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UIndy Engineering DesignSpine: Engineering Leadership Development through Interdisciplinary Teams and Early Exposure to Real Life Problems

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UIndy Engineering *DesignSpine*: Engineering Leadership Development through Interdisciplinary Teams and Early Exposure to Real Life Problems

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Abstract

The engineering challenges facing the world are very complex, and they require a new type of engineer who can work in interdisciplinary teams as well as multicultural teams to solve open-ended problems. Employers are looking for engineers who have not only technical competency but also systems (broad) and business mindsets. To develop these engineers, the R. B. Annis School of Engineering at the University of Indianapolis (UIndy) developed the *DesignSpine*. The *DesignSpine* framework makes it possible to create interdisciplinary teams of students who apply knowledge and principles of Six Sigma, project management, research methods, entrepreneurship, and leadership and communication (SPREL). Furthermore, in the *DesignSpine*, students create innovative solutions to real-world problems from external stakeholders beginning from their sophomore year. This paper describes the *DesignSpine* framework and the implementation strategy.

Introduction

The problems and challenges facing the world are so complex, and the world is so dynamic that it is practically impossible for the challenges to be addressed by a single person or discipline. In addition, employers are looking for every opportunity to reduce the cost of doing business by replacing humans with machines. Advancements in internet and communication technologies have also turned the world into a global village where employers have easier access to talents, materials, information, and funds from all around the globe. Consequently, the modern engineer must be a leader; must be able to work in teams with people with diverse knowledge and culture; and must be a fast and life-long learner to remain relevant and adaptable in this ever-changing world. The modern engineering leaders must be equipped to ***Lead, Design, Build and Sell***.

Lead: A leader has been defined as: "*One or more people who selects, equips, trains, and influences one or more follower(s) who have diverse gifts, abilities, and skills and focuses the follower(s) to the organization's mission and objectives causing the follower(s) to willingly and enthusiastically expend spiritual, emotional, and physical energy in a concerted coordinated effort to achieve the organizational mission and objectives*" [1]. Simply stated, leadership is the art of motivating a group of people to act towards achieving a common goal [2]. With the complexity of the challenges facing the world, a modern engineer must be aware that he or she must work effectively with others from various disciplines and cultural backgrounds to successfully develop and deploy innovative solutions. Engineers are originators of creative ideas and solutions. Before those ideas can be developed and converted into products that meet the needs of the society, engineers need leadership skills to effectively communicate their ideas and inspire others to commit the resources required to develop the ideas. Moreover, there has been many catastrophic engineering failures that could have been avoided because they were noted by engineers before the failure occurred. The risks were however not communicated, or the engineers were not in a position of leadership to effect preventive action before deployment of the engineering system.

Design: Modern engineers should be trained and equipped to design engineering systems that solve real problems facing the industry. Therefore, it is important to expose engineering students to such challenges while still in school. As noted by Bystrom and Eisenstein [3], engineering education was very experiential in the early days. Virtually the whole engineering curriculum required students to work with faculty and industry practitioners to solve problems from the local industry. A shift from the experiential engineering education model to an engineering science model occurred after World War II. The shift produced many of today's engineering graduates with practically no exposure to the real problems facing industry and society. It is imperative that modern engineers be exposed to real-life problems from industry while still in school through a series of design projects. These projects should enable them to develop critical-to-success competencies such as understanding the customer and translating customer requirements into functional requirements.

In addition, there has been a shift toward increasing emphasis on engineering design [4] in the first [5-7], and senior years [8, 9]. A gulf however exits between student experiences with engineering design in the first year and the capstone culminating experience because of little or no design experience in the sophomore and junior year [4]. A study at the University of Colorado at Boulder on the impact on student learning indicated a deterioration in student confidence in both professional and technical skills between the end of the first year and the beginning of the senior year with the decline being statistically significant for all the assessed categories [10]. An exception to the nationwide pattern was found in the engineering curricula introduced at Rowan University, in which students work on their learning with respect to engineering design in each of their eight semesters [11]. A multiyear study by the Carnegie Foundation for the Advancement of Teaching recommended a thick spine spanning the four years of the engineering curriculum to provide experience in line with the demands of professional practice that links theory and practice [12].

