Iron Range Engineering, US

Case Study Part A – Best Practice Activity

Design project

Student cohort: **150**
Location: **100% online**
Duration: **1 semester (16 weeks)**
Date delivered: **Jan – May 2021**
Activity type: **Team project**
New/existing: **Existing**
Hands-on: **Prototyping + experiments**
Cross time-zones: **In some projects**
Case study approved: **September 2021**

Distinctive feature of case study

Building motivation and self-directed learning through design projects that connect learning across the curriculum

Abstract

Activity overview

Each semester of Iron Range Engineering's two bachelor-level programmes are structured around a 16-week design project; students engage in these projects from programme entry and throughout their studies. These projects tackle open-ended challenges set by external clients that address a real industry or societal need. Projects are undertaken in one of two modes: 'campus-based' (prior to emergency teaching, students worked in teams with peers on campus) and 'work-based' (projects are embedded in paid work placements taken by students in companies across the US).

Independent review

The most striking feature of the Iron Range design projects is their curricular integration. The projects act as a hub that feed into and draw upon students' learning across almost all other components of the programmes. The success of the design projects turn, in part, on students' capacity to establish a close collaboration with team-mates and to immerse themselves in the context of the industry problem they are solving. Both elements were stress-tested by the introduction of emergency teaching in March 2020. However, the "*close-knit*" Iron Range community and one-to-one mentorship offered by instructors went a long way to offset the barriers introduced by the online pivot.

Activity details

Design projects typically follow a 'design sprint' structure: the 16-week projects are divided into three 'sprints' with teams expected to progress through an entire design cycle during each sprint. While teams are mentored by practicing engineers, students are expected to lead and manage all aspects of the project independently.

1. Activity overview

Based in rural Minnesota, Iron Range Engineering offers two programmes that culminate in a bachelor degree. Taken together, these two programmes[1] will be termed 'Iron Range' hereafter. Design projects – each 16 weeks in duration – are embedded in each semester of study in the Iron Range programmes, and form the spine around which the curriculum is built. The design projects take two broad forms which, prior to COVID-19 emergency teaching restrictions, were distinguished by their mode of delivery:

- **'campus-based' projects:** students tackle authentic problems posed by external (typically industry) clients, devoting around 10 hours per week to their project. Project teams are often vertically integrated, meaning that they bring together students from all semesters of study;
- **'work-based' projects:** working a 35–40 hour week on paid industry work placements, students form teams with their co-workers to tackle projects set by their employer. Most other curricular elements are delivered remotely (typically via asynchronously online learning).

During COVID-19 emergency teaching, however, both 'campus-based' and 'work-based' projects were predominantly delivered online. Three features set these Iron Range design projects apart from traditional engineering team-based projects:

- **they span the programme:** students engage in a range of design projects (taken from different sectors and perspectives) from matriculation and throughout their studies;
- **they are authentic:** project briefs are set by external clients to address a real industry or societal need. Students self-manage all aspects of the project independently;
- **they connect students' learning:** design projects draw upon and feed into almost every other component of the Iron Range curriculum (as discussed further in Section 2.1).

2. Independent review

2.1. Distinctive features

The most striking feature of the Iron Range design projects is their integration with the rest of the curriculum. As illustrated in Figure 1, the Iron Range curriculum is divided into three, roughly equal threads: technical, design and professional. The design projects act as a hub that connects and integrates students' learning across all three threads of the programme. The connections between the projects and the wider curriculum take two major forms, as described below.

Some of these connections to the design project are **written into the curriculum**. For example, as part of each semester's 'design workshops', students typically deliver six technical papers, all in journal article format. Most of these papers relate to students' design projects and explore the particular

[1] Further information on the structure and operation of these two programmes is given in Section 3.8.

design processes that they or their company have adopted. In a second example, students are asked to reflect on their learning and development each week within a 'learning journal'. The prompts given for student self-reflection often relate to particular experiences in their design project.

Other connections to the design project are **identified and shaped by students themselves**. For example, half of the technical thread is devoted to 'student-led advanced' (SLA) courses in which each student must identify the topic they wish to learn and (in most cases) design their own syllabus and assessment protocols to achieve this goal (under the guidance of an instructor). Students typically use SLA courses as an opportunity to master key concepts associated with their design project to help them improve or advance their ideas. In addition, 'deep learning activities' (DLAs) are embedded into all technical courses, and require students to undertake an experiment to explore one aspect of the course in more depth. Students often use DLAs to investigate key questions related to their design project. For example, one student interviewee, who was engaged on a water treatment project with a civil engineering consultancy firm in the Spring of 2021, designed an SLA competency in pump optimisation. For the linked DLA, he planned to collect and analyse data from a pumping station at his host company to evaluate the systems performance and offer recommendations for optimisation.

