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GLOBAL PRODUCT DEVELOPMENT: PROJECT-BASED MULTIDISCIPLINARY JOINT COURSE

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ABSTRACT
Over three years 2016-2019, four top universities in Asia joined hands in offering a truly collaborative course ~ Global Product Development (GPD). Leveraging modern teaching tools to overcome geographical and cultural separations, the joint course provided unique learning opportunities for 180 undergraduate students. The high-level course objective was to prepare students to face future global challenges by providing the project-based experiential learning opportunity in developing a human-centred product from early conceptualisation to deployment. Lean product development cycle is used as a guide to help student teams in bringing to potential users a Minimum Viable Prototype (MVP) in the shortest time and at lowest cost. Students work in multidisciplinary and multicultural teams to iterate through (a) seeking and defining a global design problem, (b) developing the engineering design alternatives to solve it, and (c) building prototypes of different levels of fidelity to support the product development. Within the span of a 15-week semester, the project teams learnt from real-time video-streamed lectures, collaborated through different online tools, and worked and presented during 3 face-to-face meeting opportunities at the three campuses. Strategic milestones and checkpoints are embedded to maximise project learning and allowed flexible yet accountable assessment mechanisms. In this paper, we will share the iterative course design, the three parties' contributions, effective online tools used to manage students' communications and progress, and the challenges and rewards in the joint venture. Finally, a start-up success will be discussed in the paper to illustrate distinctive impact of the joint course.

Keywords: Project-based learning, capstone course, multidisciplinary engineering education

1 INTRODUCTION

Reinventing engineering education has been on the agenda for many leading education institutions, and the collaborating universities here shared similar goals as budget is allocated into education innovations. There have been many attempts to turn upside down the model of engineering education through problem- and project-based learning [6] and it is widely agreed that learning as part of a multidisciplinary team enriches the learning experience both in developing technical competencies and collaborative skills [5]. Although multidisciplinary project-based learning can be carried out within a single institution [2], the collaborators of the joint course propose to mirror real-world project as much as possible by introducing geographical and cultural diversity to the capstone course. Each of the research-focused institutions participated in the joint course also realised that complementary strengths can be found from each other among different science, engineering and business disciplines.

In Spring of 2016, faculties from the Robotics Institute at Hong Kong University of Science and Technology (HKUST), IdeaFactory at Seoul National University (SNU), Industrial Design Engineering at Beijing University of Aeronautics and Astronautics (BUAA) and Mechanical Engineering at Tsinghua University (THU) jointly proposed a collaborative product development to nurture global first-movers of the future. The shared objectives for the joint course are 1) to cultivate world-class students working closely toward a common goal, 2) to strengthen communication and interaction in-person and remotely across geographical separation and multidisciplinary setting, 3) to break down cultural barriers in a borderless world.

Three classes of students have taken the transformational course which focused on problem ownership, design process and diversity within the scope of developing a global product. The course demands on teachers, students, and university supports are non-traditional. While similar courses have been offered between institutions of closer proximity (e.g. Imperial College London x Royal College of Art, and HKUST x China Academy of Art), GPD is a more ambitious venture considering the geographic separation and language barriers in between. We will put in introspection GPD's course design, course impact and future development of the pedagogical success in the following sections.

2 COURSE DESIGN

Figure 1 shows the overall course design with the 15-week semester roughly dissected into three portions of problem definition, engineering design and prototyping. A strong emphasis is placed on finding/ defining a novel and valuable problem rather than focusing on a novel solution.

What is not shown in this simple figure is the practice throughout course duration of iterative lean development, parallel customer and business development, and human-centred design principles. E.g. although prototyping towards the end refers to the development of the minimum viable prototype to be shown at the final exhibition, the practice of prototyping proof-of-concepts is constantly done from the beginning as a problem identification tool, to midterm when working principles are evaluated. The overlay of blue loops demonstrates the application of iterative lean development (Build- Learn-Measure) and most teams can complete roughly 5 iterations of various redesign depth within the course.

