PROJECT BASED LEARNING IN THE CONTEXT OF CUTTING-EDGE ROBOTICS COMPETITION

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ABSTRACT
RoboMaster is an annual robotics competition pitting student's cutting edge robot designs in a Multiplayer Online Battle Arena (MOBA) gamified shoot-out battle. The highly technical-advanced competition rules are designed to encourage innovation in robotics automation and intelligent systems while placing robot battles at centre-stage. It manages to display the beauty of engineering technology and popularize robotics to the wider audience by balancing technical challenge and entertainment value. Hong Kong University of Science and Technology (HKUST) sees RoboMaster as a unique platform for promoting STEM to the wider university student body. Through 4 years of team development and student participations, we have homegrown a group of outstanding scientific and technological engineers who have excelled in both academic research and entrepreneurial ventures. In this paper we review the development, growth and success of the 4 years of the HKUST RoboMaster ENTERPRIZE team and evaluate assessable learning outcomes of the competition as a project course. The degree of engineering design complexity and resulting the comprehensive learning outcomes, inspired the launch of a new bachelor programme in which many foundation engineering courses are replaced by year-long cornerstone project courses mirroring the RoboMaster project course. The outcome is a more individualized high-impact programme allowing students to build their engineering studies around technologies of our time.

Keywords: Project-based learning, multidisciplinary robotics competition, team-based design

1 INTRODUCTION
Project-based learning (PBL) has been proven effective in many contexts [2] and encouraging student teams to join competitions are also common in higher education [4]. In recent years, these two activities have combined in pedagogical innovation to provide even more well-rounded and comprehensive learning opportunities for students in engineering design.

Launched by DJI a few years ago, RoboMaster is one of the largest and most popular robotics competitions in the world. In the past game year, RoboMaster attracted around 7,000 students from 173 university teams around the globe to participate, while millions of live and online audiences watched and cheered on. It attracts millions of students and technology hobbyists by its overwhelming competition theme, exciting visual impact and intense competition. DJI hosts the competition in hope for creating a positive landscape for robotics industries drawing attention through its intense battles, strict scientific standards, and innovative event schedules. There is also a genuine desire to promote and co-develop project-based learning components to universities in the region.

Project-based learning has shown real success within the HKUST campus in uncovering students' makers potential and extending their learning beyond the traditional classroom. Survey of global emerging trends in education innovation strongly indicates the move towards multidisciplinary, student driven and highly individualized programme design [1]. HKUST RoboMaster team also helps drives on-campus advanced prototyping facilities and an open technology laboratory. Through experiments and tests in robotics competitions, scientific theory and practice are more closely integrated.

In this paper we review the development, growth and success of the 4 years of the HKUST RoboMaster ENTERPRIZE team and evaluate assessable learning outcomes of the competition as a project course. We believe that this model could be a suitable blue-print for the engineering design education community in creating more formal scaffolded education programme towards student competitions and providing students with recognition and assessable learning outcomes that can help in their academic and career development.

2 THE COMPETITION

The match itself is arguably the most advanced and complex robotic competition for undergraduate students in the world. Each team is to engineer 6 type of robots and each type of robot has different roles and functions within the whole game. Taking RoboMaster 2017 as an example, there are two kinds of shooting pellets: 17mm small plastic pellet and 42mm golf balls that would result in different scoring against opposite team. Base robot is a fully autonomous robot with self-defence mechanism using computer vision to identify incoming attackers. Infantry robots that can load and fire 17mm pellets are remote-controlled robots with maximum agility and manoeuvrability. Hero robot is a remote-controlled robot that can load and shoot 42mm golf balls for offenses or disablement of enemy base. Engineer is a remote-controlled robot providing supporting function such as transporting energy-depleted robot to re-charging station and refilling ammunition for the Hero robot. The Supply Depot automatically loads 17mm pellets to Infantry. Finally, the team must programme a remote-controlled drone to unlock game's power play.
The game is an 8 vs 8 strategic robot combat game. Each game has two teams (Red Team and Blue Team) fighting against each other through shooting pellets to deplete opposing team's overall energy. The game field of 18m x 10m takes centre stage at the Shenzhen Bay Sports Centre every year. The 2017 game field shown below hints at the strategies involved in playing the game.

