cream sticks, aluminium foil and craft eyes, see Fig. 2 (left, middle). Low-fi prototyping permitted for students to easily take apart their prototype, reiterate the design thinking process and iterate when needed. At the end of activity 3, students were presented with several examples of storyboarding and were given time to draft their own storyboard to prepare for the storyboard pitch on Day 5.

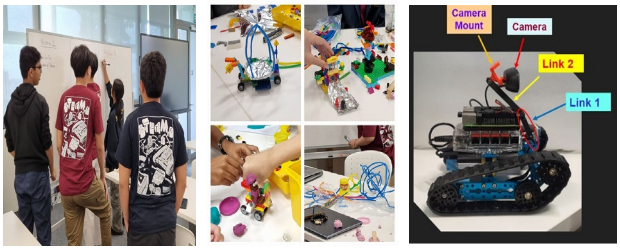


Figure 2. Students ideating (left), prototyping (middle), and camera links (right)

3.3 Day 2 AM Session 3 and PM Session 4: Computer-Aided Design (CAD) for Additive Manufacturing (Space-age Fabrication Technologies)

In this session, we introduced students to computer-aided design (CAD) and 3D printing as tools at the *Develop* phase of *Double Diamand Design Thinking framework*. Students were presented with the challenge to fabricate a structural arm to mount the camera onto the robot. To accomplish this task, students were required to create drawings and 3D print two camera connectors (Link 1 and Link 2) of different lengths as shown in Fig. 2 (right). We leveraged this opportunity in the morning session to introduce Fusion360, a CAD software to create 3D sketches of the connectors. Students experienced a typical workflow of modelling in Fusion360 and learned a variety of basic functions, such as creating sketches on different planes, extrude, evolve, mirror symmetry, constraints, and fillet. We also emphasized parametric modelling as it provided flexibility for design modification and subsequent improvements. Subsequently, students employed PrusaSlicer, a slicer software to convert a .stl format 3D file to a g-code file for 3D printing in the afternoon session wherein students made use of Prusa i3 MK3S and MK3S+ 3D Printers in our own Dyson-SUTD Innovation Studio to print the camera arms. We also arranged a lab tour to the SUTD Fabrication Lab and the SUTD Digital Manufacturing and Design (DManD) Centre to broaden students' horizons on various cutting edge additive manufacturing technologies that open up numerous possibilities of 3D printing in industry and research, for various applications, manufacturing processes and fast prototyping.

3.4 Day 3 AM Session 5: Robot Assembly and Driving

The Makeblock *mBot Ranger* model was used for the A.I. design challenge. The *mBot Ranger* comes with treads for locomotion, with separate light, sound, and ultrasonic sensors, attached to a modular mainboard which is compatible with Arduino and Raspberry Pi packages [14]. The components are mounted to a configurable aluminium alloy frame to form a moving robot. Students assembled the robot in its tracked configuration while a customized 3D printed arm was then attached to the robot using a specialized attachment plate. The other end of the 3D printed arm was then connected to the Logitech C310 camera that would be used as the visual implement for object detection in the design challenge.

3.5 Day 3 PM Session 6: Introduction to A.I. Principles

In this session, we set up a software pipeline that is not only powerful but also cost-effective. This included YOLOv5 [15], an advanced computer vision model that the students learned to train, fine-tune, and execute an object detection model.

At its core is a convolutional neural network. The students learned to train this model using a Jupyter Notebook with a Python script that was easy to tweak. The script utilized the complimentary storage capabilities of Google Drive to keep their materials and work safe while the training was performed online using the Google Colab [16] environment, an online service that let us use a virtual computer to execute our script. For the crucial step of image labelling, we used the Roboflow [17] online platform, a user-friendly website for image annotation. The labelled images were then exported from Roboflow and uploaded to Google Colab. Once they had the trained weights, they uploaded the weights onto a Raspberry Pi via MS Remote Desktop, hence allowing our students to perform *model inference* using the robot's camera remotely. This software pipeline effectively demonstrated the end-to-end process of developing an AI model to students, see Fig. 3 (left) for the overall process. We provided figurines for students to take pictures or videos (see Step 1), then these pictures are loaded into Roboflow, which we leveraged to annotate the taken pictures; see Step 2. A key challenge is the exact, consistent, and comprehensive labelling of objects using tight boxes. Overall, we instructed and guided the students to aim for a large and diverse data set to achieve the best results in model training. Steps 3 to 5 represent the actual training and evaluation performed in the Google Colab environment. In the augmentation, the students can apply general transformations to the dataset. For example, if the resolution differs between the camera on the robot and the camera used to collect the training data, the students can adjust to this before starting the model training process. The first AI session aimed to produce a baseline model and provide the students with the tools and techniques to optimize it further.

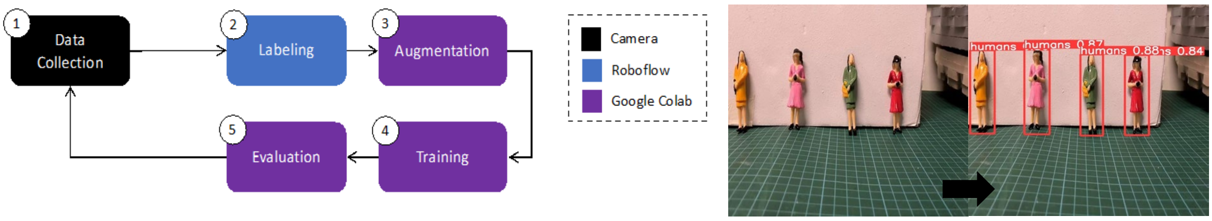


Figure 3. A.I. training workflow (left) and an A.I detection illustration (right)

3.6 Day 4 AM Session 7: A.I. Image Recognition Training

This session introduced the *model deployment and inference.* The robot was equipped with a Raspberry Pi, which via remote access from their laptops, the students could copy the machine learning model (i.e., only its parameters) to the Raspberry Pi and place it in the already prepared folder structure. A ready-to-use Python script allows the students to take pictures with the onboard camera and observe how the model automatically annotates the objects in the picture, see Fig. 3 (right). After evaluating their first model, the students must identify deficiencies of their model by testing it on several scenarios. For example, they might observe that an object is undetected or misclassified. Therefore, it was essential to extend the training dataset. For instance, their initial data needed to be more representative of a particular class of interest, or they needed to take pictures from additional angles under different lighting conditions. This experience not only solidified their theoretical knowledge but also provided a foundation for critical thinking and problem-solving skills in A.I. applications.