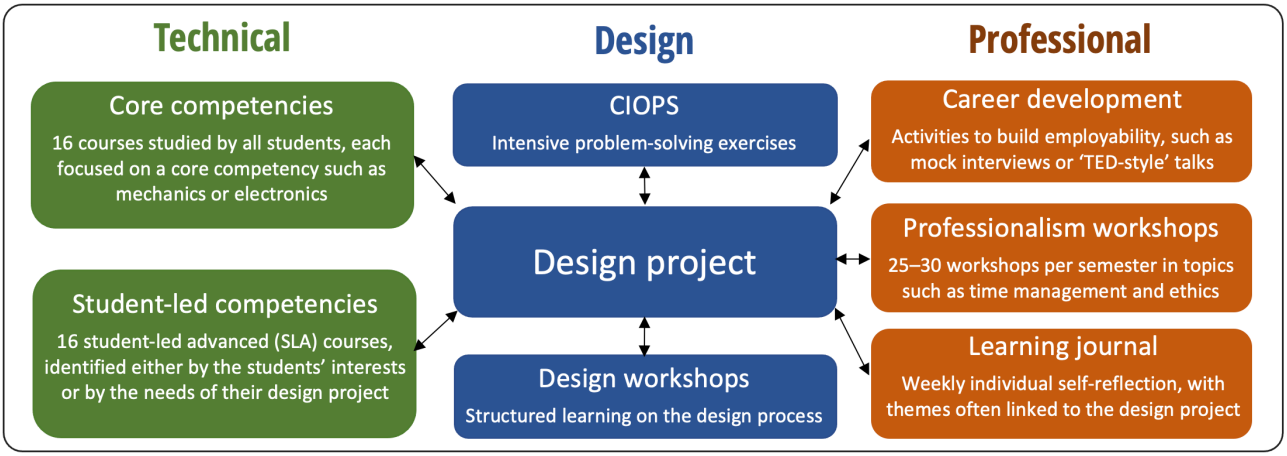


Figure 1. Connectivity apparent between the design project and all other elements of the Iron Range curriculum

As well as offering a mechanism for students to apply, synthesise, and contextualise their learning, the cross-curricular connectivity of the design projects also advances many of the core principles that lie at the heart of the Iron Range approach. For example, it provides a platform to further **autonomy and self-directed learning**. In particular, while the design project is a team-based activity, the components it connects to across the curriculum are typically undertaken individually. This provides a mechanism for each individual student to identify elements of their design project that they are of particular interest/relevance to them and build this learning in a way, and at a pace, that suits them best. The projects' curricular integration is also used to foster **intrinsic motivation** by establishing a driver for learning that is not based around academic grades, but instead rests on students' desire to produce the best possible showcase for their talents and achievements to prospective employers. With the design projects (and associated employability activities) touching almost every element of the curriculum, such triggers for intrinsic motivation are embedded programme-wide.

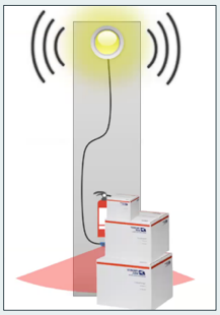
Student interview feedback pointed to the efficacy of this approach. When describing the synergy between her design project and self-designed SLA competency, one Iron Range alumnus noted:

> "*it really made the class much more real, like I've taken an [SLA] advanced hydraulics class, but then you're also designing a hydraulic system for a local mine, and you're presenting to very experienced engineers. That just creates a little more urgency: these are potential people that would hire you, so you also want to know what you're talking about... It's like almost like a pre-job interview*".

An illustration of the curricular connectivity of the Iron Range design projects is given in Box 1.

Box 1. Example of connectivity between the design project and the rest of the Iron Range curriculum

One interviewee for the case study was Kennedy St. John, a first-year student who had just completed a paid work placement at the United States Postal Service (USPS). As part of her placement, Kennedy was asked to design a system that triggered an alert if access to a fire extinguisher in a USPS facility was obstructed. Working with a USPS colleague over the course of a semester, she developed and validated a device to meet the brief, which she called the Obstruction Warning Light (OWL).