Build: Modern engineers must not only design, but also be knowledgeable about what it will take to produce the design. They must develop hands-on skills and be exposed to building at least models and prototypes of their designs. The knowledge will enhance their capacity in designing solutions that are easier and more economical to produce.

Sell: Many great business enterprises have been founded by people with science or engineering competencies. Examples of such companies include Eli Lilly, Microsoft, Google, Bose, Ford, and GE. These companies have provided jobs for many, as well as developed and marketed products that have enhanced the quality of lives of many people all over the world. The founders were able to convert their ideas and inventions into marketable products through their entrepreneurial acumen. The modern engineers need to have the entrepreneurial training to identify commercially viable opportunities and develop commercially viable solutions. They can be entrepreneurs starting their businesses or intrapreneurs who help their employers to launch new products and move into new markets.

Overview of the *DesignSpine*

The mission of the R. B. Annis School of Engineering at the University of Indianapolis (UIndy) is to: *“Develop modern engineering leaders through interdisciplinary education to create outstanding solutions.”*

The R. B. Annis School of Engineering (RBASOE) is pursuing its mission of developing modern engineering leaders through the UIndy Engineering *DesignSpine*. The DesignSpine is a project-based learning (PBL) approach that enables instructors and students to develop creativity and supportive learning environments [13]. PBL is a model that organizes learning around projects [14]. Projects are complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making, or investigative activities; give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentations [15, 16]. The PBL includes activities such as metacognitive thinking, creation of an original product, use of communication skills in a group, class or society, and presentation of the final products [17, 18]. PBL supports students development in the seven core skill areas identified by educators [13]: 1. Critical thinking and problem-solving. 2. Creativity and innovation. 3. Cooperation, teamwork and leadership. 4. Intercultural understanding. 5. Fluency in communication and information. 6. Computer and communication technology. 7. Career and self-development. The projects and teamwork are the artifacts and ways by which the real-world needs to study both today and future [13].

Apart from teaching and exposing the students to traditional and fundamental engineering education unique to each engineering discipline, the *DesignSpine* involves a three-thronged strategy that breaks down the barriers among engineering disciplines while exposing the students to real-life, open-ended problems from industry and other external stakeholders (Figure 1). The *DesignSpine* has three key components:

- *DesignSpine* SPREL (defined in the following section)
- Interdisciplinary project teams
- Real-life, open-ended projects from external stakeholders