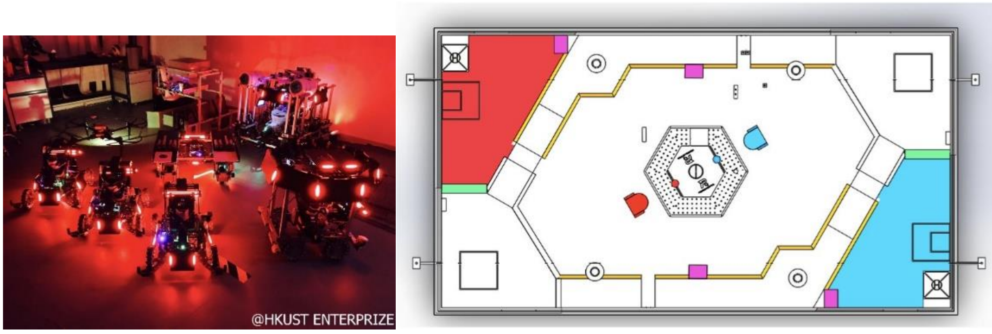


Figure 1. HKUST Enterprise 2017 Fleet and Game field

First gamer's viewpoint for the 6 remote-controlled robot makes the game exciting to watch and to participate in. Certain systems that need to be implemented by students in all robots from all teams include Ultra-wideband (UWB) used to accurately locate the robots, rectangular pressure-sensing plates measuring pellet hits and working as part of the game judging system, and live video streaming stacks to provide robot's view to the control station and audience viewing.
New elements are introduced in the game each year either as an additional robot requirement or in the game rules. In 2017, there was a focus on robot automation and image processing. Infantry was to be equipped with computer vision to identify and shoot at target symbol randomly appearing in a 3x3 matrix to unlock a period of power play. Drone was introduced as a required robot in 2018 which focuses on stable take-off and landing. The drone was further required to drop golf balls at enemy's base accurately in 2019. An autonomous base defending robot, Sentry, that is mounted and slides on a rail was also introduced in 2019.
While new elements are introduced, the base chassis and platform are common to many of these robots, therefore teams with prior years' experience and development have the advantage of building upon mechatronics design and codes to tackle the new games' challenges. Documentation and knowledge transfer therefore becomes an important part of each university team. Since 2016, HKUST ENTERPRIZE team has established on GitHub detailed version control codes, hardware and mechanical designs, and accumulated training materials, manufacturing and supply chain records to be shared with succeeding teams.

2.1 Engineering Complexity

The competition prides itself with the demanding engineering requirements in order to satisfy basic system tests to enter the competition. Each robot, stand-alone, is a fully functional product that would challenge even trained engineers. A sample short list of basic skills and knowledge necessary to build any of the robots include:

- Mechanical locomotive and suspension design
- Pneumatic or electrical actuation and control
- Kinematic analysis for Mecanum wheeled vehicle
- PID controller
- Circuit board design and prototyping
- MCU programming: drivers, communication protocols stack, etc.
- Power storage and distribution

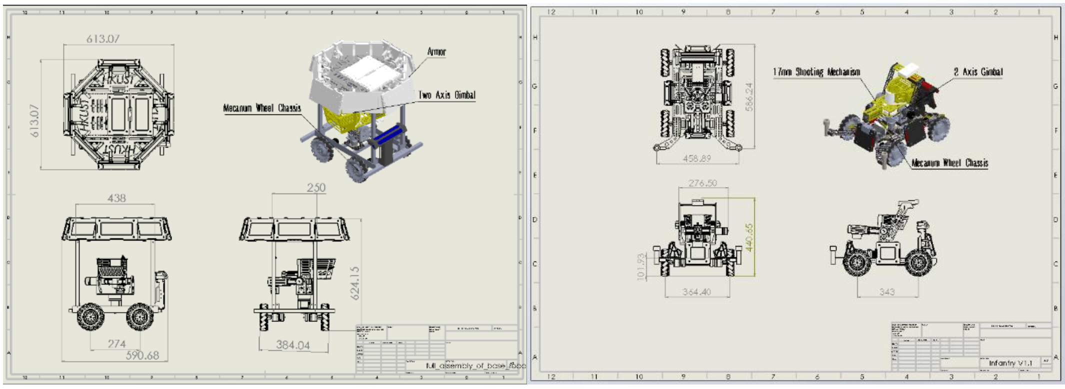


Figure 2. Engineering Drawing of Base and Infantry of HKUST Enterprise 2017 Fleet

2.2 Advanced Project Management Training

For the HKUST ENTERPRIZE team, all level of students is welcome and in the team formation process, commitment and learning ability are given more weights than prior experience. However, there is only about 9 months for the teaming, R&D and build of the set of 8 robots yearly. A highly intensive training and development timeline is therefore needed.