3.7 Day 4 PM Session 8 and Day 5 AM Session 9: Self-Immersion Design

In these sessions, students had the flexibility to organize their time and efforts according to their priorities and needs, such as CAD printing, A.I. object recognition training and optimization, robot piloting and camera feed.

3.8 Day 5 PM Session 10: A.I. Rescue Robot and Storyboard Pitch Challenges

The A.I. rescue robot challenge required all teams to integrate and combine all of the competencies learnt throughout the workshop. The challenge scenario consisted of a populated area hit by a landslide wherein students undertook the role of rescue robot operators to overcome the complicated terrain displaying potential risks to human rescuers [18, 19]. The modified Makeblock robots were piloted by the students to navigate through the terrain using both direct sight and the camera feed. Teams detected a set of figurines placed within the arena and scored points based on number of accurate and successful detection of selected objects, and whether they could complete their journey through the arena within the allocated time. The arena was split into two terrain zones, the outdoor disaster zone at a populated urban area, and an indoor disaster zone set within a hospital site context. At specific locations, the robots, piloted by the student teams, had to choose their paths based on ethical considerations, such as choosing to save a VIP vs a larger group of injured civilians. The teams would score points based on the quantity of objects detected with their trained object detection model, and whether they fall into the correct object class categories, human (5 pts) or pet animals (3 pts). Points for obtaining bonus objectives were also awarded to teams. Furthermore, each student team were given 3 minutes to give a storyboard pitch to convince the judges that they had the best systems-approach solution to deploying A.I-equipped rescue robots to the disaster area. Each team was assessed based on their ethical sensitivity, geographic considerations, understanding of A.I., systems design, clarity of message, and their unique selling point (USP). There were 4 judges, each with a different background (academic and industry) and varied disciplines (Social science, Physics, and Engineering).

4 WORKSHOP RESULTS

The student self-perception of the workshop is summarized in Fig 4 below.

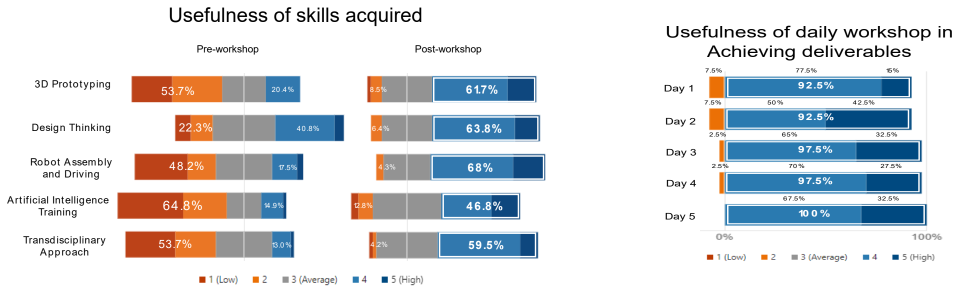


Figure 4. Student feedback on usefulness of skills acquired (left), and usefulness of daily workshops in achieving the deliverables on day 5 (right)

All respondents (40 students) agreed that the day 5 design challenge competition allowed them to experience, learn, and apply human-centric design, technology, and engineering to solve real-world issues. 90% of the respondents declared that they are more likely to consider undergraduate studies in engineering or technological design (not shown), and the activity students enjoyed the most were *Hands-on learning, Teamwork* and the *Socio-ethical context* discussion of the workshop (not shown). All skills imparted were found to be valuable, especially the CAD 3D printing prototyping session on day 2 and the A.I. training on days 3 and 4. In addition, 70% of the respondents found the pace and depth of the workshop “just right.” Finally, 68% of respondents at the end of the workshop recollected the theme of ethics, and when combined with the two key words repeated the most, *ethics* and *decision*, it implies that students did not see the topic of robotics in isolation, but rather as an intricate design component within a larger system – as a transdisciplinary design exercise.

5 WORKSHOP DISCUSSION AND SUMMARY

Taken together, and after 2 consecutive years, we believe that this unique 5-day collaborative workshop programme offers a unique opportunity to equip students with 21st century competencies required to practice, within a university setting, transdisciplinary design, wherein students are expected to problem-solve in contextual settings beyond the classroom. The *storyboard challenge* with its rubrics to allow students to showcase their systems understanding of the problem and potential solutions, and the *design challenge* with its metrics to allow students to display their technical skills, proved to be an integrated, intricate, and strong component of the workshop. In summary, this *A.I. Rescue Robotics* workshop validated via positive student self-perception feedback our transdisciplinary design training approach, which was previously used successfully to another workshop based on *Medical Supplies* and *Drones* [1], by applying the *STEAMxD* framework of bringing faculty from different disciplines (Humanities, Design, Physics, Engineering, A.I.) to work together to create an integrated designette (product) that is larger than its comprising units. Finally, this work provides valuable insights on how transdisciplinary design education can be delivered within the classroom using social science/humanities, technology, engineering, and design thinking for solving real-world problems.

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