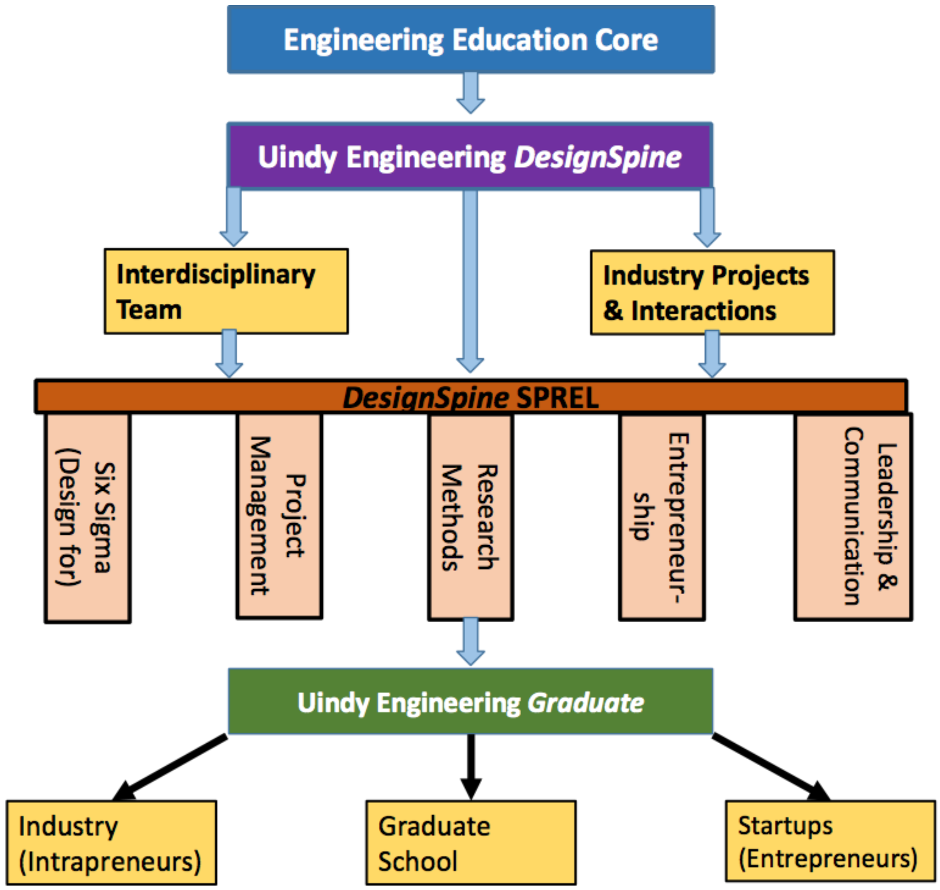

Figure 1: Overview of the UIndy Engineering *DesignSpine*

DesignSpine SPREL

In the *DesignSpine*, students not only work in interdisciplinary teams and work on real life problems, but also acquire critical skills that they may not be readily exposed to through a traditional engineering education. The five focus areas are:

- Six Sigma (Design for Six Sigma)
- Project management
- Research
- Entrepreneurship
- Leadership & communication

The *DesignSpine* experience is a four-year sequence starting during the first semester, which provides the foundation for the sequence. As students move through the *DesignSpine* sequence, faculty enhance the experience by introducing new SPREL concepts as shown in Table 1. The knowledge acquired is cumulative and the students apply what they learned repeatedly in future projects and thereby gaining mastery of the knowledge and needed skills. This concept is unlike many senior capstone design project approaches used at various institutions where students emphasize technical component of the design process.

Table 1: Integration of the *DesignSpine* SPREL into UIndy engineering curriculum

Year	Fall	Winter
1st year	Systems-based Design Process Project Management Principles & Tools	Systems-based Design Process Project Management Principles & Tools
Sophomore	Design for Six Sigma (DFSS) Project Management Research Methods	Design for Six Sigma (DFSS) Project Management Research Methods
Junior	Entrepreneurship (Business Model Development using BMC): Opportunity Identification & Customer Discovery	Entrepreneurship (Business Plan & Financing): Customer Discovery
Senior	Leadership & Communication	Leadership & Communication

The course loads for the *DesignSpine* sequence are as shown in Table 2. The students are expected to add about nine (9) hours per week outside the lab. In the first year, the focus is to introduce the students to teamwork and systems-based design methodology. Furthermore, students are introduced to project management principles in line with the Project Management Institute (PMI) Project Management Body of Knowledge (PMBOK). The first year in the *DesignSpine* sequence culminates with an internal team-based project, where upperclassmen students act as clients or mentors. By providing this scaffolding and structure, students can employ the newly learned knowledge and skills to subsequent projects and build upon it. From the sophomore year to the senior year, the students are introduced to projects from external stakeholders namely from industry and collaborative projects with faculty outside the School of Engineering.

Exposing students to real-life, open-ended problems from external stakeholders early during their academic tenure is important. It enhances students' understanding of the voice of the customer (how to relate and communicate with clients, how to understand customer requirements, how to translate customer requirements to functional requirements) and develop competency in project management. By the time students reach their senior year, they would have worked on two external projects in an interdisciplinary setting. Consequently, it is theorized that students will be less focused on the process by the time they reach their fourth and final *DesignSpine* project. By the time the students will be graduating, they will have a portfolio of projects. Thus, these portfolios will make RBASOE students' more attractive to employers and better equipped to tackle the challenges they will face in industry.

Table 2: Load Distribution for the *DesignSpine* Sequence

Course Code	Credit Hours	Contact Hours	Lecture Hours	Lab Hours
ENGR 196	3	5	2	3
ENGR 198	1	3	0	3
ENGR 296/298	1	3	0	3
ENGR 396/398	1	3	0	3
ENGR 496	1	3	0	3
ENGR 498	2	6	0	6

Another advantage of the *DesignSpine* is the opportunity to work in interdisciplinary teams over multiple projects as it will help students develop an appreciation for other disciplines. Moreover, it will help students develop the skills needed in relating to and working with others effectively. This experience also provides an opportunity for the students to sharpen and enhance their creativity and problem-solving skills as they work on different projects each year. The support they get from their team members will increase their confidence and help them to find their area of strength as they work on different projects. These are benefits that may not be readily available with the senior design capstone project approach. The goal is that the students upon graduation will be adequately equipped to pursue graduate school, enter the workforce, or start their technology startup businesses (Figure 1).