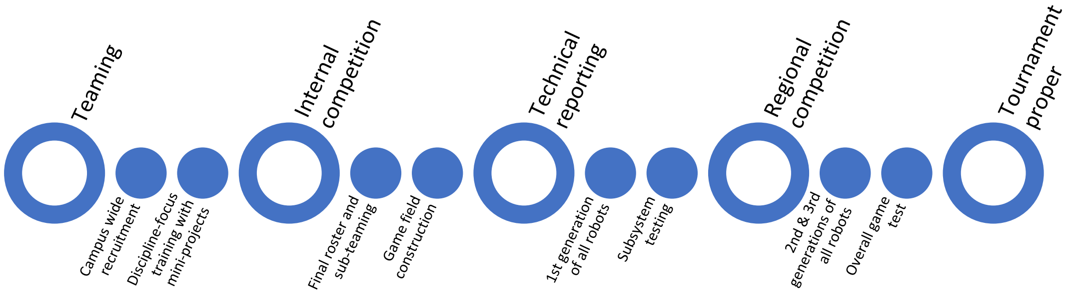


Figure 3. Project timeline from recruitment to tournament (Oct to Jul each academic year)

3 ROBOMASTER AS A PROJECT COURSE

The project is framed as a 4-credit course at HKUST, and it spans over the spring and summer semesters. Students who are officially selected into the team after the internal competition can enrol in the course. In this section, we will describe characteristics of the project course.

3.1 Training by Disciplines and Mini-Projects

At the beginning of the academic year, right after recruitment is completed, a 5-day intensive tutorial followed by 5 weeks of mini-projects and homework help students to learn the basics. The training is mainly divided to two technical streams with the following training covered.

Mechanical Team

1. Basic skills and competence in SOLIDWORKS 3D CAD design
2. Basic knowledge and usage on non-powered mechanical tools and parts
3. Basic skills and competence in manual handwork
4. Basic knowledge and usage on 3D printing
5. Basic understanding of mechanical design and manufacture process and thinking

6. Basic knowledge and usage on pneumatics

Hardware and Embedded System Team
1. C program basic and RTOS Introduction
2. Basic electronics: basic PCB, wiring, connector soldering
3. Basic STM32 Programming: GPIO programming, config GPIO to control peripherals
4. CAN communication
5. Basic PID controller motor tuning
6. Mecanum wheel kinematics

3.2 Internal Competition

A unique feature of the ENTERPRIZE team is the use of an early internal competition for delivering learning components, teaming and screening (in order of importance) at the end of 2-month training. Just as the RoboMaster match itself, the internal competition game rules change every year. In the mock-up competition, teams of 5 are to develop from the chassis of Infantry a remote-control robot tackling mini-challenges that echo certain requirements from the real competition. The idea is to practise agile product development within 2-3 short weeks to 1) identify students who are versatile in the process and 2) test solutions to bite-sized engineering problems from the main competition. E.g., in 2018, hardware students were asked to develop new board to include P/S distribution, XT-30/ XT-60/ GH 1.25mm compatibility, DBUS invert, 24V to 5V regulator, within 2 weeks. As for the internal competition of that year, teams were to build an 'Engineer' robot to pick up and load ammunition into an autonomous 'Turret' robot that shoots at a display when certain number appears.

