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The DesignSpine: Evolution of an Authentic Project-Based Integration of Design in an Engineering Curriculum

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Abstract
A common theme among business leaders is that young engineers will require a proclivity to adapt to novel technologies and prepare for jobs or even entire industries that do not yet exist. The introduction of modern design spine curricula is one variation of the project-based learning environment, with the potential to develop and equip students to effectively design viable solutions to real life problems facing our world. This paper summarizes a novel design spine program at the R. B. Annis School of Engineering at the University of Indianapolis, now in its fifth year, that contains a number of additions of interest to the greater engineering education community. The *DesignSpine* program implements three years of industrial client projects. Most engineering programs include one year of open-ended student projects. In addition, the *DesignSpine* program has an entire year devoted to project-based entrepreneurial development with external business mentors. The program's first year contains training in Agile and Design for Six Sigma methodologies. Finally, the program involves participation from *all* faculty and technical staff in the engineering school - an *all hands on deck* approach. We summarize the curricular changes and decisions made over the past five years, as well as present novel data gleaned from student and faculty reflections. A major change in the curriculum was a change from a model with 10 weeks of typical coursework and only 5 weeks of DesignSpine to a more integrated 15 full weeks, as both student teams and clients needed more time to effectively work on the design project. Also, as the program grew, there was the need to change the leadership and structure of the committee responsible for running the *DesignSpine*. The change highlights the fact that leadership must be willing to assess and implement changes as deemed necessary as a program grows, the skillset requirements change, and as competent people join the team. It must never be business as usual, nor change for the sake of change, but an objective assessment of needs and capabilities needed for growth and success. The paper will be of interest to programs which aim to truly integrate design into an engineering curriculum.

INTRODUCTION

The Need for *DesignSpine*
Training the next generation of engineers is a complex process which must evolve beyond a traditional classroom approach, where students can develop communication, teaming, and entrepreneurial skills, and to prepare for entire industries that do not yet exist. This observation is in line with a 2020 National Academy of Engineering report [1] that sought to provide an answer to the question: "What will or should engineering education be like today, or in the near future, to prepare the next generation of students for effective engagement in the engineering profession in 2020?" The report indicates that first and foremost, engineering education must produce technically excellent and innovative graduates. The challenge, however, is to equip those technically competent graduates such that they are better prepared to work in a constantly changing global economy. In the same vein, the Institute for the Future (University of Phoenix Research Institute) report on Future Work Skills 2020 stated that successful individuals will be

those who can demonstrate foresight in navigating a rapidly changing landscape of organizational forms and skill requirements [2].

The successful future 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 [3]. Consequently, educational institutions need to focus on methodologies and techniques that will help their students develop the skills, competencies and mindsets that will ensure that they remain relevant in spite of the ever-changing and unpredictable world we live in [4].

The R B Annis School of Engineering (RBASOE) was founded with these goals in mind to not only train future engineering leaders who are technically competent, but who are also equipped to adapt to and solve future complex engineering problems that our nation and world will face. The school is accomplishing her mission through the RBASOE Engineering *DesignSpine* [3-5]. 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. The *DesignSpine* has three key components [3]:

- *DesignSpine* SPREL that emphasizes Six sigma (Design for Six Sigma); Project management; Research; Entrepreneurial mindset; and Leadership & communication
- Multidisciplinary project teams
- Real life and open-ended projects from external stakeholders

The program is unique in many ways. The first year of the program contains training in Agile and Design for Six Sigma, followed by three years of external industrial client projects. The program has an entire year devoted to project-based entrepreneurial development under the guidance of external business mentors. Finally, the program involves participation from all faculty and technical staff in the engineering college - an *all hands on deck* approach.

Focus of the Paper

This paper summarizes the continuous improvement changes the RBASOE engineering *DesignSpine* program has undergone in its five years of implementation. The paper also contains key lessons learned from this unique program that will be of interest to the greater engineering education community. We summarize the curricular changes and decisions made over the past five years, as well as present novel data gleaned from student and faculty reflections. This paper will be of interest to programs which aim to truly integrate design into an engineering curriculum.