This design project drew upon and fed into Kennedy's learning across all three threads (technical, design and professional) of the curriculum, which included:

1. **technical:** Kennedy selected programming as one of her SLA competences and designed a syllabus to develop this competence, which she subsequently used to inform the programming of an Arduino device used during prototyping of the OWL;
2. **design:** during the one-week 'intensive problem-solving' activity, scheduled at the semester end, students were asked to identify an out-of-scope aspect of their design project to develop further. Kennedy chose to advance the design of the OWL to allow it to be reset and adjusted remotely. In addition, as part of the 'design workshops', Kennedy delivered a series of technical papers that reviewed the design processes adopted by USPS, such as their approach to iterative design.
3. **professional:** Kennedy delivered four separate presentations on the OWL project, each to a different audience. She noted how these repeated experiences, together with the support and feedback offered during professionalism workshops, helped to hone her public speaking skills.

The USPS is pursuing a patent for the OWL device, which is being deployed across its facilities nationwide.

2.2. Success factors

The Iron Range design projects are ill-defined and challenging by design. Taken from across a range of sectors and company profiles, these projects call upon students to assume the role of a professional engineer from entry to the programme and take a lead in managing all aspects of the project including liaison with the company client. Establishing the conditions for students to successfully navigate such projects is not straight-forward, particularly given that that the programmes' intake (of students from regional Community Colleges[1]) may have had no prior experience of student-led or project-based learning. Interview feedback suggested that four inter-related factors underpin Iron Range's success in fostering the competencies and conditions necessary for students to navigate these projects:

- **clarity of expectations and goals:** a range of mechanisms are put in place to make clear to students what is expected of them and why. While the design project briefs are open-ended, the expectations on teams are made explicit, both in terms of their professional approach and the deliverables required. Students also participate in 'learning to learn' courses which explore pedagogical theories and outline the evidence-based rationale for Iron Range's curricular design. Student interview feedback suggested that appreciating why they have been immersed in ill-defined or challenging project experiences has proved crucial to building their engagement and maintaining their focus on design projects, particularly during emergency teaching.
- **community of support:** one theme repeatedly highlighted by interviewees was the collegial "*close-knit*" community of support that extends across instructors and students in programmes. This culture was seen as an important counterbalance to the open-ended and complex nature of the design projects. In the words of one instructor, while the design projects are designed "*to put students in an uncomfortable position… there's a soft cushion landing for them, so it's not so risky for students to get out of their comfort zone*". The support offered is typically personalised and one-to-one, with regular and on-call mentorship offered throughout the programmes. Indeed, when asked to describe Iron Range as a whole, one student simply said: "*I would say it's very challenging and very supportive at the same time*".
- **iterative competency development:** as students progress through the Iron Range programmes, they are repeatedly exposed to a set of core concepts and experiences. A major focus of this 'triple helix' approach is to progressively build professional and employability competencies. Indeed, it is estimated that students will deliver around 100 presentations by the close of their Iron Range education. A surprising number of student interviewees spoke about how these repeated experiences of delivering presentations and practice interviews – in conjunction with feedback provided by instructors and peers – had helped them to overcome a deeply-held anxiety about public speaking. During emergency teaching, this 'triple helix' approach appeared to play a crucial role in fostering students' confidence in liaising with, and presenting to, industry clients that they may have never met face-to-face.
- **responsive programme design:** the student voice has long played an important role in shaping the design of Iron Range curricular activities. Student feedback and preferences are often captured in real time to decide, for example, the structure of a class or the priority topics to be covered in a design workshop. This responsive approach – combined with the small size of the student cohort – proved particularly valuable during emergency teaching. Students reported how problems that they flagged up to instructors were rectified rapidly, and curricular elements were quickly adapted to better suit students' online working modes and conditions.

Underpinning each of these factors is a remarkable capacity and willingness to support ongoing educational experimentation and evidence-based change that spans both Iron Range programmes. Continuous curricular renewal – in response to pedagogical evidence, best practice examples from peer institutions, and feedback from external advisors, staff, students and alumni – is integral to the Iron

Range culture. Enabling such a unique experimental culture is undoubtedly supported by the fact that Iron Range is based on a stand-alone satellite campus, located 300 miles from the institution that credentials its programmes, Minnesota State University, Mankato[1]. As one Iron Range instructor commented: "*the mothership is a long way away… we are in our own separate place, just like a bubble – just us faculty, our industry partners, and the students together. We feel kind of allowed to try things, we just try to use evidence-based practices, see what happens and then iterate*".