Project management and process orientation with Design for Six Sigma

Design for Six Sigma is a customer-oriented development process for transforming customer's wants into design solutions that are useful to the customer [19]. The DFSS process helps in imbibing two key concepts into the *DesignSpine* engineering students: customer-focus and "design it right the first time" to avoid painful and expensive consequences later. The DFSS project management process provides a framework through which our students can see and experience the integration of project management principles and the technical knowledge they learned in different classes and the application in the design of solutions to meet client's needs. The process consists of four phases with gate reviews at the end of each phase (Figure 2). The process incorporates the principle of agile product development in which the project team is in continual communication with the client and potential product users for inputs to drive the design decisions being made from the beginning to the end of the project. This strategy ensures that the team designs and develops a solution or product that the users want and will use.

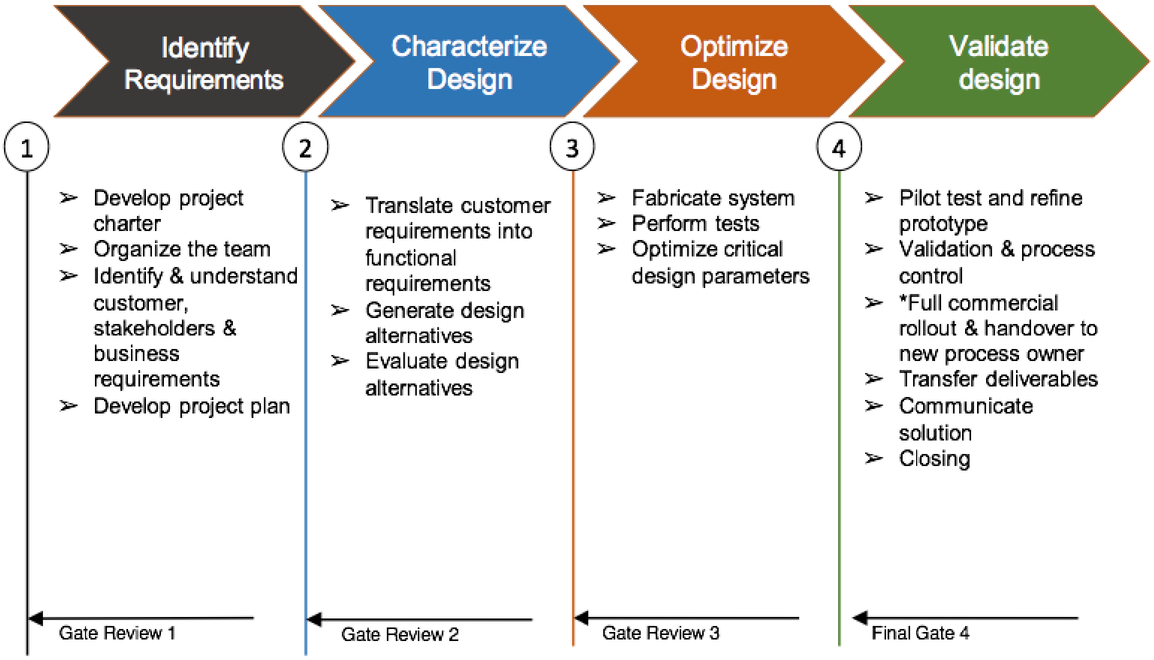

Figure 2: The four phases of the Design for Six Sigma (DFSS)

Table 3 provides details of the *DesignSpine* DFSS project management process including the different tools the students may apply at different phases of the process. While it may be difficult to execute some components of the fourth phase on some projects, faculty in the RBASOE want the students to be aware of the entire process highlighted in Figure 2.

Industry-academia partnership for modern engineering leaders development

The *DesignSpine* enables effective industry-academia partnership in the development of the modern engineering leaders from their sophomore year. At the topmost level (Figure 3), industry and other stakeholders, external to the RBASOE, serve as project sponsors. These clients provide students with real-life problems and provide project funding. The *DesignSpine* process is managed internally at the RBASOE by the *DesignSpine* Coordinator, an engineering faculty, who coordinates the interactions and collaborations between industry and the RBASOE. At the execution level, industry partners provide the *DesignSpine* project teams with a team of industry experts who works with the *DesignSpine* team. The industry team provides the necessary support and specialized knowledge that may be needed by the *DesignSpine* team to successfully meet the customer's needs.

Each team has a Faculty Lead (FL) who is the assigned faculty to a particular project. The FL is a faculty with some expertise in the project domain area who takes internal ownership of a project and guides the project team in getting the needed resources for actualizing the project goals. In addition to the FL, the team is supported by the pool of faculty experts covering areas including computer science, computer engineering, electrical engineering, industrial and systems engineering, mechanical engineering, project management, and, software engineering. The curriculum and faculty load is designed in such a way that all *DesignSpine* courses are scheduled at the same time and all RBASOE faculty are deployed to assist project teams. Exposure to a team of experts from industry and academia will give students different perspectives in understanding and developing competencies in solving real-life problems and in relating to persons in academia as well as those in industry.

Table 3: Overview of the *DesignSpine* DFSS project management process

Phase	**Identify Requirements**	**Characterize the Design**	**Optimize the Design**	**Validate the Design**
Description	Identify all Critical-to-Satisfaction (CTS) metrics such as CTQ (Quality), CTD (Delivery), CTC (Cost) to conceive and optimize designs	Develop design entities that will be able to deliver the functional requirements	Fabricate design & optimize design parameters setting	Test and evaluate real-life performance to ensure it meets design requirements & that process controls in manufacturing result in production of the optimized design entity
Tools	Market/customer research; Stakeholder analysis; Quality Function Deployment (QFD); Kano analysis; Risk analysis; Gantt chart; Pareto Analysis	TRIZ, QFD, Design for X, DFMEA & PFMEA, Design review, CAD/CAE, Simulation, Process management, Cost/Benefits analysis	Design/simulation tools; DOE; Taguchi method, parameter design, tolerance design; Reliability-based design; Robustness assessment	Process capability modeling; DOE; Reliability testing; Poka-yoke, error proofing; Process control plan, Training
Outputs or Deliverables	Project charter; project management plan; Voice of the customer (VOC) with CTS metrics	Preliminary design report with CAD/CAE models & analysis results, design evaluation matrix, testing plan, fabrication & budget	Fabricated system; enhanced design blueprint; test result report	Final prototype/design blueprint; Final design report (with opportunities for future work/projects & lessons learned)
Gate Review (GR)	**GR 1:** Ascertain that team identifies and understands what is important to the customer	**GR 2:** Evaluate design concepts and finalize/approve design selection and fabrication budget	**GR 3:** Prototype demonstration/presentation of test results	**Final Gate:** Final presentation, system demonstration, and deliverables hand over
Phase duration (weeks)	6	8	10	4

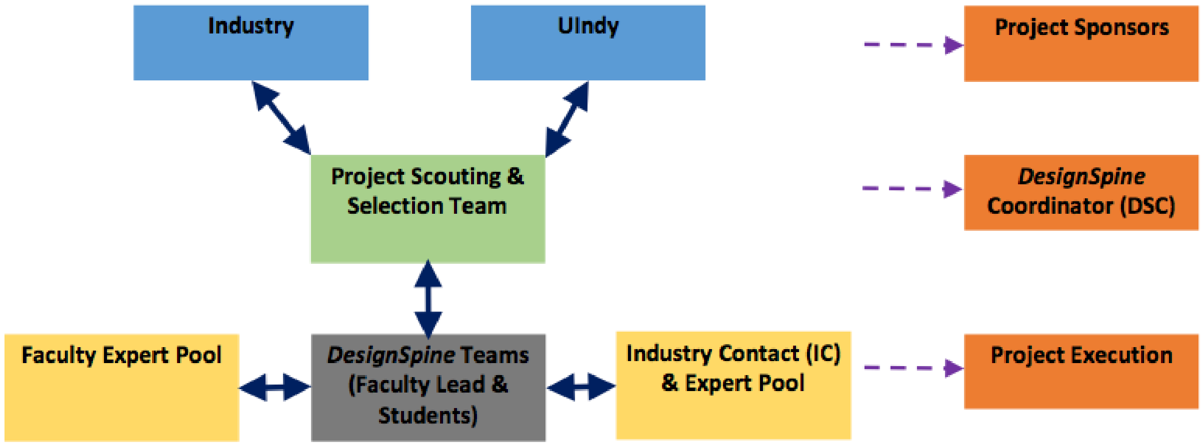

Figure 3: Industry-academia partnership in developing the modern engineering leaders

Current projects and leadership development

The *DesignSpine* was initiated during the 2016-2017 academic year with a cohort of fifteen students and six faculty members. In this section, the progress of the first *DesignSpine* cohort, which has completed the first half of their sophomore year, will be presented. During the first year, the engineering students were introduced to the different engineering disciplines, project management principles, and systems-based design. Moreover, they were introduced to teamwork and effective communication, which are critical skills for leadership development. During the first year, students completed two projects in an interdisciplinary setting. For the first project, the teams designed, fabricated and tested (launched) a rocket (Figure 4). The rocket project supported many disciplines as students had to complete electrical circuitry, code an embedded device, and 3D modeling and printing. For the second project the teams participated in a mock design, where students completed the first two-phases as shown in Figure 2.

Figure 4: Freshmen *DesignSpine* project teams working on rocket launch project a) & b) teams using computer aided design and drafting tools to design structural components of rocket, c) & d) teams programming and installing sensor system in rocket, e) & f) rocket launch

During the sophomore year (Figure 5), students were subdivided into three interdisciplinary teams working on projects from external stakeholders. At the time of these projects, the RBASOE offered three engineering programs: industrial and systems, mechanical, and software engineering. Each team is composed of at least one students from each discipline. The first project is the design of custom orthosis to promote usage of orthosis as prescribed by a physician, and thereby enhance patient's’ healing outcome. The project is a collaboration between the R. B. Annis School of Engineering and the School of Occupational Therapy at the University of Indianapolis (UIndy). The other two projects are with industry partners, which are protected through non-disclosure agreement.

The projects provide the team members with ample leadership development opportunities apart from the opportunities to apply and develop their technical competencies. First, each team has a project manager and an assistant project manager who are responsible for coordinating the team’s activities toward achieving set goals. They learned how to plan, delegate, and be accountable as well as make others accountable for specific assigned responsibilities. In addition, other members of each team have the opportunity to lead at least one task during the project. They also learn to communicate their ideas with other team members and get their buy-in in implementing their ideas.

Figure 5: RBASOE *DesignSpine* project teams (sophomore students) using ideation spaces while working on phases I and II of the Design for Six Sigma process

Another critical avenue through which the *DesignSpine* is helping the students to develop their leadership abilities is leadership modeling by the faculty. In the lab, as students work on their design projects, they get to see how the faculty discuss design questions and make decisions from different viewpoints. The faculty model leadership by encouraging the students to be confident and to challenge design suggestions and assumptions even when they come from the faculty. This scenario has become prevalent as the students develop and evaluate different design concepts. Interactions with faculty are further facilitated by periodic (weekly or biweekly) meetings and status reports to each team’s Faculty Lead. The teams have completed two gate reviews with excellent performance and feedback from the client as well as the faculty team. In January 2018, the teams will start working on the remaining two phases of the DFSS process.

Conclusion

The UIndy Engineering *DesignSpine* is devised to equip students to become modern engineering leaders by exposing them to real-life open-ended projects from external stakeholders as early as their sophomore year on to their senior year. The first set of engineering students to go through the *DesignSpine* are completing their first semester of the sophomore year that covers the first two phases of the DFSS process, namely identify requirements and characterize design, respectively. There are currently three project teams working on projects from external stakeholders. The teams have completed two gate reviews with excellent performance and feedback from the clients as well as the faculty team. In January 2018, the teams will start working on the remaining two phases of the DFSS process. The goal is that by going through this process multiple times with different projects, the creative problem-solving, as well as the leadership and communication skills of the students, will be greatly developed. Furthermore, by the time of graduation, the students would have developed a portfolio of projects with external stakeholders that will make them better equipped for and attractive to industry.

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