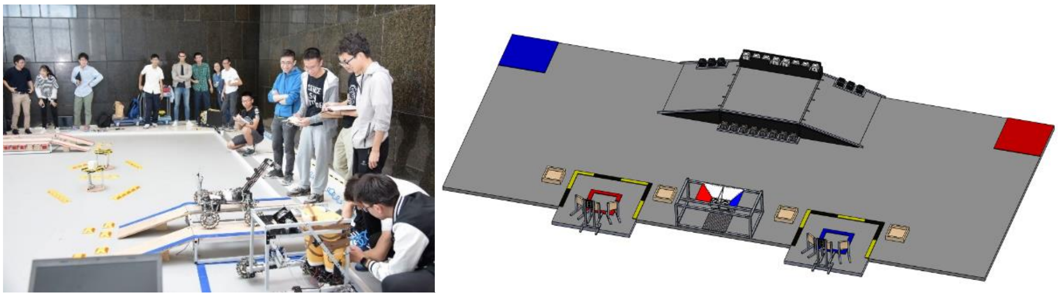


Figure 4. Internal competition in 2017 (left) and Internal game field of 2018 (right)

3.3 Team Organisation Structure

ENTERPRIZE team when founded in 2016 was only run by 8 HKUST robotics fanatics representing HKUST at the RoboMaster competition. The team has grown in the past 4 years to 40 people strong in 2019; which is still considered undermanned compared to top winning teams of 50+. Its performance has also risen through the ranks; established as champions in the international qualifier for 4 years in a row and reached top 12 out of 173 teams in 2019. Literature has shown how a large team size manifests as a technical project management challenge to the students and faculty alike [3]. The team organization is mostly student-driven with guidance from supervising faculty. Operating like a real-world engineering team, each student reports to his/her technical manager for platform design, and 'robot' product manager for functional feature design and implementation.
The competition is highly costly with the multiple generation of iterative prototyping needed to bring the robots to game-ready. Each year, 2-3 students also focus on promotion and fundraising, and they have been successful in obtaining sponsorship from ADI, Infineon and Kerry Logistics in the past.

4 LEARNING OUTCOMES AND IMPACT

At the end of the 2019 season, a survey was conducted with past members to assess the impact the project course has made. So far, 50 students responded with 10 studying in graduate schools, 5 working in technology companies and 35 are still undergraduate students.

4.1 Technical Competencies Development

Within the multidisciplinary project course of heavy technical focus, many students have expressed that they learned more effectively and developed deeper understanding of some concepts that are normally taught in class. To obtain quantitative assessment of the phenomenon, students were asked to estimate proportion of courses that could be covered by learning components achieved in the project course.

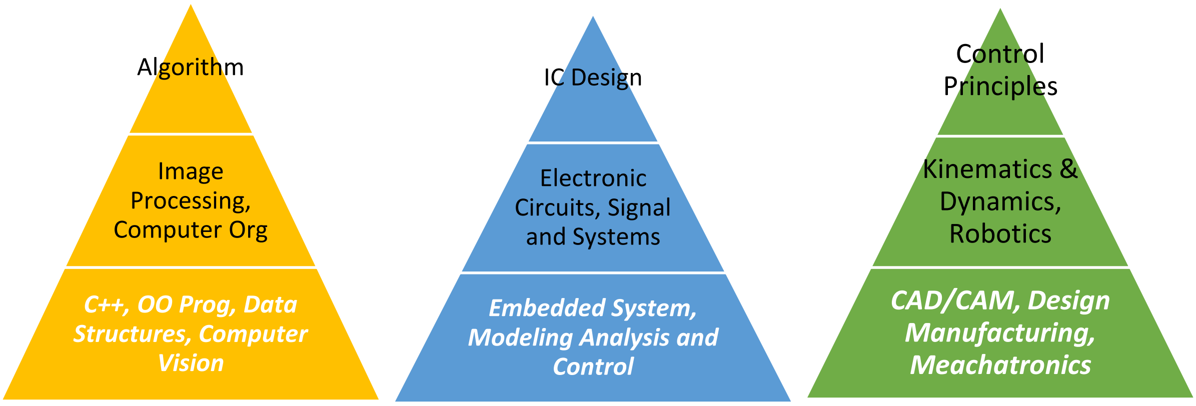


Figure 5. Foundations in Computer Science/ Computer Engineering CS (yellow), Electrical and Electronic Engineering EE (blue) and Mechanical Engineering ME (green) formed by students within their learning experience in RoboMaster

4.5% of all response entries even went as far to claim that 100% of certain course is covered in their ENTERPRIZE project experience. The data summarized above are useful when consideration is made to turn courses into PBL mode and/ or the possibility of offering course credit equivalence if specific project components are fulfilled and demonstrated in ENTERPRIZE.