The population for this study is a relatively young engineering department (pre-ABET accreditation) situated within a liberal arts teaching college in the Midwest. The University of Indianapolis has about 5,000 full time students and is located in an urban environment. The composition of the university is diverse, serving a higher percentage of underrepresented groups on average among its peer institutions. The total student population of the department is ~200 students with about a 10:1 ratio of students-to-faculty and staff. Most classes are taught by tenure-track faculty. The engineering program has a four-year, project-based learning curriculum, where all engineering majors take team-based project courses with external clients for three years. The students' first-year experience revolves around team-based labs and lectures with a second semester of the first year devoted to learning fundamentals of *Design for Six Sigma* and *Agile* with a client internal to the department. In the second year they have a more general design project with an assigned external client; the third year that focuses more on the development of an independent, entrepreneurial project proposal under the guidance of a business mentor; and the fourth year involves an external client like the second year and adds leadership training.

LITERATURE REVIEW

The school was started on a foundation of mechanical, industrial and systems, and software engineering curricula, with an integrated design spine concept with two interesting caveats. The first item revolved around a design spine in a *liberal education* core at a teaching college. At our institution, a total of roughly *60 hours* in general education and liberal arts core is required for graduation, with topics ranging from literature, history, religion, the social sciences, and competency specialties that include writing and speaking, a capstone sequence, and critical thinking. The second item to overcome was how to train engineers for the realities of a shifting technological landscape that they will experience upon graduation.

The main conjecture of design or professional *spines* in engineering education is that at their core they train students for the reality outside of academia. Previous iterations of our own work were based on the core principle that incorporating design throughout the curriculum, along with a focus on *professional skills* has advantages compared to the piecemeal and disjointed approaches, or ones where design is relegated to the senior capstone experience [3, 4]. We developed our notion of professional skills influenced by a series of publications in *Burning Glass* [6, 7], emphasizing overall communication, organizational, and writing skills as a top priority for our graduates.

A brief review of design spines and their history was previously undertaken by the faculty team in another report [8]. In this work, the authors summarized historical efforts by seminal authors in the field such as Sheppard, Frank, and others influential in the development and defining of the *design or professional spine* educational philosophy in the engineering education sphere [9, 10].

In the intervening years since our last report, a number of reports and works on design spines have been published [11-16]. One of the more novel recent approaches took place in implementing design spines through a series of design challenge activities. The idea of *challenge* activities is established but using them to implement a design spine is quite new. Datye and their colleagues developed a series of substantial, large-scale projects incorporated across multiple classes in a chemical engineering curriculum to teach design principles. The projects incorporated elements of working with engineering alumni, considering entrepreneurial factors, and community interfacing, all geared at solving various phenomena.

Khan's recent work interviewing instructors that had participated in design spine teaching methodologies spoke positively of the benefits of the methodology, including its role in developing students' identity and developing cognitive faculties that will serve them in a changing industrial landscape. The work stopped short of interviewing students to determine if their *perception* of engineering design had changed as a result of their experience [14]. Like we would assert, they stated that a design spine program can be strengthened *by setting its vision that must be clearly articulated by leadership to instructors*. The particular role of communication of core values of a design spine program resounds well with us, as we have various points of contact among faculty design instructors and the general faculty cohort, to keep students and projects on the right path.

One paper seemingly prognosticates the downfall of the traditional engineering curriculum as it no longer provides skills required for the changing job landscape and adds that *there is still the dilemma of how to integrate the skills required of future engineers without compromising their technical foundation* [15]. They write that from a *philosophical* standpoint, design spines lead to more *authentic* learning opportunities, but conclude that further research is required to state that they do so with confidence.

METHODOLOGY

The Continuous Improvement Cycle

Continuous improvement is critical for the success and sustained relevance of any program. At the R. B. Annis School of Engineering, the following mechanisms were put in place to receive feedback, review feedback, proffer solutions, implement solutions and re-assess implemented solutions (Figure 1).

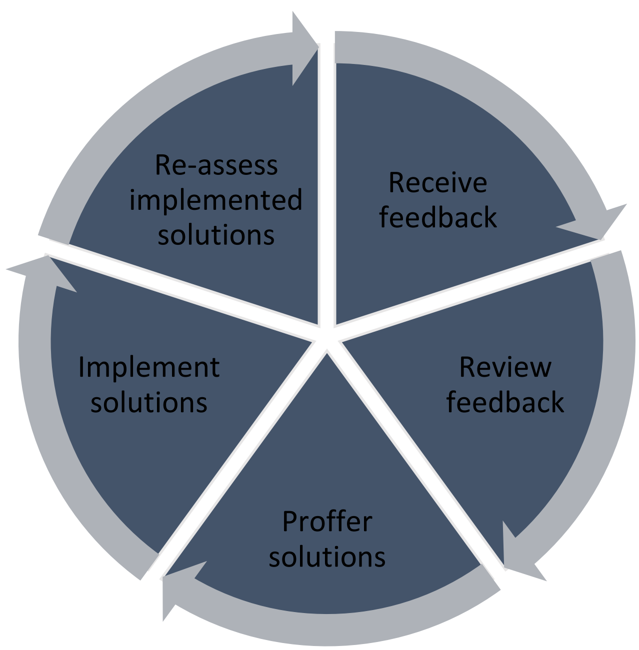

Figure 1: The continuous improvement cycle

Receive Feedback: The need for changes are usually initiated due to faculty or students' observations reported via students' complaints to any faculty, via the mid-semester course evaluation or end-of-semester course evaluation. Faculty and staff working with different teams may also observe the needs for changes as they work with different teams.

Review and Proffer Feedback: The first channel for reviewing received feedback for changes are at the Weekly Faculty and Staff *DesignSpine* Meeting. At this meeting, faculty and staff can bring before the entire faculty any issues they observed or any complaints (or praise) they might have received. This channel provides a just in time approach for addressing and seeking solutions to any issue with inputs from all faculty and staff. If the issue requires more attention, it is assigned to the *DesignSpine* Committee for further investigation, get inputs from faculty and bring recommendations for solutions to the faculty for approval in subsequent meetings.

While feedback from mid-semester course evaluation can be brought to the Weekly Faculty and Staff *DesignSpine* meeting, it may also be included with the end of semester course evaluation administered by the university administration. Every faculty is required by the RBASOE to report such feedback in the Faculty Course Assessment Report (FCAR) [17]. The FCAR provides an input for the Program Course Assessment report (PCAR) Meeting where the feedbacks from the FCARS are reviewed by all other faculty. During the PCAR meetings, the DesignSpine Course Instructor is asked questions on the feedback and content of the FCAR by faculty from different programs. The PCAR meetings provide opportunities to identify areas that need improvement as well as potential solutions. These identified needs may be transferred to the *DesignSpine* Committee for further actions if immediate solutions cannot be proffered or agreed on during the PCAR meetings.

Implement Solutions: The implementation of faculty-approved solutions depends on the nature of the proposed solution. For solutions that cut across different *DesignSpine* courses, like the review of rubrics, the *DesignSpine* Committee reviewed existing rubrics and made improvements with inputs from the *DesignSpine* Course Coordinators. The approved and improved rubrics are now given to the *DesignSpine* Course Coordinators to use for future assessments. There are other changes that may involve a change in the *DesignSpine* structure or process. Similar changes may require approval from all faculty and staff. The *DesignSpine* Committee will bring such to the Weekly *DesignSpine* Faculty and Staff Meeting where the faculty will review and vote on such changes. If approved via a majority vote, the *DesignSpine* Committee will implement and document such changes. All faculty, staff and students will be made aware of the changes and required to follow such as appropriate.

Re-assess Implemented Solutions: The Weekly Faculty and Staff *DesignSpine* Meetings provide a continual avenue for prompt reassessment of implemented changes and solutions. The end of semester PCAR meetings also provide a great avenue to re-assess implemented changes and solutions.

***DesignSpine* Committee**

A key component for driving the *DesignSpine* continuous improvement cycle is the *DesignSpine* Committee. The *DesignSpine* Committee was created to provide leadership and unifying structure for the effective development and implementation of the *DesignSpine* across the different levels and programs of the RBASOE. The *DesignSpine* is a core component of the RBASOE curriculum in her pursuit of developing modern engineering leaders who create outstanding solutions.

The responsibilities of the *DesignSpine* (DS) Committee includes:

1. Recommending to the RBASOE faculty, staff and Associate Dean strategies and methods for enhancing the achievement of DS outcomes for approval and adoption.
2. Development of DS curriculum and course goals, strategies for effective implementation of the DS framework, including but not limited to curricular material such as rubrics and templates. The goal is a unified approach through the DS curriculum. Significant changes to DS curriculum are brought to the attention of the entire engineering faculty.
3. Fostering partnership development among both internal (within the School of Engineering) and external stakeholders (industry, and outside of Engineering but within the University of Indianapolis) for DS projects, mentoring, support, and other value-adding collaborations.
4. Training of faculty and staff on relevant tools, concepts, and methods for the success of the DS.
5. Enabling the assessment, data gathering, improvement, reporting, and publication of DS outcomes.
6. Facilitate grant and other funding opportunities to support the *DesignSpine* program
7. Develop the *DesignSpine* Handbook, describing procedures for all of the above.

RESULTS and DISCUSSION

DesignSpine **Courses Duration**

The first cohort of *DesignSpine* courses involving external clients started in the Fall of 2017. The RBASOE engineering curriculum was set up for each semester to have 10 weeks of classes and five weeks focused purely on *DesignSpine* courses and projects. Clients, faculty, and students expressed that the project timeline was too aggressive. Completing a *DesignSpine* project in 10 weeks (over two 5-week courses spread over two semesters) was very stressful for students, faculty, and clients. There was not enough time for the iterations required for a successful design solution. Consequently, the *DesignSpine* courses were changed from 5-week courses to full-semester courses in Fall 2018. Contact hours did not change, but the course descriptions and schedules did change. As a result of this change, clients, students, and faculty found sufficient time spread across the semester for students and faculty to engage and also interact with clients so as to develop more effective design solutions.

<u>Key Lessons:</u> Use data-informed decision making and be quick to make modifications as appropriate based on inputs from relevant stakeholders.

DesignSpine **Committee Changes**

Introduction of Co-chairs

The *DesignSpine* Committee was headed by a faculty who served as the chair of the committee. As the school grew and the responsibility demand on the chair grew, in the Fall of 2021, the R.

B. Annis School leadership saw the need to distribute tasks and responsibilities within the leadership of the *DesignSpine* Committee with two co-chairs. The DS coordinators co-chairs the *DesignSpine* Committee, and should be an instructor in a current DS course or have significant teaching experience within the DS framework. The two coordinators are designated as follows:

- Co-Coordinator/Co-chair (Administration) with the primary function of interfacing with faculty and the implementation of DS projects.
- Co-Coordinator/Co-chair (Industry collaboration & support) with the primary function of interfacing with external stakeholders for sustained and mutually beneficial relationship building.

The implementation of the co-chairs system in Fall 2021 has already produced significant positive results. The co-chairs have been assigned to responsibilities in the areas of their strength which have resulted in significant improvement initiatives such as rubric alignments; well-run meetings; and improved staff and faculty morale. There has also been a better focus and coordination in engaging, recruiting and managing external relationships with having a co-chair that is focused externally.

<u>Key Lessons:</u> Leadership must be willing to assess and implement leadership changes as deemed necessary as a program grows, the skillset requirements change, and as competent people join the team. It must never be business as usual, nor change for the sake of change, but an objective assessment of needs and capabilities needed for growth and success.