2.3. Challenges faced

Interview feedback pointed to a number of challenges associated with the design projects during emergency teaching conditions. While fears that multiple companies might 'lay off' work placement students after the pandemic first hit were not realised, two particular challenges remained.

The **first challenge** was distinct to the 'campus-based' design projects and concerned students' capacity to collaborate on projects and engage informally when working online. Prior to emergency teaching, each 'campus-based' design project team was allocated a dedicated room to use for the duration of the 16-week project. Interview feedback suggested that the Iron Range culture of peer support and collaboration was rooted within these spaces, fostering "*a very organic way of problem-solving*" with students working together on personal interest projects and assignments as well as their design projects. Following the online pivot, the loss of the project rooms was felt particularly strongly. Interviewees reported that students often struggled to "*reach out to one another*" in their design project teams and many of the "*informal conversations you have in the project* room" were lost.

The **second major challenge** facing the design projects during emergency teaching was students' lack of exposure to the industry context. Prior to March 2020, the face-to-face relationships established with industry clients and opportunities to physically explore the host company played a crucial role in shaping teams' conception of their project brief: "*students would go on site, see the facility, take measurements of where the problem is happening… get to know the client and ask them a lot of questions*". Even before the introduction of emergency teaching, a challenge consistently faced by teams was to "*get all the information you think you need [from the industry client] to address the problem… and know what questions to ask*" to ensure that they understood the project needs and constraints. This challenge was exacerbated after March 2020. Many teams were unable to meet their industry client, see equipment/facilities in person or collect on-site data relating their project brief: "*to get a hands-on feel for what's going on… something for their brains to picture when they're working on the project*".

Taken together, these two challenges affected teams' time management and progress on their projects. Interview feedback suggested that "*the projects essentially didn't get as far as they would have normally*", with students investing disproportionate time on background research at the expense of ideas generation and design development. The inability of many teams to produce physical prototypes during emergency teaching was noted to "*make it harder to produce something that feels valuable*" and appeared to further inhibit students' confidence and progress.

Two broad strategies were employed by Iron Range instructors to address these challenges. The first was to offer more explicit and targeted feedback during regular design review meetings to help teams identify and remove blockages to project progress. The second was to call upon students "*to be more intentional with their interactions*". In their communications with industry clients, teams were encouraged "*to be more persistent*" when requesting information and data, with a greater reliance on clear written communication and more frequent contact. Instructors also suggested that teams use video conferencing as a proxy for in-person collaboration in project team rooms: "*keep Zoom open with peers throughout the day… if you need something, just unmute and ask, have a quick conversation and get back to what you are doing*". Although experiences by teams varied, this approach clearly helped many students to foster ongoing informal collaboration and connectivity. As one noted, "*once you get over the weirdness of it, it was nice to see each other, even if no one was talking, just to know they were there*".

3. Activity details

This section provides further details about the Iron Range design projects. Specific information on the two programmes in which the design projects are embedded – including the structure, operation and focus of the programmes – is provided in at the end of this section (in Section 3.8).

3.1. Participants and project groups

All Iron Range students participate in one design project each semester. In the spring semester (January to May) 2021, approximately 150 students took part in a design project.

As noted in Section 1 (Activity Overview), Iron Range design projects take two forms: 'campus-based' and work-based'. Students engaged in **'campus-based' projects** work in teams of between four and six. Team members select and agree their individual team roles, which often include team leader, project manager and one individual focused on 'team morale'. Students engaged in **'work-based' projects** form their design project teams with co-workers from their host company.

3.2. Challenge/project brief

For the 'campus-based' design projects, prospective project briefs are prepared in advance by Iron Range project coordinators in collaboration with industry partners. Prior to the start of the semester, students are asked to select their preferred project options. It is recommended that industry clients propose 'back burner' projects for these briefs: ones which are of interest to the company, but not business critical. In the spring semester of 2021, these briefs included projects: to develop a filtration system that produces drinking water with minimal energy usage; and to design a 'universal ladder step' that can be used across a range of different agricultural vehicles to provide driver access. Students also have the option to establish an independent team-based project, either to enter an engineering design

competition (such as the Baja SAE[2] competition) or to pursue their own entrepreneurial idea. Examples of such student-led entrepreneurial projects undertaken in the spring of 2021 included: one to develop a technical and business framework for the use of virtual reality in engineering education; and one to examine the feasibility of a renewable energy pump storage hydropower system.

