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Delivering the Senior Capstone Project: Comparing Year-Long, Single Semester and Hybrid Approaches

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Abstract

This paper details the evolution of the capstone design experience for Western Kentucky University Mechanical Engineering (WKU ME) students, placing it in the context of the overall four year project-focused WKU ME curriculum. Starting in 2009, the senior project experience was changed from a single, year-long design-build-test project, to the current approach where a fall semester single-semester design-only project is followed by a second design-build-test project in the spring semester. To date, the experiences with student teams in the four cohorts to the present have been positive and have produced both expected and unexpected benefits. Issues related to the students' experiences, faculty management, and industrial partner accommodations will be discussed.

Ongoing assessment of the capstone course sequence and the Professional Component outcomes is presented. The WKU ME program has a stable Professional Component framework to ensure that: program graduates acquire and demonstrate appropriate professional engineering abilities; student teams can execute a capstone project as independently as possible; WKU ME faculty can offer a project-based curriculum building on previous coursework and assess student progress meaningfully at each academic level.

Introduction

Western Kentucky University (WKU) initiated engineering programs in Civil, Electrical and Mechanical Engineering starting in 2000, graduating initial cohorts in 2004. The three programs are now stable and mature, have been successfully evaluated twice by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (EAC of ABET)[1], and have graduated 400 students with baccalaureate degrees as of May 2012. The defining emphasis of the WKU Department of Engineering is to deliver undergraduate, project-based learning engineering programs so that[2]:

> … Western Kentucky University engineering students master engineering by working on projects. From the very beginning of our programs, WKU Engineering has embraced project-based learning as our primary approach to engaged deep learning.
>
> … they learn to be engineers by applying their textbook learning to complex projects-by doing their work as students the way real engineers do their work.
>
> They work on projects at every level in their program of study, from …steam engine models in their first engineering classes, to industrially-sponsored projects …in their capstone classes. …WKU engineers not only master technical skills and knowledge, but also acquire and hone professional skills such as teamwork, communication, and ethical professional behavior.

The Mechanical Engineering faculty at WKU have developed, implemented, assessed and adjusted a structured Professional Plan to assure that ME graduates truly experience key areas of the engineering profession and demonstrate the ability to perform in a professional manner. The ME curriculum delivery is guided by this plan, which defines and organizes how students acquire design tools and skills, integrate their evolving competencies in mathematical and technical analysis to the project experiences, teach and reinforce effective communication in all forms, and couple the design experiences with methods to make professionally ethical decisions. The four Professional Components are defined:

- Engineering Design (teaching and practicing design skills)
- Professional Communications (conveying designs and interacting with peers)
- Professional Tools (teaching and implementing design tools)
- Professional Ethics (evaluating and practicing appropriate professional behavior)

Each component has defined attributes and goals, a structure for implementation across the four years of the curriculum, and coordinated assessment activities monitoring student outcomes. This structure helps to coordinate the efforts of the WKU ME faculty members, and assure student success in developing these skills, recognizing that desired student professional outcomes are only completed through multiple courses and faculty members. The result is that professional experiences can be integrated throughout the curriculum, rather than delivered in an isolated or inconsistent way.

The overall structure of the entire WKU ME Professional Component Plans has been discussed previously[3], providing definitions and attributes of the four components and all of the original rubrics for our efforts to assess student performance. The implementation of the Engineering Design component, in particular the role of the design-build-test philosophy in our design pedagogy has been covered[4]. The rational for the transition from controlled internal projects at the underclass level to externally supported projects for the upper classmen was also presented[5]. While we have not formally published the Professional Communications component, the Engineering Ethics[6] and Professional Tools[7] plans have been presented, describing ethics and design tool instruction across the design curriculum, and our assessment and evolution of the activities.

This paper will focus on the current implementation of the capstone design. Prior to 2009, a moderate scope design-only project for an external customer was conducted in the Junior Design class, followed by a yearlong, design-build-test senior project sequence. In the spring 2009 semester that design-only project was removed from the Junior Design class and the current two project approach of a design-only project in the senior fall semester, followed by a design-build-test project in the senior spring semester began. This current implementation has produced positive results with the 2009-10, 2010-11 and 2011-12 academic year cohorts (and seems to be continuing with the 2012-13 cohort in progress). Ongoing assessment of the capstone course sequence and the Professional Component outcomes will be presented.