Equipped with this feedback from the multidisciplinary group and recognizing the needs for new model for engineering education, a new degree programme of Integrative Systems and Design (ISD) [5] was founded in 2017 with special year-long cornerstone projects mimicking the structure of the RoboMaster project course. These projects provide a platform for ISD students with different disciplinary strengths to develop their design and engineering competencies through student-driven project-based learning.

These new courses took lessons from the RoboMaster project course in advancing students' knowledge, competencies and abilities in systems design and/ or disciplinary technical focus (CS/ EE/ ME).

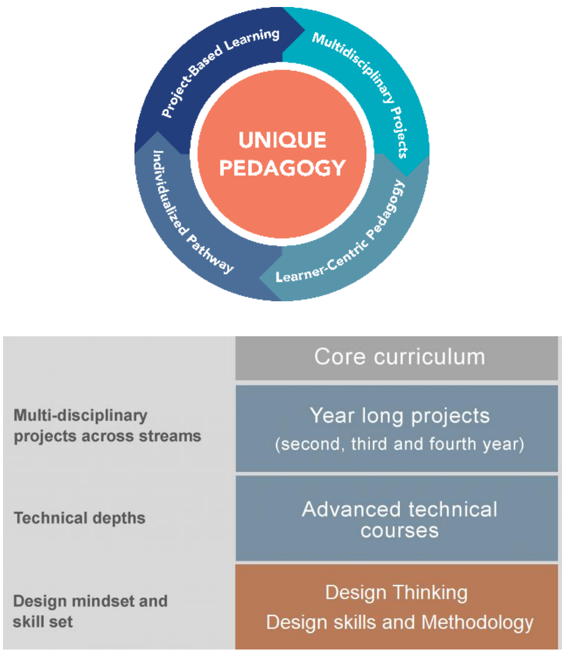


Figure 6. ISD Degree Programme Characteristics

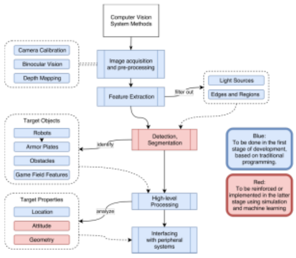
4.2 Research Competencies Development

Aside from hands-on robotics skills, the additional challenges put in the game each year also encourages some students to go through more rigorous academic research process and develop theoretical understanding in order to create competitive solutions. Three examples from investigative studies to white papers are listed below.

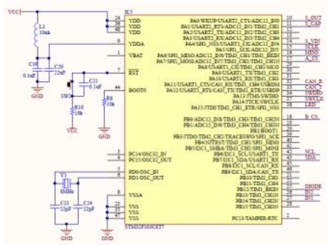
Table 1. Research publications from ENTERPRIZE and illustrative photos/diagrams

2016 When the pellet shooting mechanism was in its infancy stage, a Year 4 mechanical student Jack Zheng designed, performed and documented sets of experiments to select the right type of high-speed silicon parallel rotating wheels and the 'pellet' barrel to optimize the 'shooting mechanism in a 10-page report. Testing was done with various motor speed (20-30m/s), frequency of shot made (5-10/sec) and clearance for pellet passing (57-60mm) evaluated against shooting accuracy, precision and abrasion to the barrel.

2017 As the computer vision requirement increased to support autonomous tracking and aiming of enemies' pressure plates for higher precision shots, the PG teaching assistant Beck Pang presented his work at ICRA (International Conference on Robotics and Automation) that year using computer vision and machine learning to simulate and experiment the control algorithm to position of the Infantry robot and its gimbal for best aiming.



2018 Year 2 student Alex Wong designed a super-capacitor module through inventive power switching between when the chassis is operating vs. when it is at rest. The design contributes to higher instantaneous acceleration for the Infantry robot. His work was submitted as a white paper to the competition organizer's call for innovation entries and won an additional paper award.



5 CONCLUSIONS

For four years, under the theme and motivation of competing in advanced robotics event, RoboMaster, HKUST has developed a multidisciplinary credit-bearing project course and about 100 students have participated and contributed to the growth of the student-driven endeavour. Beyond being a typical extra-curricular activity, the course has shown potential in supporting students' technical advancement and developing students' research capability. The lessons learned in design education pedagogical approach has inspired the creation of a new degree programme focusing on using similar project courses as cornerstones to integrate disciplinary technical learning, an alternative to the traditional model.

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