For the 'work-based' design projects, students are expected to identify prospective employers and prepare applications for their work placements entirely independently. The design project is one component of the work that student conduct while on their work placement. The scope and focus of the design project will be first discussed by the student and their employer, and later agreed with the student's Iron Range facilitator. Examples of 'work-based' design projects undertaken by Iron Range students in the Spring of 2021 included: one to redesign a 'tumbler' for rotating foodstuff in a food processing plant; and one to support an upgrade to an energy substation in a regional city authority.

3.3. Structure of the activity

The structure of the 16-week design projects is not fixed: it varies between the 'campus-based' and 'work-based' projects and is adjusted semester-by-semester. However, the core components of the design projects delivered in the spring semester of 2021 are summarised in the table below.

Agreement of scope	At the launch of the 16-week project, teams/students met with their client to explore the problem and agree the scope for their design project. Teams/students then put together a 'scoping document' to lay out the expectations and responsibilities of both the team/student and industry client, which both parties signed. Agreement was also reached over the team roles to be taken by each student and the ongoing mode/frequency of communication with the industry client.
Design sprints	The rest of the 16-week project was divided into three 'design sprints', each of 4–7 weeks in duration. Following the Agile management approach, each 'sprint' involved one complete cycle of the design process, from problem definition through to evaluation of a selected idea[3]. With each subsequent sprint, teams/students iteratively built upon and refined their ideas. This 'design sprint' model was adopted as a mechanism to help students structure the project and ensure that momentum was maintained throughout the 16-week activity, particularly during the early weeks.
Design evaluation	Each 'design sprint' culminated in a report to the industry client and a 45-minute 'design review' oral presentation to an expert panel where students described the work delivered and reflected upon their learning (see Section 3.5 for more information about project assessment). At the close of Sprints 1 and 2, the design review panel provided feedback to the teams/students about their expectations for the next sprint.

[2] Baja SAE: https://www.bajasae.net
[3] Students were asked to structure the design process according to the eight elements steps of the 'design wheel': problem definition; design objectives; learning objectives; planning; team monitoring; ideas generation and selection; modelling and testing; and design evaluation.

3.4. Learning goals/objectives

The overarching learning outcomes for the design projects are the 'student outcomes' stipulated by the Accreditation Board for Engineering and Technology (ABET) for engineering programme accreditation[4].

In addition, each student is asked to identify their own set of 'individual learning goals' that are tailored to the needs and focus of their design project. These are checked and agreed by their facilitator in the early weeks of their project. Examples of these 'individual learning goals' devised by Iron Range students for their spring 2021 design projects included:

- *"to learn how a professional design process takes place and where I best fit into it"*
- *"to get a better understanding of how bearings function and how they are used/tested in industry"*
- *"to provide the best possible product, and to exceed expectations".*

3.5. Assessment.

A typical summative assessment protocol for the Iron Range design projects is outlined below, along with an indication of the proportion of the marks allocated to each core component.

1. **Project poster and engagement:** the quality of the poster outlining the project brief and the students' participation in the design workshops**.** *Graded by the design instructor.*	17.5%
2. **Design documents:** as part of their 'design workshops', students are asked to prepare six design papers each semester, all of which must adhere to a technical journal style. Four of these papers are directly linked to their design project (including a final paper on how the project was planned and executed) and grades for these papers count towards the design project score. *Graded by the facilitator.*	27.5%
3. **Individual contribution:** for 'campus-based' projects, the contribution of each individual student is evaluated at the end of each sprint via: peer assessment (captured through anonymised team surveys); an assessment by the team facilitator; and an 'individual contribution memo' produced by each student.	20%
4. **Scoping document:** at the semester launch, a document is compiled by each team/student to agree the project scope, focus and roles. *Graded by the facilitator.*	2.5%
5. **Design review:** 45-minute oral presentations delivered to a design review panel at the end of each sprint. *Graded by the design review panel.*	20%
6. **Final deliverables:** the project solution, as evidenced by drawings, prototypes and a technical report. The report is developed iteratively over the three 'design sprints'. Included in this report is a 'learning document' where students reflect on their learning throughout the project and the extent to which they have achieved the goals that they set themselves at the project's launch. *Graded by the facilitator.*	12.5%

[4] ABET: Criteria for Accrediting Engineering Programs, 2020 – 2021: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/

It should be noted that items 1, 2 and 3 in the table above are assessed individually, while items 4, 5 and 6 are assessed across the team. The technical report is also sent to the industry client at the end of each sprint.