DesignSpine Committee Composition

Initially, the *DesignSpine* Committee comprised primarily the three *DesignSpine* course coordinators, a fourth faculty who is knowledgeable about the Agile project management approach and the Associate Dean (Ex-Officio Member). The school leadership saw a need to expand the membership of the *DesignSpine* Committee to be more representative of the programs and the skill sets needed to make effective decisions. Consequently, the membership of the committee was expanded to include the laboratory managers, the director of engineering instruction, as well as ensure that every program in the school has a representative.

<u>Key Lessons:</u> Continually improve by ensuring that you have a representative and integrated team to make effective decisions that can be implemented successfully. Make the best use of your available greatest asset – your people.

Faculty Teaching Committee

Composition Change

In the Fall of 2017 and Spring of 2018 when the first set of sophomore student teams worked with external clients on a *DesignSpine* project, the faculty team received significant complaints from the students stating that they had limited time to work on their assigned project because different faculty were coming at different time to ask them questions about their project. In addition, some faculty were giving contrary advice to the student teams which left the students confused. The leadership of the RBASOE realized that there was a need to have a better coordinated system to guide faculty interactions with student teams. This gave birth to the Faculty Team Committee (FTC) in the Fall of 2018. The FTC is comprised of 2-3 faculty.

Role Change: From Evaluators to Coaches
The role of the FTC was primarily to conduct weekly meetings and evaluation of their assigned team. This role limited the value-adding contributions of the FTC to their assigned teams. The X school faculty realized that to enhance the value-adding contributions of the FTC, their role has to expand beyond just being an evaluator. They needed to have an ownership in the success of their assigned team by serving as a coach, who not only evaluates but is also committed in helping his or her teams to access the resources and support needed to successfully complete their project. This FTC role transformation from evaluators to coaches was implemented in Fall 2019.

The FTC role transformation from just evaluators to coaches has resulted in practically an elimination of complaints about confusing advice from multiple faculty, and there is increased support from faculty to their assigned teams. It has also helped faculty to be more focused and develop a sense of ownership and participation in the *DesignSpine* process.

<u>Key Lessons:</u> Faculty needs to have a sense of ownership in the process. assigning them roles as coaches will help them to develop a sense of ownership that will enhance their commitment to support their teams and help them in successfully completing the project. Being just an evaluator poses the faculty more as a threat to their students instead of seeing them as their partner and supporter for success. Having a good dynamic and relationship between faculty and their student teams is crucial for student learning, growth and project success.

Introduction of Agile Project Management
The *DesignSpine* was started using the Design for Six Sigma methodology that is widely used in industry. There were however software-based projects for which the Agile methodology was better-suited. Consequently, the school invested in one faculty member in computer science/software engineering to take a training course on the Agile/Scrum methodology. The faculty, after undergoing the training, trained other faculty in the Agile/Scrum methodology.

The result of this approach has been that practically all faculty has been exposed to Agile/Scrum training and activities, irrespective of their discipline. In addition, the Agile methodology has become an option for different *DesignSpine* projects. Every academic year, there have been roughly two software-based *DesignSpine* projects that use the Agile methodology.

<u>Key Lessons:</u> Expand the competencies of your team by investing in their professional development and targeted training to equip them with new tools needed for the success and growth of your program. Leverage limited resources by investing in the training of faculty who can then train other faculty members, thereby increasing your team's capabilities, economically.

Technical Demos and Impetus
Over the past three years, a series of *technical demonstrations* were added to both the first and second semesters of the second and fourth year of the *DesignSpine* course sequences. Initially, the technical demonstration was conceived as a *minimum viable product* report that would occur

in the second semester of the courses, in-between the initial building phase and the final product handoff to the client. The reasons for establishing were three-fold: first, faculty felt that there was an overemphasis on *professional* skills in the presentation-centric, stage-gate process of traditional *gate reviews*; second, there needed to be more points allocated towards the successful technical review of building a product; and third, the faculty wanted an opportunity to do a build check that would correct any problems before the project handoff of the completed product. Students would have a week to address any serious deficiencies that affected their evaluations and attempt another demonstration period if not satisfied with their initial review.

One of the unpredicted effects of this first technical demonstration implementation was that students would form closer relationships with *technical* advisors that they would choose to evaluate them during their review. These faculty could be from outside of the engineering school, and possess special technical knowledge related to their projects. Students worked with them for significantly longer than simply the technical demonstration period, but sought their advice throughout the second semester of the course.

After the success of the second-semester technical demonstration period, a first semester technical demonstration period was added. This early technical period was designed not to be a *minimum viable product* evaluation, but more of a *proof of concept* of a component, sub-component, or process identified by the team and their faculty advisors ahead of time. One of the net contentions of this first technical demo was that students started considering what key components/sub-components/processes they were developing earlier in the project overall, as opposed to targeting a variety without proper consideration.

<u>Key Lessons:</u> The technical demo provides a safe space for students to demonstrate their technical faculties without the presence of their clients.

Capstone Requirements

Senior year engineering students are required to participate in a culminating major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints. This capstone experience is a combination of coursework completed by students nearing graduation that allows them to “put together” the knowledge and skills they have acquired in their program and apply it to a major project or assignment. In the senior year, students take two *DesignSpine* courses (ENGR 496-Engineering Design Lab VII and ENGR 498-Engineering Design Lab VIII) where they work in multidisciplinary teams on open-ended projects from external clients or design and fabricate complex systems to meet the requirements of regional and national competitions. The knowledge and experience from earlier courses are applied to develop solutions that meet set requirements and constraints while considering public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. The key phases of a *DesignSpine* capstone project include identifying constraints, creating and analyzing design alternatives, fabricating and testing the designs, optimizing the designs, and completing a final prototype. Additionally, the courses have learning objectives that include gaining strong communication skills (both written and verbal), and gaining the ability to work effectively in teams by treating each other with respect, keeping the team on track, and making valuable contributions to the team. The student teams also present their projects externally at professional conferences and to the Industrial Advisory Board.

While these are multidisciplinary teams, each student on each team needs to identify and incorporate appropriate engineering standards, multiple realistic constraints, and relevant engineering literature for their discipline major and projects. Each project may contain multiple subsystems which all have their own constraints. Any discipline specific sub-systems are based on knowledge and skills acquired by students in earlier coursework of their respective engineering program.

In order to ensure that each student on a multidisciplinary *DesignSpine* team meets the requirement to incorporate appropriate engineering standards, multiple realistic constraints, and relevant engineering literature for their discipline major, the RBASOE leadership made some changes as follows:

- The complete capstone experience includes the *DesignSpine* course and the completion of an open-ended project in another discipline specific course (e.g., MENG 440-Mechatronics, ISEN 450-Lean Methods & Processes, SWEN 400-Software Project Management), typically taken by the students in their senior year.
- A path is also created for all engineering students to satisfy the required Honor College Project using their *DesignSpine* Capstone Project.
- Engineering standards were covered implicitly, but not necessarily documented explicitly in the culminating design experiences. Therefore, the requirements for capstone experience and competition criteria were formalized for students to include the incorporation of appropriate engineering standards in their project report.

<u>Key Lessons:</u> There may be a need to identify other discipline specific courses to ensure that capstone requirements are fully met, especially for design spine curriculum that uses multidisciplinary teams. Also, introducing standards in earlier courses of the *DesignSpine* will help students to gain better mastery on the importance and application of relevant engineering standards for their projects.

CONCLUDING REMARKS

This paper has provided a concise summary of some of the key changes that the project-based *DesignSpine* curriculum has undergone over its first five years of implementation. The motivations for the changes and the results of implementing the changes have also been described. Most importantly, key lessons learned from the implementation of the changes that have helped in the evolution of a quality *DesignSpine* curriculum have been shared to facilitate knowledge transfer across the engineering education community. With the knowledge shared, we hope that it will be easier and faster for other institutions you may want to implement a Design spine-based curriculum or improve their existing curriculum. Future work will focus on comparing the results of our *DesignSpine* framework and implementation with other design frameworks.

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