Chapter 2
The Design Spine: The Core Design Modules Behind Taylor's School of Engineering Project-Based Learning

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Abstract Taylor's University School of Engineering is a project-based learning school where the syllabus for each undergraduate programme is designed to provide every student with the opportunity to apply theories taught in class. This is realised through a series of design and project modules starting from semester 1 all the way through to semester 8. The design challenges offered to students throughout these eight semesters would progress from one where there are known solutions, to one where it is a real-world challenge with business value and finally to a research challenge where students are expected to publish their findings. In this chapter, how these design and project modules are structured, their objectives and the challenges of offering these modules are discussed.

Keywords Project-based learning · Engineering design
Undergraduate engineering programme

2.1 The Origin of Project-Based Learning and the Design Spine at Taylor's School of Engineering

Taylor's University School of Engineering was once an engineering school at Taylor's College offering twinning programme with the University of Birmingham and the University of Sheffield before that. In 2004, the head of department at the time was also pursuing his Ph.D. At one point, needing some assistance with his experiment, he carved out a small portion of his experiment and offered it as a project to some

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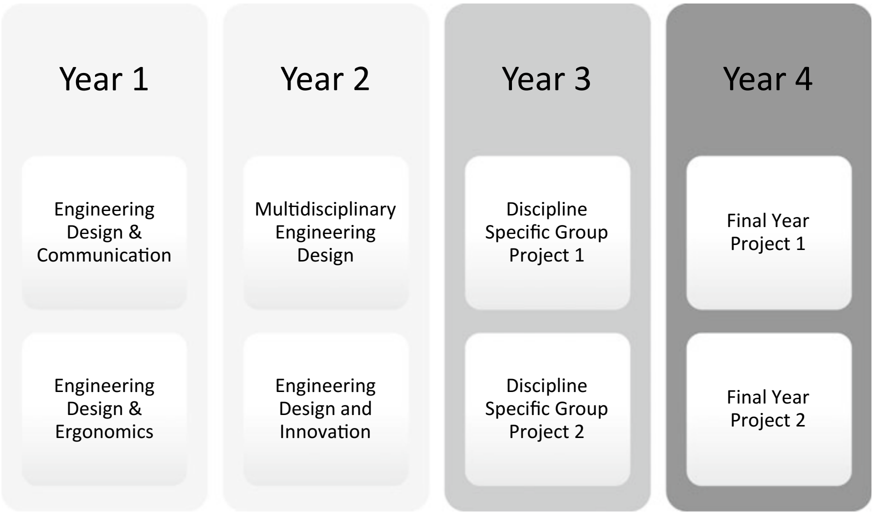

Fig. 2.1 Organisation of the design and project modules

students. He saw how this simple project would pique the interest of students working on the project and he even received complaints from students who were not offered this 'project' of being biased! Over time, he offered more projects and finally with the permission from the University of Birmingham, a project/design module was created.

From experience gained from this project module, this head of department and his team, when they were designing the syllabi for the undergraduate engineering programmes for Taylor's University College,[1] incorporated a design spine consisting of a series of design/project modules spanning from semester 1 all the way through to semester 8. The current structure of the design spine consists of eight modules as depicted in Fig. 2.1. With the exception for Final Year Project 2, which carries a 6-credits weightage, the remaining seven design modules are all 3-credits each. The four design modules in year 1 and 2 are also common modules attended by students from the various undergraduate engineering programmes. These first four design modules are also multidisciplinary and team-based. The modules in year 3 are also team-based but are discipline-specific and are implemented as capstone projects. Final year project, on the other hand, is individual research project where every student is required to publish their research findings.

[1]On its way to becoming a full university in 2010, Taylor's College was awarded the University College status in 2006. Beyond 2010 after Taylor's University College was awarded a full University status, Taylor's College remains as a separate institution offering pre-university programmes.

2.2 Details of the Design/Project Modules

The structure of the design/project modules along the design spine is one such that each module would build on the knowledge and experience students would have gained from preceding modules as they progress through the programme. As a means to illustrate this, details for each of these modules along with their learning outcomes and objectives are detailed in the following subsections.

2.2.1 Engineering Design and Communication

This is the first design module and its objective is twofold. First, it is to introduce students, who would have just completed their high school certificate or other equivalent pre-university qualification, to the basics principles of engineering design and a number of basic skills important to engineering design. In particular, this module emphasises on technical communication skills such as reporting, sketching and drafting.