A variety of earlier research has been presented related to the organization, implementation and assessment of capstone projects. Overall administrative plans have been presented to facilitate the activities necessary to organize the diversity of the external project process[8]. Detailed efforts to direct students at the team level, using a Stage/Gate review process has also been applied[9]. Precise assessment results are less available, and qualitative responses from students, industry customers and faculty advisors are more common that quantitative measures. An in-progress study is attempting to map pre-course, mid-course and end-of-course assessment goals to assessment methods[10]. Mechanical Engineering Technology programs have developed quantitative assessment rubrics, however it is a challenge to determine any actions that could be taken based on these results[11].

The Original Engineering Design Structure

The Engineering Design Plan developed by the WKU ME faculty integrated the design process throughout the ME curriculum as a continuous process from the first to the final semester. There was consensus regarding the attributes of Engineering Design[12,13, 14]:

- Engineering design as a systematic application of basic sciences, mathematics and engineering sciences to generate/evaluate/specify systems, components, or processes.
- Form and function of design to achieve defined objectives and satisfy constraints.
- Design includes aspects of creativity, complexity, and iterative decision-making to optimize solutions, and compromise between multiple, sometimes conflicting, needs.

Elements of design, such as synthesis, analysis, construction and testing were incorporated, and Features of Design referenced by ABET (creativity, open-ended, formulation of specifications, alternative solutions, realistic, written/oral reporting, among others) proved useful in creating an assessment framework to be used throughout the curriculum (shown in Table 1).

Engineering Design Courses	Credits
ME175/6 Freshman Experience	2/1
ME200 Sophomore Design	2
ME300 Junior Design	2
ME400 Mechanical Engineering Design	2
ME412 ME Senior Projects	3

Table 1: List of Original Engineering Design Courses

The approach provided experiences that either introduced or reinforced the design process, combining a structured approach to solving problems with an appreciation for the art of engineering design. Freshmen would individually build artifacts (Figure 1a) in a design project with minimal engineering science, but develop manufacturing skills required for realistic designs. Sophomores executed projects involving construction and testing of a design (Figure 1b), and executed a team design-only project. Juniors extended the sophomore design experiences technically and also expanded the design problem to include a project involving an external customer (Figures 1c and d).

The intention behind these lower level activities is to prepare our students to execute meaningful senior capstone design projects – satisfying ABET, and to be prepared to enter the workforce and be productive engineers – meeting the WKU mission. As the WKU ME faculty has guided the students through the projects, the general concept of "engineering design" has become more accurately "prototype realization". While not the complete scope of all design projects, pedagogically and practically, it makes sense to focus on this aspect of design during the undergraduate education process.

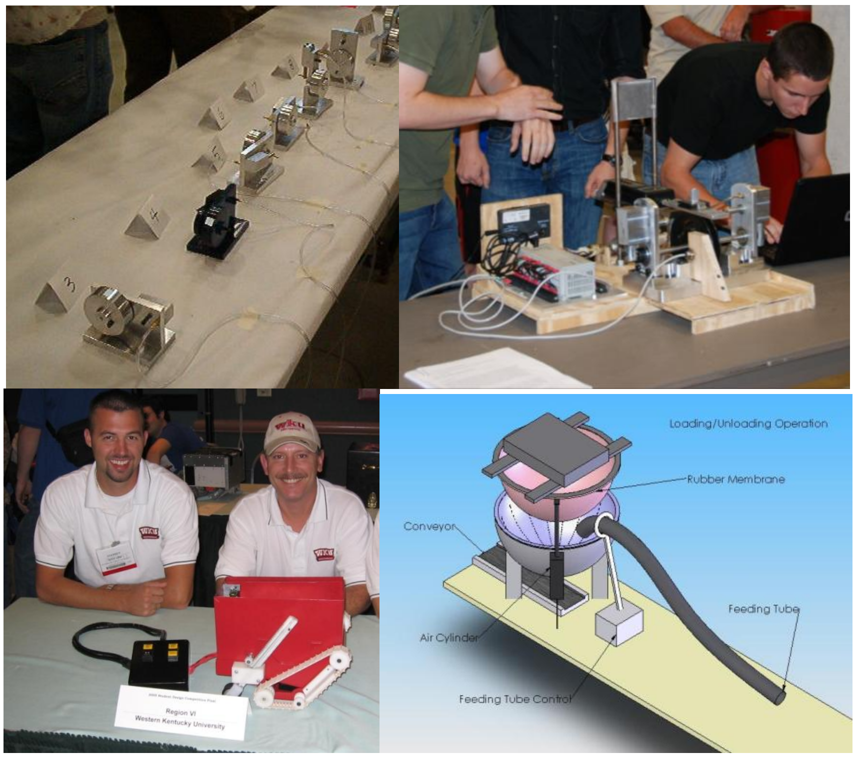

Figure 1: a – top left) Freshman Air-Powered Steam Engines, b– top right) Sophomore Engine Efficiency Tester, c–bottom left) Junior ASME Student Design Competition and d–bottom right) Junior external design-only project

So how have we done? To cite an old joke: "*the operation was a success, but the patient died!*" The WKU ME program did an excellent job of providing design experiences, and the students were rising to the challenge. However for both the students and the faculty members, as well as for our project infrastructure, the effort required was proving unsustainable. This is a classic resource limitation problem for us, involving limited money, facilities and equipment to provide so many student project experiences, but equally importantly the limitations on both faculty and student time. To sustain quality with increasing student numbers, change was required and this is discussed below.