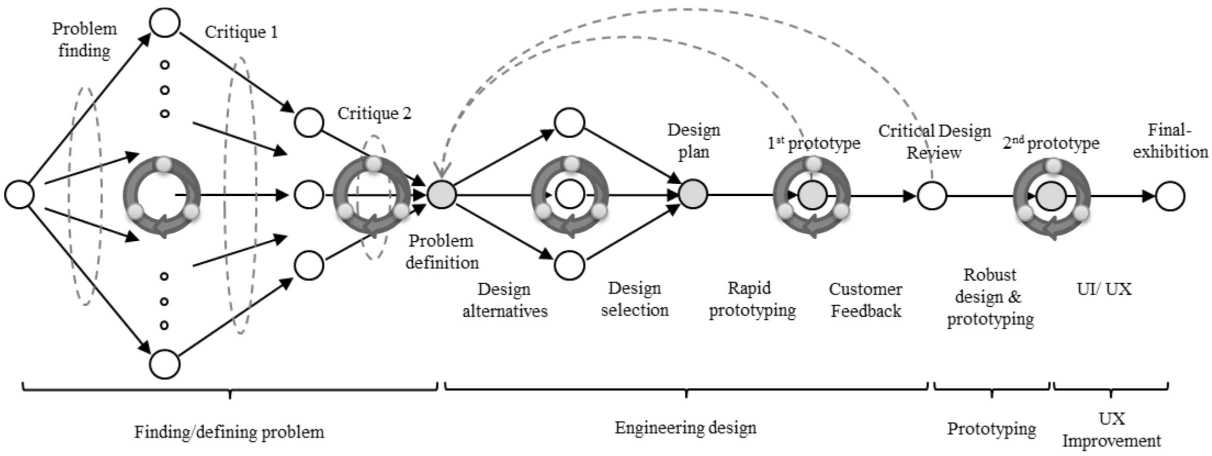

Figure 1. GPD Overall Course Design

2.1 Learning Outcome and Expectations

The key course intended learning outcomes include:

- The ability to identify and articulate customer needs after market research
- Effective collaboration in an international, geographically distributed, multidisciplinary team
- Proficiency with design tools and systems engineering principles to develop a global product
- The ability to present in front of diverse audience in a public exhibition
- Fostering of interests and ambition in creating new start-up targeting the global market

Over the course of the semester, student teams took the project from the earliest stages of defining and scoping the problem and conducting user research, all the way through to the creation of a functional prototype. The deliverables of the course include preliminary (PDR), critical (CDR) and final (FDR) design reviews. At the final exhibition, the teams were asked to showcase a functional prototype, a business model canvas and media assets to technical evaluators and potential investors. We believe that these course requirements truly support learning-by-doing pedagogical direction and maximised the benefits of student-driven learning. Alumni of GPD found careers in design and engineering in industry, become intrapreneurs for innovative companies, or continue to start companies of their own. This data and success stories will be shared in later sections.

2.2 Multidisciplinary Teaching Team

The teaching and mentorship duties are shared among faculties from the 3 to 4 collaborating departments each year. Corresponding faculties covered relevant lecture topics and workshop activities, and roughly shared the heavy load of course logistics and mentorship unique to the course. The expert areas and resources available from each partner are listed in the table below.

Table 1. Faculties' Expert Areas and Resources Available from Collaborating Departments

Departments, University	Expert Areas	Resources Available
Industrial Design Engineering, BUAA	industrial design, design thinking, hand-modelling, graphics design	early stage prototyping, components sourcing and access to Chinese suppliers
Integrative Systems and Design, HKUST	robotics and AI, IoT and network, business model innovation	prototyping fund, support by hardware start-ups spun off from HKUST
IdeaFactory, SNU	rapid prototyping, market research, mechanical engineering design	rapid prototyping facilities, technical mentors' network, patent fund
Academy of Arts & Design, THU	3D modelling and rendering, multimedia and information design	sketching and modelling facilities, multimedia production
Mechanical Engineering, THU	mechanical and mechanism design	prototyping facilities, components sourcing and access to Chinese suppliers

The first three departments have participated in all three years, while the two departments from Tsinghua University participated respectively in 2016 and 2017. This mix is also representative the students make up of that year's class.