In this module, all students are organised into teams of five. Each team will consist of students from at least two engineering disciplines. Each team will work on a project on offer or proposed a project. In order to ensure alignment with the module learning outcomes, all proposed projects will need to be approved by the module coordinator.

The learning outcomes for this module are as follows.

1. Produce useful ideas and concepts using Brain Storming.
2. Design a system that solves a complex engineering challenge using a Design Process.
3. Conclude findings from working in a team through technical documentation.

2.2.2 Engineering Design and Ergonomics

Building on top of what students have learned from the *Engineering Design and Communication* module, the objective of this module is to equip students with the knowledge and skills related to human–machine interface in engineering design. Students are organised into teams in much the same manner as Engineering Design and Communication but the projects on offered now have a skew towards human factor, occupational health and safety.

The learning outcomes for this module are as follows:

1. Produce useful ideas and concepts using Cognitive Ergonomics.
2. Design a system that solves a complex engineering challenge with an emphasis on Human Factors.
3. Evaluate the occupational health and safety of an engineering system as well as its success in being sustainable.

2.2.3 Multidisciplinary Engineering Design

The objective of this module is to introduce students to real-life work environments where engineers from different disciplines and backgrounds work together to accomplish a given task. Note that in this module, learning outcome 1 now focuses on very specific techniques.

The learning outcomes of this module are as follows:

1. Apply techniques, such as Trimming, Random Entry and Systems Thinking to Conceive, Design, Implement and Operate a system which solves a complex engineering challenge.
2. Evaluate the manufacturability (in terms of production effectiveness) and sustainability of an engineering system.
3. Explain the role of ethics in engineering design.

2.2.4 Engineering Design and Innovation

With the foundation built over the previous three design modules, the objective of this fourth design module is to introduce students to Design Thinking as the core design process. Other than Design Thinking, the concept of business value, TRIZ and effective presentation technique based on neuromarketing are also taught in this module. Unlike the previous three design modules, students will need to form their own team and proposed their own project. And not only must the proposed project be aligned with the module's learning outcomes, students must be able to justify the business value associated with the challenge they are attempting to solve.

The learning outcomes of this module are as follows:

1. Identify a complex engineering challenge that has business value.
2. Design a system, with the aid of design tools and techniques, which solves a complex engineering challenge that has business value.
3. Explain the importance of intellectual property rights as a legal instrument for commercial monopoly.

2.2.5 Group Project 1

This is the first part of a two-part discipline-specific group project. This module is concern mostly on the analysis of a discipline-specific engineering challenge and the synthesis of a solution to solve the challenge. The challenge offered would need to be complex enough where its solution will involve the application of multiple fields within the discipline.

The learning outcomes of this module are as follows:[2]

1. Analyse and identify root causes of a given challenge.
2. Justify proposals and suggestions based on sound technical knowledge.
3. Develop effective solutions.
4. Analyse the implication of design on manufacturability, testability, usability, ease of maintenance and sustainability.
5. Evaluate design using appropriate method/methods.
6. Organise one's work diligently and thoroughly.

2.2.6 Group Project 2

This is the second part of the two-part discipline-specific project where the focus is towards the construction/implementation of a design developed a semester earlier.

The learning outcomes of this module are as follows:

1. Create a functioning prototype based on design.
2. Evaluate the functionality of prototype against design.
3. Evaluate the design based on performance, cost and sustainability to optimise the design if necessary.
4. Execute project closure.

2.2.7 Final Year Project 1

This is the first of a two-part individual research project. The focus of this module is very much on the formulation of the scope and objective of the research, literature review and preparation for experiments.

The learning outcomes of this module are as follows:

1. Formulate the scope and objectives of a particular research project.
2. Organise critical literature review.
3. Build a research plan using project management tools.
4. Design and Prepare research methodology.
5. Compile the findings in both written and verbal form.

[2]Though there are variations between the learning outcomes for this module for the three undergraduate programmes currently active at Taylor's University School of Engineering, the essence they capture is essentially the same.

2.2.8 Final Year Project 2

This is the second of a two-part final year project where the focus is very much on the collection and analysis of results. Students are expected to submit a conference paper at the very least on top of a thesis that captures their work for the whole year.

The learning outcomes of this module are as follows:

1. Evaluate results using research-based knowledge and research methods which include experiment design, data analysis and the synthesis of information to provide conclusions.
2. Compile and present a final year project thesis and a peer-reviewed conference paper.
3. Apply project management tools to execute the research plan.

2.3 The Motivation Behind Project-Based Learning

The implementation of project-based learning and the inclusion of the design spine go beyond Taylor's University School of Engineering being part of the CDIO™ Initiative [1, 2]. As mentioned earlier, it was observed that project work help motivates students. Correctly prescribed, it has the potential to draw the best from participating students. A case in point is that of a student whose A-level results were so poor, he could not get a place to study in the UK and had to grudgingly settle for a place at Taylor's University School of Engineering. The project he was working on in semester 1 was so interesting to him he wanted to know more. So much so he started to study. Not only material taught in class but whatever he needed to understand to complete his project. His CGPA at the end of semester 1 was 4.0/4.0. This student completed his study with a CGPA of 3.33/4.0 and was heavily involved with the school's racing team.

We believe our observation with project-based learning is consistent with Dale's Cone of Experience [3]. Projects, correctly prescribed, give student that direct and purposeful experience. They will understand why and the importance of what they are taught in class and hence the observed motivation in students working on projects. It may be interesting to note that Taylor's University School of Engineering attempted to convert lab experiments to be case-based, in other words, a contrived experience in Dale's Cone of Experience terminology. This, unfortunately, due to resource constraints, was never rolled out even after a successful trial.

Though this was the motivation behind the adoption of project-based learning and the creation of the project spine in the syllabus, its impact is best understood from the student and academic staff perspectives. In the following chapter, an alumnus of the school attempts to give reasons behind the effectiveness of project-based learning followed by the perspective from a member of the faculty.

2.4 Challenges in Implementing Project-Based Learning

Just as having a world-class syllabus will not guarantee that all graduates will be world class; having a design spine, even with a well design syllabus for each module in the spine, will not guarantee that all students having successfully completed all modules in the design spine will be well versed with project work. The following are some challenges we have experienced since the inception of the design spine and project-based learning at the school.

Though these challenges can be daunting, the benefit of the design spine in a project-based learning school can have benefit as the feedback from employers of our graduate continues to affirm this.

2.4.1 Module Coordinator

The interpretation of the syllabus and the standard set for each module lies in the hand of the module coordinator. A module coordinator with extensive project experience will be better able to guide students at a much higher standard/level as one who has little to no project experience. We have noticed that a module coordinator who has been involved in commercial/industrial projects, especially those who have experienced bringing a concept to market, generally make good design coordinator. A maker, i.e. a person who likes to make/build things, is another.

2.4.2 Project Supervisor

Project teams will need to be supervised and it is not possible, nor practical in some cases, for the module coordinator to supervise all project teams. A project supervisor may be familiar with the theoretical aspect of the project but not the design process. A solution around this is for all supervisors to be trained in the design process before they are allowed to supervise projects. Our experience shows that even this will take time. An alternative to this is for teams needing technical supervisor to be supervised by a technical supervisor while the module coordinator remains as a co-supervisor assisting these teams with the design process.

2.4.3 Project Offering

Even for a small school with around 100 students per intake, each module will have around 20 teams on average. And with just the first four design modules, the school will need to come up with 80 projects every semester. A solution around this is not to offer specific projects but to offer a generic challenge/theme, such as *tool for old age*, *solutions for natural disaster*, *assess to clean water,* etc. and to allow students to propose projects that are aligned to the assigned theme. Note that you will always allow good project proposal by teams that are not aligned to the suggested theme as long as the activities for these projects will allow them to gain the necessary learning outcomes for the module. Prior to us adopting the approach of providing project theme to guide students with their project proposal, we noticed that there is a tendency for module coordinator to repeat projects and students may copy solutions from their seniors, making minor changes to make it their own! There is also a tendency for module coordinator to repeat project theme but its impact is not as severe as repeating specific projects as there are many possible projects for a given theme.

2.4.4 Students are not Familiar with Engineering Design

Unlike mathematics, physic or chemistry, students entering an engineering undergraduate degree programme would not be familiar project or engineering design. In fact, most undergraduate engineering degree programme will introduce students to project and/or design in year 3 of their 4-year programme. The rationale is that students would need to have the necessary knowledge before they can work on meaningful engineering challenges and as such module introducing students to engineering design is only introduced later in the programme. However, as there are other dimensions of learning associated with engineering design other than technical knowledge, students need also to be exposed to these other learning dimensions, especially the effective learning domain, in order to better prepare students before they are introduced to engineering design involving more complex engineering challenges.

This challenge is a lot more complex than one may expect as students who are introduced to project early will become very familiar with teamwork, always having a challenge to solve and integrate into the workplace after graduation very well. This is confirmed from feedback we received from employers and alumni alike. However, there is a risk of students developing bad habits early in the programme that they are unwilling/unable to correct. Jumping to conclusion and proposing solution(s) from the get-go without verifying what they are trying to solve and/or not having proper basis for their proposal being two of the major bad habits/tendencies we have to deal with. These are natural tendencies common amongst students fresh from high school but need to be corrected if there were to be able to take on complex engineering challenge. How engineering design is gradually introduced to students is detailed in the following section.

2.5 Introducing Students to Engineering Design

How engineers think and what they consider when solving a challenge, though structured, is not structured in a manner that can be described in an algorithm. It is more like a collection of many algorithms coupled with rule and/or experienced based decision-making process where these algorithms can even be mix and match together as and when appropriate. It takes into account as many relevant factors as necessary while considering available options. The impact each option has on the end user, on manufacturability, testability, ease of maintenance, etc. is also considered. The path it takes to arrive at the final solution is also seldom the same and this process is not intuitive to the uninitiated and may even seem, at time, to be contradictory to our natural tendency. Most experienced engineers would have learned this skill over time through years of hands-on experience and it is definitely not something that can be taught to students, fresh off high school, in a module spanning a little over 3 months. Accordingly, the first three design modules within the design spine are very much to put students through a series of projects with increasing level of complexity that will allow them to gain some basic engineering design experience before they are introduced to Design Thinking as a core engineering design process in the fourth semester.

The experience, skills and knowledge that students will gain from the preliminary design modules in the first 3 semesters can be grouped under the following headings:

- Working in teams,
- Design process,
- Technical documentation,
- Thinking tools and techniques, and
- Human factor.

The intention is for students to gain exposure and experience in these areas as they progress through the three preliminary design modules. The rationale behind the selection of these areas is described in the following sections.

2.5.1 Working in Teams

Engineers inevitably work in teams and students need not only to be comfortable with working in team but also to understand the stages team goes through from formation to adjourning. For this, students are not only organised into multidisciplinary teams (team consisting of students from two or more engineering disciplines), they are taught and are assessed on their ability to identify the stage their team is at within the framework of the Tuckman's model [4] on a weekly basis. They are also assessed on their ability to identify the action(s) needed to advance their team towards the performing stage. Conflict among team members is not uncommon and students will have the opportunity to learn to deal with these conflicts.

2.5.2 Design Process

As mentioned above, students who are new to engineering design generally have the tendency where they would propose the first idea that comes to mind as the solution for a given challenge. This tendency is so strong that it takes effort just to get students to trust the design process. Accordingly, students are taught the CDIO design process [2, 5]. Students are required to apply the CDIO design process for their projects from semester 1 to semester 3.

2.5.3 Technical Documentation

Documentation is an important element in engineering design. One must be able to keep detail records so as to allow anyone else skilled in the art to reproduce one's work or to have sufficient evidence that will be accepted in a court to support when an invention was developed, etc. In this aspect, students are taught how to keep an inventor's logbook, meeting minutes and how to write a good technical report. Students are also taught engineering drawing.

2.5.4 Thinking Tools and Techniques

The ability to think critically and the ability to apply thinking techniques to generate new idea are crucial skill in engineering design. Starting with brainstorming and 5 Whys in semester 1, students would be introduced to other thinking tools and techniques, such as lateral thinking and trimming, by the time they complete semester 3.

2.5.5 Human Factor

Products/solutions we design are ultimately used by human and even if it is not used by human are maintained by human. Where our solution interacts with human, it is crucial that these interfaces be designed not only to avoid injury but also a joy to use. Accordingly, students are introduced to the concept of human factor in design and are taught ergonomics specifically.

2.6 Design Thinking at Taylor's University School of Engineering

Following the three preliminary design modules, all engineering students are taught Design Thinking as a core engineering design process in semester 4. They are also introduced to TRIZ [6], but Design Thinking is intended to be the core design process students will use from this point in. Accordingly, it is important that details of Design Thinking at Taylor's University School of Engineering and in particular how the module is structured and run will be described in the following sections.

2.6.1 How Design Thinking Was Introduced to Taylor's University School of Engineering

The very first intake for Taylor's University School of Engineering was in September 2009. Three undergraduate programmes, namely, Bachelor of Engineering (Honours) in Chemical Engineering, Electrical and Electronic Engineering and Mechanical Engineering, were on offer. The founding team had already designed the curriculum for these programmes to be project-based and there were seven design/project modules in these original programmes. At that time, the author of this chapter had only joined the team a few months earlier. He was a co-founder of an IT and innovation consulting company prior to joining Taylor's and was a programme manager with Intel's IT Innovation Centre at Cyberjaya prior to that. He was also a trainer for an in-house Design Thinking workshop at Intel. Noticing the gap in what is now considered the design spine in the syllabi, he suggested incorporating the training material he had developed after leaving Intel to be a design module in the syllabi of these programmes. This module is now the semester 4 Engineering Design and Innovation module.

The content for this module has remained largely unchanged since its introduction in early 2010; however, the way it is conducted has changed tremendously. Classes were earlier conducted like corporate training sessions. Today, classes are flipped and there is no background music before the start of class!

2.6.2 Learning Outcomes and Lesson Plan

Semester 4 Engineering Design and Innovation (ED&I) is the module where Design Thinking is taught at Taylor's University School of Engineering. It may be interesting to note that Design Thinking is not mentioned in the learning outcome for this module as this is not a Design Thinking only module but and engineering design module where Design Thinking is taught as a core design process. In this module, the concept of business value [7] is also introduced.

Table 2.1 Generic lecture plan

Semester week	Delivery
1	Module introduction Lecture 1 introduction to creativity, design & innovation
	Lecture 2 innovation 101 Tutorial examples of innovation
	Lecture 3 design thinking: understand Tutorial Taylor's parking challenge
2	Lecture 4 Design thinking: observe Tutorial Petrol station forecourt & vending machine
	Lecture 5 design thinking: ideate Workshop campus parking challenge
	Lecture 6 design thinking: prototype Tutorial various cases
3	Lecture 7 introduction to business value Tutorial various cases
	Lecture 8 Introduction to intellectual property
	Lecture 9 Neuromarketing presentation technique
4	Lecture 10 Return-on-failure Tutorial review of previous semesters' samples
	Lecture 11 Introduction to TRIZ level 1 (part 1 of 2)
	Lecture 12 Introduction to TRIZ level 1 (part 2 of 2)
5	Lecture 13 Grand challenges for engineering and CDIO a reminder Workshop wallet design
	Workshop water bottle design
	Lecture 14 revision class

The learning outcomes for the module are as follows:

1. Identify a complex engineering challenge that has business value.
2. Design a system, with the aid of design tools and techniques, which solves a complex engineering challenge that has business value.
3. Explain the importance of intellectual property rights as a legal instrument for commercial monopoly.

The intention of these learning outcomes is to equip students with some of the basic skill important to a technopreneur that is also commonly found in experienced senior engineer. Another important skill that is taught in this module, though not captured in the learning outcome, is the technique for effective presentation.

The lesson plan for this module is as shown in Table 2.1. Instead of the usual 2-hour lecture followed by another 2-hour tutorial per week, the lesson plan for this module would have three 2-h our sessions per week for at least 5 weeks. And these sessions are not marked as tutorial or lecture as tutorial and exercises are mixed with lecture as appropriate. The reasons for such an arrangement are as follows.

2.7 Students Cannot Apply Material Taught Late in the Semester

In a 14-week semester, students will need to progress through their project where they could settle on a design sometime around the middle of the semester giving them sufficient time to build and test the design on the later part of the semester. Whatever material taught in the later part of the semester will be too late for student to apply it on their project. Accordingly, it is important that techniques you would like student to apply on their project during the semester had to be delivered before they have advanced too far into their project.

2.8 Validation of Understanding and Efficient Use of Time

Having tutorial exercise or activity immediately after the delivery of the material helps students with a quick revision of the material as well as improves retention. Frequently, some of these activities take no more than 30 min and it would be an efficient use of time just to slot this into the lecture slot.

2.8.1 Projects

As is the case for all design and project modules at Taylor's University School of Engineering, students taking the Engineering Design and Innovation module will need to organise themselves into teams of not more than 5. Each team will need to be made up of students from at least two disciplines. Each team is to propose their own project and the project they propose must be able to show that they are able to identify a challenge, especially one that requires an engineering solution, that has business value. In other words, they will need to show that they have attained learning outcome 1.

Once a team has an approved project, they will work on the project through the semester with regular supervision. Each team will have at least one time slot allocated to them with their supervisor once every fortnight and there is no limit to the number of additional meetings they would like to have with their supervisor in between these allotted time slots. The module coordinator will be the main supervisor for every team and should there be a need for a technical supervisor; these teams will need to be able to convince an appropriate lecturer(s) to be their co-supervisor(s). The rationale for this is that it is crucial that students gain a working understanding of the material taught in class, especially the process for Design Thinking.

As a means to facilitate students with their project proposal, a theme may be suggested. An example could be 'access to clean water' or 'solutions related to annual flooding along the east coast' or 'solutions applicable to refugee camp', etc.

From time to time, there will be team(s) that are not able to come up with a suitable project in the first 4 weeks before the project proposal is due. A reserved list of projects is then used to assign to these team(s). It must be emphasised that by doing so, these teams will miss the opportunity to experience learning outcome 1 on their own and it would not be surprising that these students will tend to have lower scores for their learning outcome 1.

2.9 Flipped Classes

Today, in order to have more time for in-depth discussions with students in class, classes are flipped. Students are required to attend all lectures online prior to each lecture and face-to-face time is reserved for Q&A, in-depth discussion and tutorial. Recording of classes from a previous semester is hosted on OpenLearning and is accessible at https://www.openlearning.com/courses/engineeringdesignandinnovation/.

2.10 Business Value Augmented Design Thinking Process

A Google image search for the phrase ‘design thinking process’ will produce a number of different Design Thinking processes from various institutions. You may even find variants from the same institution. Each of these processes is essentially the same but with different emphases.

The Design Thinking process that was introduced to Taylor’s University School of Engineering is captured in Fig. 2.2. This diagram is to be understood in the following manner. We start at the grey block on the far left. We can only be in a valid black block at any point, and grey blocks are only transitional to connect a valid black block to another. We can only traverse from a block to another adjacent block. Accordingly, starting at the grey block on the left, the first valid step can either be *Understand* or *Observe*. We would then iterate between the understanding and observation steps until we are able to ascertain the business value of the project (the leftmost vertical line). You would drop the project if there is no business value and you will continue to iterate through the understanding and observation steps until you have gained sufficient insight into the challenge that you have understood the root cause or have gained an inspiration that you have some confidence will lead to a good solution. It is only when you have reached this stage would you proceed to the *Ideate* step. Concepts generated from ideation are evaluated in the *Prototype* step. It is common to iterate through the ideation and prototyping steps until we are happy with the solution at hand.

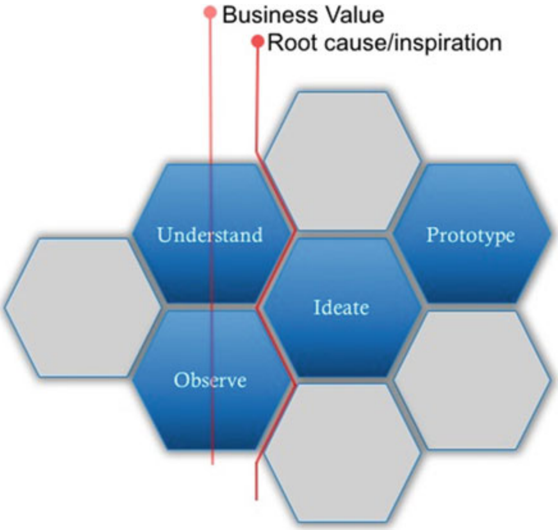

Fig. 2.2 Business value augmented design thinking process

It is not unusual that during ideation or prototyping that we discover we lack understanding or data and will need to return to the understand or the observe stage. You will again return back to the ideation steps once you have gathered a revised root cause or inspiration. This whole iteration will continue until you are happy with the solution at hand.

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