3.6. The teaching team

The teaching team supporting the delivery of the design projects includes almost all Iron Range instructors (which comprises 11 PhD professors and 12 professional engineering facilitators):

- **project coordinators:** four Iron Range professors oversee and manage the design projects. These roles include, for example: supporting facilitators and meeting with them on a weekly basis to coordinate activities and track progress; working with industry clients to identify suitable project briefs (in the case of 'campus based' projects) and liaising with employers to ensure that students are engaged on engineering appropriate tasks (in the case of 'work-based' projects).
- **team facilitators:** who provide mentorship to teams (in the case of 'campus-based' projects) or students (in the case of 'work-based' projects), meeting with them regularly throughout the semester. Facilitators typically have a background in professional engineering and are hired as adjunct professors specifically to fulfil this project role. Facilitators meet on a weekly basis with the program director, "*to calibrate and align what we're doing this week*".
- **industry clients:** one or two industry clients oversee and support each design project. The frequency and nature of meetings with the relevant students/team are agreed at the project launch.
- **design review panel:** this panel brings together Iron Range instructors and technical specialists with expertise relevant to the particular project. Design panels typically come together at the end of each 'design sprint' to review the project's progress and the students' learning on the basis of their oral presentation.

3.7. Technology used

Google Classroom and Google Docs were used to manage all course information and student/team submissions. Although no other technology was mandated, many students used Slack to communicate with team-mates and SolidWorks to model their design ideas. Many also used iPads and Apple Pencils, which were provided to all Iron Range students following the introduction of emergency teaching in March 2020.

3.8. Further details on the Iron Range programmes

Iron Range Engineering[5] offers two 'upper division' bachelor-level programmes: the Iron Range Engineering (**IRE**) programme and the Iron Range Engineering Bell (**Bell**) programme. Students joining both programmes have already completed their 'lower division' study – two foundational years in engineering higher education – at a Community College. IRE and Bell students graduate with an integrated Bachelor of Science, Engineering (BSE), accredited by Minnesota State University, Mankato.

The IRE programme is four semesters (two years) in duration and (pre COVID-19 emergency teaching) was delivered almost exclusively in person, on campus. The Bell programme is five semesters (two-and-a-half years) in duration and is primarily delivered online.

As detailed in this case study, the IRE and Bell programmes embed two types of design project: 'campus-based' projects and 'work-based' projects. A key distinction between the IRE and Bell programmes is the balance struck between these two project modes (see Figure 2). IRE students typically engage in 'campus-based' projects throughout their studies, although they can select a 'work-based' project in their final two semesters. Bell students take a 'campus-based' project in their first semester, followed by 'work-based' projects for the remainder of the programme. During emergency teaching, however, almost all elements of both programmes were delivered online.

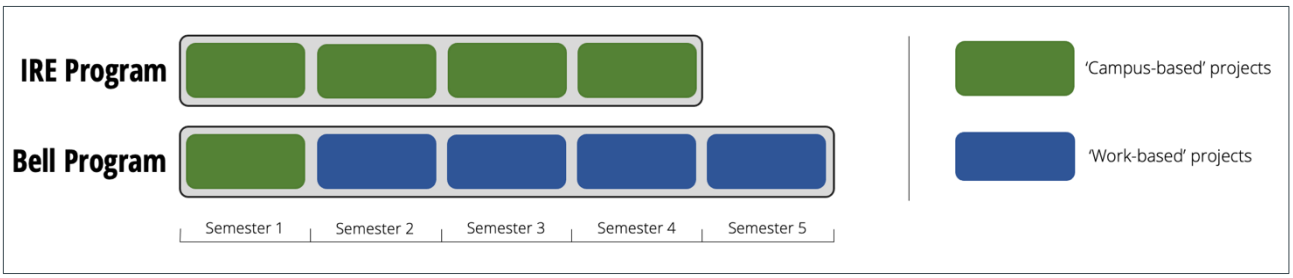


Figure 2. Typical structure of the four-semester IRE Program and five-semester Bell Program

Source of evidence

The case study for Iron Range Engineering (including Part A, this review of the Iron Range design projects, and Part B, a review of the 'institutional context' across the Iron Range programmes) drew upon one-to-one interviews with 16 individuals. The interviewees included: the directors of the two Iron Range programmes; two industry representatives who have acted as 'clients' for Iron Range design projects; one Iron Range alumnus; one Iron Range design project team facilitator; four Iron Range instructors; and six Iron Range students.

Further information about the methodology for development of CEEDA case studies is given at the project website[6].

[5] Iron Range Engineering: https://www.ire.minnstate.edu
[6] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies