



## The Use of an Iterative Industry Project in a One Semester Capstone Course

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## Abstract

Capstone projects provide students the opportunity to use the combined knowledge and skills gained throughout their educational curriculum to address a relevant (frequently industry sponsored) problem. While capstone courses are often two semesters and allow students significant time to design and advance a project, in some curricula these courses are limited to one semester. In such instances, the scope of prospective projects needs to be refined to meet the sponsor needs while also providing students with a worthwhile, yet tractable capstone experience. This work will describe the process used in one engineering technology program where students work on a certain aspect of a multi-semester industry-sponsored project.

This paper will detail the key documentation and scoping procedures that are necessary to facilitate these types of iterative multi-semester industry projects when multiple student groups are involved. An illustrative case is used to highlight how this has been implemented for one industry project that has spanned three semesters. Examples of student work and findings are presented to highlight the key scoping and documentation challenges of an iterative project necessary to meet the sponsor's expectations over the long term. Lessons that can broadly be applied to capstone projects and key lessons gleaned from these projects are also presented.

## Introduction

Capstone design courses and projects are a critical component of engineering education. These courses were originally conceived to counteract the trend of engineering education that focused more and more on the "engineering science" aspects of the discipline and less on the practical problem solving aspects<sup>1-3</sup>. A survey of capstone courses from the mid-1990s found a wide array of ways in which such courses were organized and conducted<sup>1,3</sup>. That survey found that the plurality of courses covered one semester. However, there are still a wide array of ways in which Capstone courses or course sequences are carried. The length of a Capstone course sequence will certainly have a dramatic effect on its content and what can be accomplished during the course. Some courses include content related to the design process itself while others include information about the engineering profession, legal considerations, or communication related information<sup>1</sup>. Another key aspect that influences what can be accomplished in a Capstone course is the size of each student team. The same survey found that the plurality of teams were between 4 and 6 students. The survey also found that the majority of projects were sourced from industry and internal clients; this is again likely still the case.

The importance and role of Capstone courses in engineering, and especially in engineering technology programs that pride themselves on their practical nature, has led to a significant amount of research and experimentation related to various aspects of these courses. Watkins examined a list of best practices related to project advising and was able to significantly reduce the number of negative comments and ratings associated with the course<sup>4</sup>. Others have introduced standardization and increased the focus on professional skills to improve the Capstone course experience<sup>5</sup>. Turner discusses the process of refocussing a Capstone course from project management towards a stronger focus on the design process content and activities<sup>6</sup>. Others have examined the needs and benefits of a multidisciplinary Capstone project<sup>7</sup> or of projects more focused on professional skill building and preparation<sup>8</sup>. One of the other key

benefits of Capstone courses is their role in promoting lifelong learning<sup>9</sup>. Various benefits and drawbacks associated with project type (e.g., design or test) and sources (i.e., internal or industry sponsored) have also been investigated<sup>10</sup>.

As mentioned previously, the length of any Capstone course sequence will have a dramatic effect on the types of projects that are feasible for the course(s). In some curricula, these course sequences span two years (four semesters) and allow students to go from concept to design and prototype construction with significant depth in various facets of the design process<sup>11</sup>. Multi-semester projects provide students with a unique opportunity to create a design portfolio that captures their contribution to the project<sup>12</sup>. The vast majority of Capstone course sequences have been one or two semesters<sup>1</sup>. Evidently, two-semester projects allow for more student involvement in scoping and developing a comprehensive project proposal<sup>13</sup>. While students are able to design, build and test a project-related prototype in one semester in some instances, this requires that the project should be relatively simple<sup>14</sup> or is well scoped and conceived. Those projects that are well scoped and conceived for one-semester are often internally sourced<sup>15</sup> since the appropriate level of advising can be found in-house. Some have investigated breaking up the traditional design, build, test sequence done over two semesters in to a design (in one semester), and design-build-test (in the other semester) sequence where projects may or may not be carried over<sup>16</sup>.

Assuming a one-semester Capstone course and a desire to have significant industry sponsored projects, an alternative method of project organization and scoping is needed. This work presents such a method and highlights its use through an illustrative case study. The background of the Capstone course and the project are presented in the next section. This is followed by the results of the project to date. Finally conclusions and future work are detailed.

### **Background and Illustrative Case Study**

The Capstone course in the Manufacturing and Mechanical Engineering Technology (MMET) Program at Texas A&M University comes at the end of a design and project management course sequence that includes courses in product design, machine design, and project and people management. The course is one semester in length and enrollment ranges between 25 and 45 students per semester. Historically projects have been sourced through a combination of internal (to the Program) and industry sponsors. Teams range between 4 and 5 students. Projects are typically presented during the first week of the course and students then “apply” to work on a project. The instructor then selects the teams to work on the various projects. Throughout the course of the semester, student must prepare a project proposal, and submit weekly progress memos, a mid-term report, and a final report. There are also design reviews prior to both the mid-term and final reports.

Many of the capstone course projects cannot be completed in one semester due to the complexities and requirements set by the industry sponsor. Therefore, each phase of the project should be scoped and planned precisely so the next design team can complete the project satisfactorily in a timely manner. Furthermore, to ensure a seamless project progress over a period of two semesters or more, adequate documentation and graphical communication should be provided by each design team. The documentation is presented in different conventional formats to ensure a smooth flow of information among teams that do not have the opportunity to

meet and discuss the details of each project phase. The teams must also include in their final reports what steps should be undertaken to be able to complete the project satisfactorily.

The project chosen to illustrate the use of iterative Capstone projects is centered around a novel cooling system for electronic devices. The concept, a microjet cooling system, was presented to Dell Computer by one of the authors as a way to cool laptop processors in maintenance situations. Dell and a maintenance contractor, Jabil Circuit, sponsored the project and provided some monetary support as well as a testing laptop. One of the authors served as a technical advisor to the teams throughout the iterations of the project. Given the complexities and intricacies of the chosen project, providing Dell and Jabil with a complete and functional microjet cooling system in one semester would have been unfeasible. As such, the project was broken into manageable segments that could be accomplished by a team of 4 to 5 students in one semester. These segments are detailed in the Results section below.

## Results

### *Feasibility Study*

The initial team began work on the project in the spring of 2012. This team was tasked with designing a feasible a microjet cooling system. The first step in the project involved evaluating the proposed theoretical concept and creating design concepts that could be implemented on a reasonable scale using air as a working fluid. Microjet cooling is based on using a pattern of orifices to create a jet impingement cooling system; these systems lead to high heat transfer coefficients at adequate flowrates<sup>17, 18</sup>. The students' initial concept is shown in Figure 1.

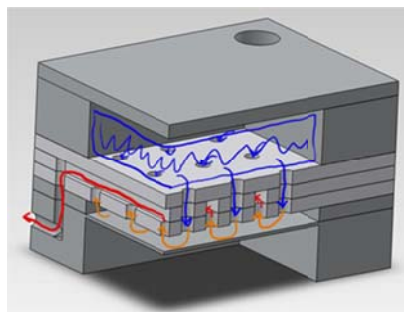


Figure 1. Preliminary Design Concept

After a series of concept refinements, a final design was proposed using a combination of aluminum, ceramic, and polycarbonate components. That design and prototype are shown in Figure 2. The fabrication of the initial prototype presented the design team with several difficulties and challenges. Initially, the design team was not experienced in the machining of ceramics and ended up needing to procure additional tooling to adequately drill holes in brittle ceramic plates. This initial design consisted of a 65 mm square. While this initial team was able to fabricate a device, they were not able to test it extensively and reliably. The design and fabrication steps required the entirety of a single semester, meaning that there was no additional time for adequate testing. A detailed design package including computer-aided design (CAD) models and computer-aided manufacturing (CAM) code was compiled and standardized with proper dimensions to pass along to the next team.

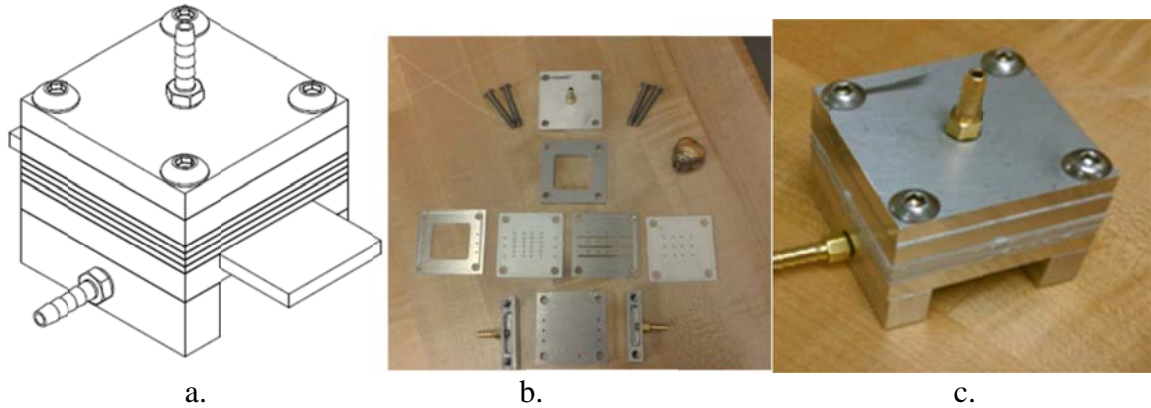


Figure 2. Preliminary Feasibility Prototype (a.) CAD Model (b.) Components (c.) Assembly.

### *Prototype Refinement*

The next team began working on the project in the fall of 2012. Their project had a much more refined scope due to the initial feedback from the sponsor. Their goal was to develop a microjet cooling system for use with the Jabil universal laptop testing system. They began work with the materials, CAD and CAM resources, and gained knowledge (from the final report) of the previous team. They were able to design and fabricate a microjet using aluminum and polymethyl methacrylate (PMMA) as base materials. Their design consisted of a 35.5 mm square, the size of the processor meant to be cooled. Their design is shown in Figures 3 and 4a.

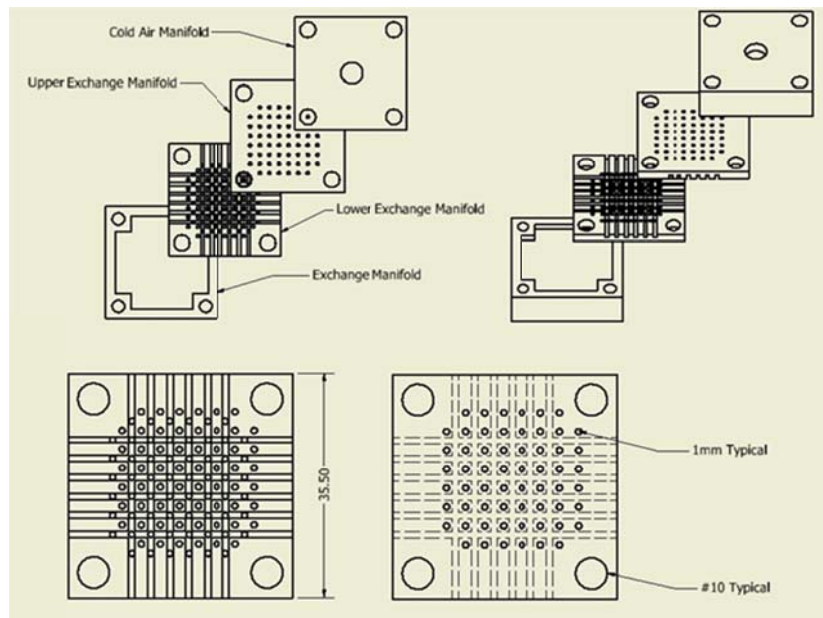


Figure 3. Refined Microjet Design

In addition to fabricating the microjet prototype, the second team was also able to test it thoroughly using a laptop provided by the sponsor. The testing on the provided laptop is shown in Figure 4b. The microjet cooling system was compared to that of the factory-installed heat sink that had a cycle time of 2 minutes. The factory heat sink performance and microjet performance are shown in Figures 5a and 5b, respectively. As shown in Figure 5b, the microjet was able to

maintain system temperatures within the range of 30° and 40C° for the majority of the 15 minute stress test. This involved running the system at 100% CPU usage and supplying the microjet with 103.4 kPa of compressed air. The testing by the second team provided two main opportunities for refinement of the microjet and system design based primarily on feedback from the sponsor. The first was related to the implementation of microjet testing; as shown in Figure 5b, this was done by holding the microjet in place manually. This was seen as a likely source of error and inconsistency in the testing procedure. Other potential sources of improvement included the enlargement of the channels in the microjet and the routing of exhaust ports to a single location. As with the previous team, a standardized package of CAD and CAM files as well as a prototype and materials were passed along to the next team.

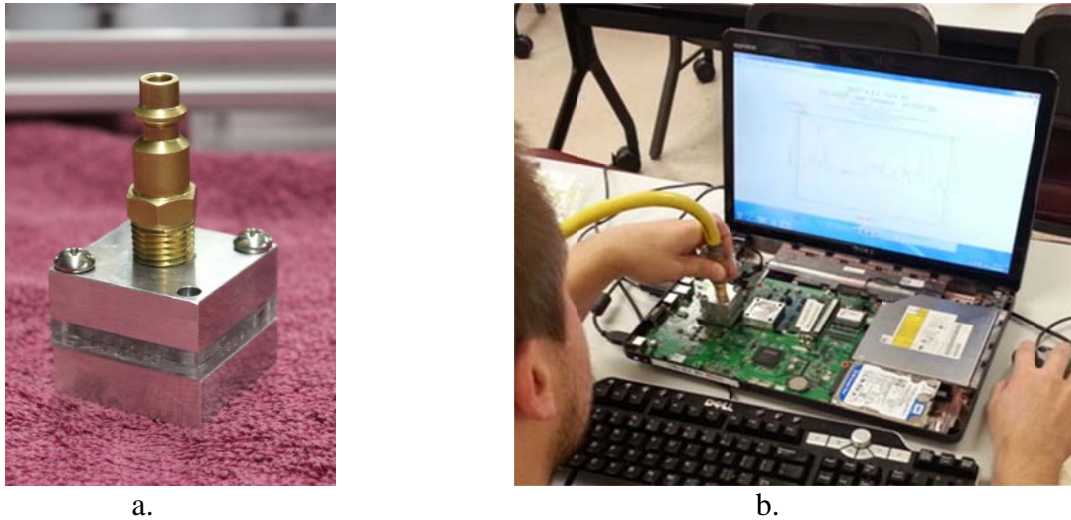
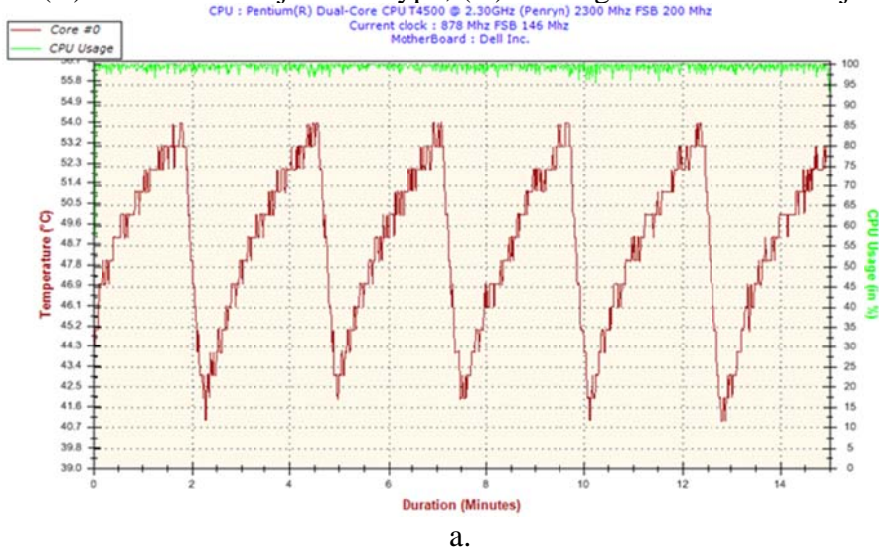
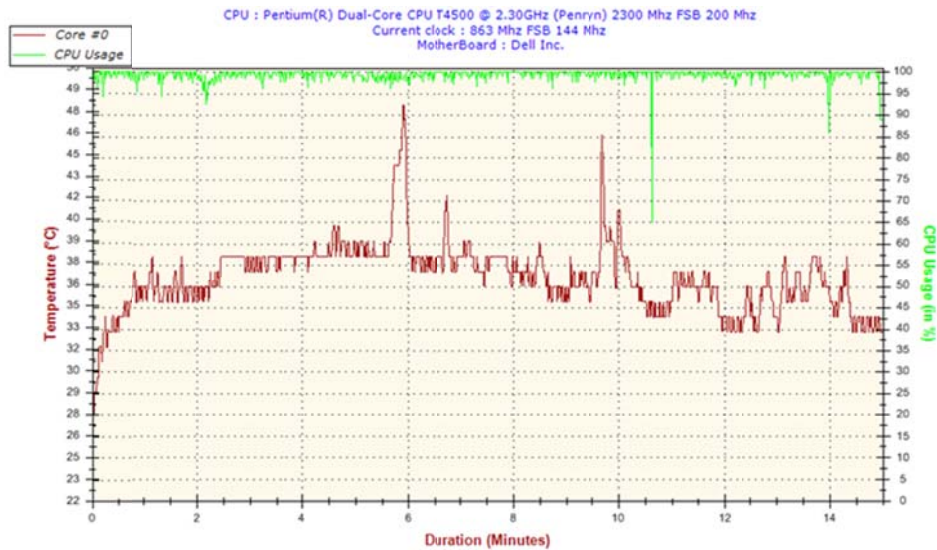


Figure 4. (a.) Refined Microjet Prototype; (b.) Testing of Refined Microjet Prototype







b.

Figure 5. Heat Sink Results (a.) Standard Factory Heat Sink (b.) Microjet Cooling System.

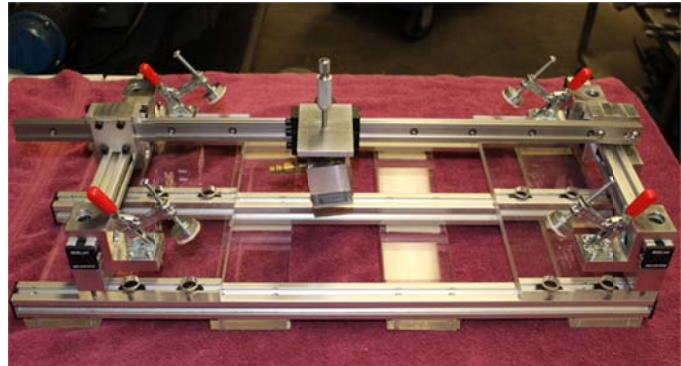
### *Implementation and Further Refinement*

The next team began work on the microjet project in the fall of 2013. While the project was offered in spring 2013, it was not selected. This team again began with a relatively broad scope of implementing the microjet solution and providing an overall proof of concept, which was narrowed down after consulting with the industry sponsors and the technical advisor. This team's goal was to create a mounting system that could accommodate different size laptops while also ensuring that no part of the computer experienced more than 90N of force. They were also tasked with further refinement of the microjet system.

The team refined the microjet such that the exhaust air was directed to a single port. This prevented exhaust from possibly heating or interfering with other components on the computer's motherboard. This required an increase in the overall height of the microjet apparatus. The further refined microjet is shown in Figure 6a. To ensure that the force of the microjet was limited, the team repurposed the spring-loaded screwing mechanism from a micrometer in a novel way to provide and regulate the contact force. The team also evaluated the contact pressure generated by the mounting device using PressureX pressure sensitive film.



a.



b.

Figure 6. (a.) Further Refined Microjet and (b.) Mounting System

A mounting system was also developed using rails in the X and Y plane to allow for laptops of varying size to be clamped into the system so the microjet could be moved and used effectively. The mounting system is shown in Figure 6b and with the testing laptop in Figure 7. The left end of the mounting system slides in the X direction to accommodate laptops of varying sizes. An additional rail allows for the microjet to be placed directly on the CPU.

While this team made significant progress in the development mounting system and a refined microjet, they were not able to test their microjet cooling system with the laptop. The CPU would prematurely shut down due primarily to the defective battery in the test laptop. Just as in previous semesters, the prototypes, CAD and CAM files, and all associated documentation were collected and made available for a future team during the next iteration of the project. Moreover, a list of pending action items was also included in the final report to facilitate and expedite the next iteration of the project.



Figure 7. Mounting System and Laptop



### *Assessment of One Semester Capstone Course*

There are several lessons that were learned after implementing the proposed one-semester iterative project approach. Firstly, the instructor needs to ensure that students turn in the proper project documentation at the end of the semester so the next group of student can easily and quickly continue with the next phase of the design project in a seamless fashion. Secondly, the technical advisor should make sure the new group of students presents and discusses a clear set of objectives with the sponsor as early as possible so any potential changes in project scope are addressed early during the design process.

In general, the course was well perceived by students, administrators, and industry collaborators. The students provided valuable feedback and made useful recommendations which will be incorporated in the future. Using an IDEA evaluation instrument: 82% of students reported making exceptional or substantial progress working with teams; 61% reported making exceptional or substantial progress expressing themselves orally or in writing; and 76% reported making exceptional or substantial in the skills related to their professional field. The following specific comments were provided by the students:

- “Course should be combined with 429 [project management course] and directly continue 429 projects into 422”
- “The course needs to be worth more hours for the amount of work required”
- “Overall I enjoyed the course. My project was challenging but fun to work on. The instructor did a great job of helping students when help was asked.”
- “Instructor greatly facilitated the success of our project.”

In general, many of the students felt that the course prepared them well for real engineering problems routinely seen in field applications. The course will continue to be enhanced with the support of industry professionals and colleagues.

### **Conclusions and Future Work**

Capstone design projects represent a significant opportunity for students to gain practical experience solving open-ended design problems. An example and discussion of how a large project was broken into segments tractable for a one-semester Capstone course with teams consisting of 4 to 5 students was presented. The results from a three semester iteration design project were used to illustrate how large industry sponsored projects can be advanced in an iterative manner.

Several key things are needed to allow for this type of iterative solution to be viable in other projects. First and foremost, an understanding, committed and flexible industry sponsor is needed to make the iterations worthwhile for all the students involved. Furthermore, the timespan from the initial concept to the most recent proof-of-concept prototype should be at least a year in duration to allow proper refinement of any complex and multifaceted design. This may or may not be viable for a lot of industry sponsors. Another necessity is the involvement of dedicated faculty to serve as technical advisors that can serve as repositories of knowledge and expertise. Furthermore, both physical and digital assets of each design phase or segment should be kept to ensure smooth transitions among design teams. This has been done in a rather *ad hoc* manner to date; whereas a faculty member retained materials in their lab and computer files on

their computer. This could be dramatically improved by the use of a product lifecycle management system or project repository space such as internet-based clouds.

Overall, the ability of students to have a relevant and meaningful Capstone experience in one semester has been shown. The use of an iterative industry project could also positively contribute to the development and attainment of professional and practical skills that are the sought after in such courses. The requirements to effectively document findings and design details in a transparent manner are the same types of demands that industrial employers will make on today's students. The need to use other's work and advance existing designs is representative of the type of skills and challenges that students will face in industry in years to come. While the MMET Program is investigating a move to a two-semester Capstone course sequence, the authors believe that curricula that use a one-semester course can still offer students a challenging and relevant experience by using iterative industry projects.

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