2.3 Face-to-Face Meetings and weekly Real-time Lecture Streaming

Three 5-day face-to-face meeting opportunities at the three locations were scheduled with different learning goals built in to the meeting programmes. The course kick-off meeting prior to semester started to provide teaming opportunities, intense ideation exercises and industry visits for problem identification. By midterm, teams would have clear problem definition and a prioritised list of customer requirements from which they would prepare different conceptual designs and present their evaluations in the preliminary design review. Historically, most of the time during the final meeting is spent on system integration for the MVP and preparation of the final pitch and exhibition.
Between these meetings, weekly lectures and workshops were hosted through Realtime video streaming collaborative classroom on the Vidyo platform (Figure 2). The software, together with messaging tools like WeChat, Slack and Trello, maximises classroom interaction. The non-traditional classroom, however, presented new challenges to keep student teams engaged, connected.

Figure 2. Real-time Lectures & Workshops

2.4 Student Teaming and Online Collaboration

During student selection over the summer prior to semester start, the faculties aimed at keeping the overall class competencies composition to include roughly 1/3 mechatronics engineering, 1/3 software engineering, and 1/3 design. Teams were required to have at least two students from Beijing, Hong Kong and Seoul, and at least one designer (art/ industrial/ business). The team forming process has been adapted year to year, but the goal of the half-day exercise is to have technically balanced team sharing common interests in a problem space. About half the teams are formed by students being drawn to a product idea or specific pain-point proposed by an ad-hoc team leader, while the rest subscribe to different thematic areas (e.g. environment, healthcare, automation, disabilities, education, etc.) suggested by the teaching team. Problems suggested by industries were considered but their scope is difficult to tackle within the short span of the course.

The geographical separation posed notable challenges for student teams to collaborate, and for the teaching team to monitor the pulse of the class. Aside from basic course management through email, course website and canvas, a structured and regular use of WeChat platform proved invaluable. The choice of WeChat (vs. WhatsApp/ Line) is made since it is the only one accessible from mainland China, but also because some of its superior features, e.g. instant group forming through a 4-digit group code, up to 10-participant video call, dedicated @All alert for group announcement, etc.

2.5 Systematic and Diverse Assessment

Difficulties in assessment have been commonly reported in the capstone course of emphasising creativity and hands-on experience [1], [3]. Valderrama et al. pointed out drawbacks of the conventional outcome-based assessment in final year engineering project such as dependency on the subject criteria of academic evaluator and not formative assessment via one final milestone in [7]. Accordingly, the authors recommended 1) to establish at least three moments or milestones for assessment, 2) to make peer evaluation and add external experts in assessment process, and 3) to define what skills students possess through the project.

In GPD, each design review accounts for 20% of the overall course. In addition, market research report, field trip (industry/ incubation hub/ electronics fair) report, concept walkthrough interview and final exhibition investment mock-up each takes up 10%. Concept walkthrough, typically done 2 weeks prior to final exhibition, is a process checkpoint borrowed from industries. It involves detailing of team's division of labour to complete the project on time, on budget and meeting the 'specs' for the home stretch. In the final exhibition, all participants are given different level of 'investment money' (e.g. 1 million for faculties, 500k for invited guests and 100k for students) which can be invested in the different projects to evaluate the business potential.

Google evaluation forms were deployed for each design reviews. Faculties and invited external reviewers' scores are averaged to account for 60% of the team's evaluation and peer review from the rest of the students account for 40%. The metric of evaluations changed with the project timeline, but the following table lists the commonly used criteria.

Table 2. Criteria used in GPD Assessments

Criteria	Evaluated at	Definition
Creativity	PDR	project ideation demonstrates creative/ divergent thinking.
Comprehensiveness	PDR	comprehensive market research and design thinking process
Completeness	PDR	problem space was rigorously and 'completely' explored
Impact	PDR, CDR, FDR	potential for having significant impact in the real world
Global	PDR, CDR, FDR	project considers offering solution to a global problem
Innovativeness	CDR, FDR	the proposed solution has innovative merits
Interdisciplinary	CDR, FDR	interdisciplinary systems design and project collaboration
Independence	CDR	project has been free of bias from one group of users
Concreteness	FDR	realistic and specific design and plan for realisation

3 COURSE EVALUATION

At the end of GPD2018, a survey [4] was launched to all 180 past students. The survey was designed to collect data both reviewing the course content, modes of delivery, assessment mechanisms, and also qualifying the overall impact of GPD on the students' advancement as an innovator either in further studies or in industry. The later will be further described in section 4. This section will discuss positive feedback and two major areas identified and in need of improvements.

Positive feedback (over 80% interviewed agrees or strongly agrees) includes a. well defined learning objectives, b. organised and planned syllabus, c. effective teaming mechanism, d. connectedness through messaging platform, and e. clear and fair course assessments. Top five methodologies taught in GPD, ranked in order of suitability and applicability are 1) design thinking, 2) market research tools, 3) usercentred design, 4) agile project development, 5) rapid prototyping. Finally, the most impactful and valuable elements GPD interviewees most appreciated were final exhibition, multicultural multidisciplinary teaming, and three face-to-face co-working opportunities.

Teamwork guidance and loading. As in most team-based project courses, encouraging individual's engagement over time and preventing freeloaders (about 20% felt free-riding was an issue in their teams) from taking advantage of shared evaluation, GPD organisation attempted to balance giving sufficient guidance while giving team sufficient autonomy. Course workload is also a contentious point (32% of students feel the workload was large), with the typical GPD undergraduate students often involved in multiple initiatives beyond nominal courses. In the future, we hope to be more selective during the student recruitment process to identify early truly passionate team members and introduce more structured team activities outside of class time.

Real-time lectures on engineering systems design. The real-time lectures were meant to both deliver uniform lecture-based learning experience to the entire class, however, 50% of the students felt that the mode of lecturing was neither suitable nor engaging. This is expressed especially for the engineering system design lectures; likely due to the technical depth of these topics that may not have applied to all team's chosen product design. Upon reflection, the teaching team plans to tailor the engineering system design teaching to different discipline subgroups' needs. E.g. industrial designers or mechanical engineers in the teams could have several special topic lessons outside of the core lectures.

4 COURSE IMPACT

From the course survey, we have identified just over half of interviewees identified themselves as current entrepreneurs or intrapreneurs. Figure 3 shows more detailed distribution of their current career. Of the 32%, 5 founders of different start-ups have reported raising funds ranging from USD100k to USD500k. Of the 40% working for companies, their roles range from designers, engineers to technology and business management. In their comments on how GPD has shaped their young career, many echoes that the course has taught them how to define problems independently, gave them opportunity to plan and budget in a lean product development cycle and had given them an invaluable international network of young professionals and mentors.

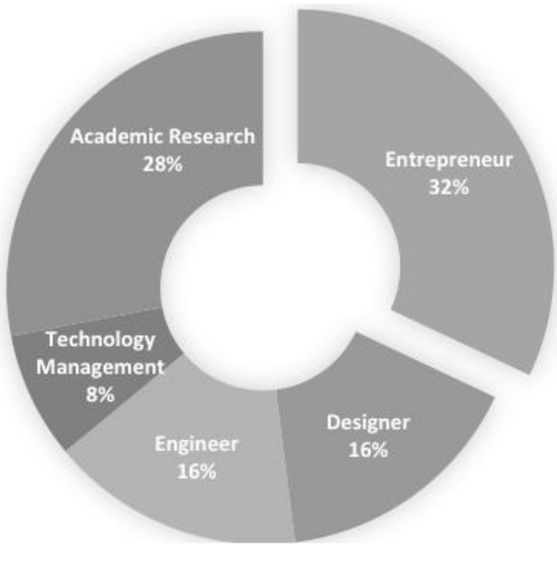

Figure 3. GPD's alumni current career

Each of the three GPD classes have produced one to two spin-offs which have continued beyond the course into full-fledged incorporated start-ups in pursuit of commercialising the product developed with GPD and/ or new opportunities gained through the building a strong multidisciplinary product team.

Team Aromeo (*https://aromeodiffuser.com/*) from GPD 206 has developed an IoT-enabled aromatherapy diffuser. The team started strong investing resources and funds towards creating proof of concepts to engage early adopters. The truly multidisciplinary team won the investment mock-up at the GPD2016 demonstrating a working prototype (Figure 4).

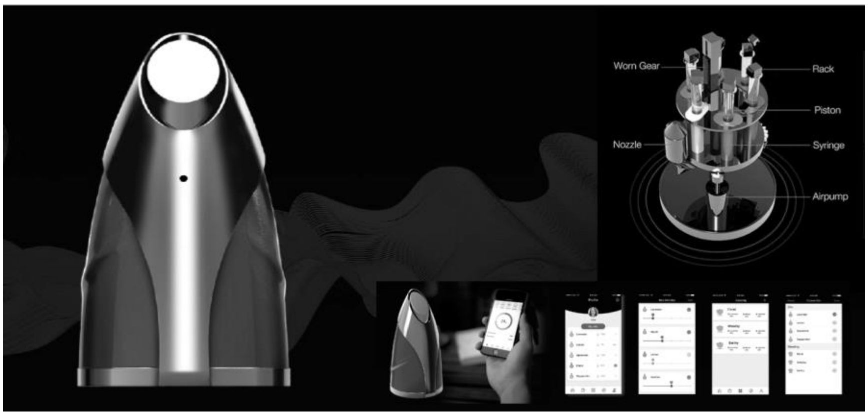

Figure 4. GPD Spinoff – Aromeo Diffuser

Every year, the partnering institutions arrange to meet in the spring term to review the previous offering's lessons learned and shortcomings to strive for continuous improvements. The inherent course unpredictability (e.g. degree of diversity in students' technical background, team dynamics, etc.) requires close collaboration, weekly adjustment and zealous mentorship from the three co-authors. Inventive assessment mechanism needs continue development, to be deployed timely and constructively; at the same time, it shouldn't translate to additional workloads for the students.

5 CONCLUSIONS

GPD has offered students a comprehensive working knowledge of the full design innovation process, from problem framing through commercialisation. Course elements are carefully designed to prepare collaborative teams in student-driven projects. The focus on using creative problem-solving and human-centred design to address real-world needs has resulted in alumni who are better prepared for a wide range of careers, including entrepreneurship in hardware technology innovation or becoming intrapreneurs for larger firms. While the joint course requires more resources and commitments from universities and faculties, we believe that every curriculum should include such collaborative course offerings, affording students real practice in working across disciplines, cultures and geographies to deliver impactful solutions; emulating their shared future in tackling complex problems.

REFERENCES

[1] Solomon G. "Project-based learning: A primer," *Technology and Learning*, vol. 23, no. 6, pp. 20–30, 2003.
[2] Shirland L.E. and Manock J.C. "Collaborative teaching of integrated product development: A case study," *Education, IEEE Transactions on*, vol. 43, no. 3, pp. 343–348, 2000.
[3] Dym C.L., Gilkeson M.M. and Phillips J.R. "Engineering design at Harvey Mudd college: Innovation institutionalised, lessons learned," *Journal of Mechanical Design*, vol. 134, no. 8, p. 080202, 2012.
[4] Halim M.A., Buniyamin N., Imazawa A., Naoe N. and Ito M. "The role of final year project and capstone project in undergraduate engineering education in Malaysia and Japan," in *Engineering Education (ICEED), 2014 IEEE 6th Conference on*. IEEE, 2014, pp.1–6.
[5] Imazawa A., Naoe N. and Ito M. "Learning through experience hands-on education at a technical college in Japan," in *Engineering Education (ICEED), 2014 IEEE 6th Conference on*. IEEE, 2014, pp. 7–12.
[6] Valderrama E., Rull´an M., S´anchez F., Pons J., Mans C., Gin´e F., Jim´enez L. and Peig E. "Guidelines for the final year project assessment in engineering," in *Frontiers in Education Conference, 2009. FIE'09. 39th IEEE.* IEEE, 2009, pp. 1–5.
[7] Leung W. and Wang Y. "Global Product Development 3 Year in Review". Survey. 1 March 2019. https://goo.gl/forms/H67ZE5whDXO7PGJA2