Revised Design Component Sequence

In 2007 the ME faculty made the first significant curricular adjustments to design delivery within the program. Other modifications then followed, with Table 2 showing the current curriculum that has been in place since 2009. The changes have included the addition of new courses, the modification of credit hours within courses, shifting design activities from between courses, and altering the division of student labor on projects. Before discussing the senior design sequence implementation, which is the primary focus of this paper, the preparation leading to this course will be briefly conveyed.

Professional Component Courses	Credits
ME176 Freshman Design I	1
ME180 Freshman Design II	3
ME200 Sophomore Design	3
ME300 Junior Design	2
ME400/ME412 Capstone Design Sequence	2/3

Table 2: Current List of Engineering Design Courses

In the freshman year, the original two-credit Freshman Experience course changed to one credit Freshman Design I and three credit Freshman Design II courses. The major design project originally implemented within the Design I course, an air-powered steam engine shown in Figure 1a, moved to the Design II course, while a simpler team-implemented design-build-test project is a part of the Design I course (Figure 2). The freshman sequence change implementation was achieved with one transitional semester where students who had the prior two-credit Design I class took a one-time three-credit Design II class; after that a few students did have a slightly redundant experience with the steam engine project in both of their freshman design classes (the old Design I and the new Design II), however they were encouraged to assist their classmates since they were "experienced".

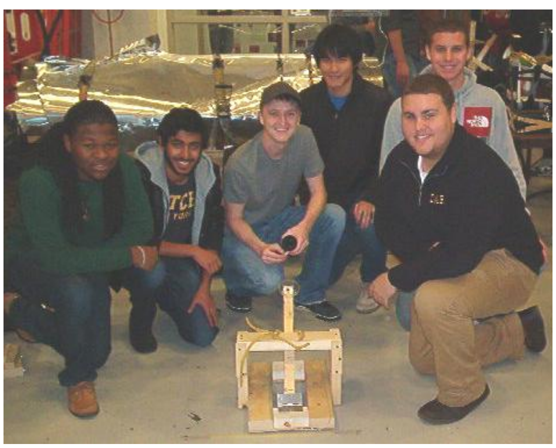

Figure 2: Tennis Ball Launcher project in Freshman Design I

The average annual enrollment of the Design I class is typically nearly twice that of the Design II class (approximately 75 students vs. 45 students), so the shifting of a more complex project to the second course not only allows more prepared students to attempt the project, but also greatly reduces the number of devices built. This freshman design modification was never intended to affect student retention. Admission policies at WKU permit any student accepted to the university to declare as a Mechanical Engineering pre-major. The second freshman design course makes it possible to offer students necessary instruction in the CAD professional tool, SolidWorks, but is done in fewer hours than an earlier 3 credit CAD course taught by the Architecture and Manufacturing Sciences program. While the number of design credits has increased, the overall number of credits within the freshman ME curriculum has decreased by 2-1/2 hours.

Sophomore Design has been modified several times in the past six years, including the addition of a 3rd credit hour to incorporate material from a previously offered industrial automation course that has now been removed from the curriculum, and the deletion of a 2nd team-based design-only project from the course. The course is restructured into a one hour lecture session and a two hour lab session format. The extra hour serves two purposes: (1) it increases time for student-faculty interaction during the design projects – an issue that had been noted in earlier student course assessments for several years, and (2) it provided additional time for computer instruction in the FEA SolidWorks Simulation tool.

Our pedagogical philosophy has been that students at this level need to develop the ability to integrate engineering science skills into the design process, to fabricate and automate increasingly complex devices based on specifications that the students generate, and to function on teams. In the original delivery, Sophomore Design course students built their own design-build-test project devices, and then worked on a team for a more complex design-only project. Economies of effort and demand for the student/faculty/facilities have been realized by removing the design-only project from the course and elevating the expectations of the design and build project, and making it a team project (Figure 3).

Figure 3: Steam Engine Tester project in Sophomore Design

The Junior Design class remains a two-credit, two-hour meeting time format; however the content of the course has been reduced. In the past, student teams completed two projects during the semester; one was the ASME Regional Student Design Competition [15] (Figure 1c for example) and the second was a design-only project involving an external customer (Figure 1d). The competition project emphasized the execution of a design process on a well-defined problem, with the final deliverable being a working device. The timing of the competition provided the need to work to complete a project under a challenging deadline. The nature of the contest changed from year to year, but the overall philosophy was constant[16]. The transition from the an external design-only project in the Junior Design class to the external project in the fall senior year was simple to implement, since 100% of the Junior Design class transitioned to their senior capstone sequence when this was done.

The external design-only project typically involved a local industrial partner of the WKU ME Program. The final project deliverable was a detailed conceptual design report and presentation, with expectations of appropriate technical analysis and some effort at component selection. This project emphasized both technical evaluation of a problem as well as introducing an external customer and the need to assess and accommodate that customer's interests. This second project was moved in Fall 2009 to the senior year design sequence. This important aspect of the revised implementation of the senior project sequence is discussed in the next section.

The Senior Capstone Project Sequence – Old and New

From the inception of the ME program in 2000, the ME faculty have focused on a project-based learning environment to best prepare seniors to implement industry-based design-build-test projects with realistic time, budget and resource constraints and subject to an external customer's needs. Beginning with the initial cohort, the senior capstone format was a typical year-long experience – project definition and execution proposal in the fall, with build and test in the spring. This format was used from the 2003 – 04 through 2008 – 09 academic years, with 91 seniors successfully executing 27 projects. Appendix Table A1summarizes the senior projects executed by the WKU ME program to date.

The results from the early year projects were certainly not disappointing. Our industry sponsors and Program Advisory Board members both favorably assessed the performance of the students on the projects. Assessment of student outcomes will be discussed later, but both student self assessment and faculty evaluations were also in general positive. Projects were being completed for the most part on time, on budget and to specifications. What is proving less sustainable is the execution of these projects at WKU subject to resource constraints at WKU, as well as an elevating expectation for faculty research productivity. In the early years of the ME program, three or four senior projects were executed each year. From 2006 to 2009, the student population had doubled, and four to eight projects were executed annually, while the number of ME faculty remained constant. To successfully implement the types of realistic, external projects that would demonstrate graduate competency, with little expectation of additional faculty staffing, it seemed necessary to train the students to truly be able to run their projects with a high level of independence.

Starting in the fall semester of 2009, the year-long single project approach was replaced with a design-only project in the fall, and a design-build-test project starting in December and concluding at the end of the spring semester. This did not mean additional work for the students over the entire curriculum since the new fall semester design-only project had been executed in prior years in the Junior Design class. The ME faculty had decided in spring 2009 that the junior class was too challenging for the students. They were already executing a competition-based design-build-test project in teams during the first half of the junior spring semester, and their performance on the ensuing industry-based, design-only project was inconsistent from year to year – good sometimes, while other times disappointing. The decision to drop the industry design project from the junior class was intended to strengthen the student experience with the competition design-build-test project.

Moving the design-only project into the senior fall offered several potential benefits, but added one major concern. The benefits have been experienced over the past three years of the two-project approach, while the concern has not been realized. The concern was that student teams would need more than five months from December until May to execute the types of design-build-test projects we have historically done over nine months. Now that we have used the two project capstone approach for three years (with the fourth cohort under the new structure ongoing), 70 students have executed 18 spring semester senior projects.

There has been no noticeable drop off of teams completing their projects, compared to the prior year-long project schedules. Some of this can be attributed to selecting projects where the scope is appropriate for the time available, and the likelihood of long delivery components is low. However, while the average scope of the one-semester projects may be slightly less than full year project scopes, they are certainly more than half the size. Average project budget has remained steady ($7900 average project budget with the earlier projects, $8000 since the change to the single semester project). Average team size is slightly larger now, (3.8 students per team vs. 3.3 students under the year long implementation) but this is as much driven by the need to handle the larger student population as it is project-driven. Schedule problems caused by scope issues arise in both year-long and semester-long versions of senior project, and can be addressed between faculty advisor and industry contact. The determination that major components could not be delivered in a suitable time caused a 2012 one-semester project to be converted into a design-only project, however this also happened in 2008 during the year-long approach to senior projects.

More importantly, benefits associated with both the fall design-only and spring design-build-test approach have been realized over the three plus years that the two-project approach has been implemented. In fall 2009 two different design projects were studied. The 20 students in the class were divided onto six teams – three teams worked on each of the two projects. In fall 2010 there were 25 students, again working on two projects with three teams investigating each project. Then, in fall 2011 25 students were divided into eight teams and investigated four different projects, with only two teams looking at each project. This caused no problems for the students, but the extra projects proved overly complicated for the instructor. In 2012 this was reduced to 28 students on six teams investigating three different projects.

The benefits of having seniors execute the industry-based design only project compared to juniors doing so the previous spring is partially a maturity or experience issue, and partially a case of giving the students a challenge at a better time for them. With the prior implementation in the Junior Design class, the students had already devoted considerable energy towards a competition project early in the semester, and did not always give their best efforts with the industry design project. In the fall senior sequence implementation, the class starts off fresh with the project at the beginning of the semester.

Another benefit is that the fall senior teams are required to execute the project under much greater scrutiny from the faculty advisor. Team behavior is more specified and controlled by advisor rules, the schedule for milestone events (conceptual and detailed design reviews, sponsor documentation and meetings, etc.) is set in the syllabus, and team interactions and self evaluation is required for course grade. These components are not explicitly required in the spring semester design-build-test capstone project, however sufficient numbers of the students will recognize the value of these activities, such that most teams tend to continue this practice on their own. This same faculty advisor driven approach was used for the Junior Design implementation of the project, however the time between the junior class in the spring, and the start of senior projects in the fall yielded much less carryover of these positive project management traits.

A third benefit that we have seen with the new approach to senior projects is the flexibility with the fall projects. It is possible to start a fall, design-only project not intending it to be implemented as a build-test project in the spring, then evaluate the design results from multiple teams in mid-fall semester and decide whether to move forward with it or not. The reverse is also possible; a project that was intended to continue through execution can be shut down after the design phase. Of the eleven fall design-only projects thus far executed, five have been continued to the build phase (one was partially executed to test the feasibility of one portion of the design) and six were not. Of the continued projects, two were originally intended to stop after the design phase and three were intended to be continued. One of the projects not continued is under consideration as a future build project.

One last benefit from the current approach is with the flexibility it offers for the spring design-build-test projects. It is now possible for students to work on research-type projects with faculty members as fulfillment of this second senior project, including working individually on projects, while still getting instruction and experience with team project activities in the fall semester project. This was implemented with one of the spring 2012 projects for the first time, and two of the spring 2013 projects, and will be continued as warranted.

Program Outcomes and Assessment

The ME faculty members continue to measure and assess all of the ME Program Outcomes that encompass ABET outcomes a-k, as well as the particular project-based program expectations. The Professional Component Plan discussed at the beginning of the paper guides the implementation of the project-based design classes. The five criteria that are assessed through senior sequence activities are shown in Table 3.

ME Program Outcomes (from ABET a-k)
Mechanical Engineering graduates have the ability to:
• Criterion 3(c): design a system, component, or process to meet desired needs • Criterion 3(d): function on multi-disciplinary teams

- Criterion 3(g): communicate effectively
- Criterion 3(i): recognize the need for, and an ability to engage in life-long learning
- Criterion 3(k): use the techniques, skills, and modern engineering tools necessary for engineering practice

Table 3: ME Program Outcomes related to the Senior Sequence

The senior sequence course outcomes are with achieving these program outcomes. Specifically for the design-build-test portion of the sequence the course outcomes are as follows, students will be able to:

1. Use structured problem solving techniques, appraise client's needs, produce product/project definition documents, and propose appropriate engineering solutions.
2. Execute designs from inception to completion, and convey/document solutions in a wide variety of formats – including effective oral business presentations, and clear, concise project documentation that flows from general to specific.
3. Successfully manage projects using management tools such as timelines, responsibility charts, etc.
4. Participate effectively in multi-disciplinary teams, demonstrating that they are effective team members and evaluating the performance of team members.

Faculty assess these course outcomes through graded work in the courses, and at the end of the semester, students are asked to self assess their abilities to achieve the stated objectives. The average scores (on a ten-point scale) for faculty and student assessment are shown in Table 4. The key observations are that there was not a quality issue that led to the revised approach in 2009 to the two-course senior sequence, nor has there been any drop in performance since then.

Year	Faculty Evaluation	Student Self Assessment
2004 – 05	8.7	9.1
2005 – 06	8.7	9.0
2006 – 07	8.6	8.9
2007 – 08	8.9	8.5
2008 – 09	8.5	8.3
2009 – 10	8.7	9.0
2010 – 11	8.7	8.9
2011 – 12	8.7	8.7

Table 4: Average Assessment Score for Senior Sequence Courses

At the program outcome level, the assessment of each criterion is achieved using a variety of measures, including evaluation of selected student course work, student exit interviews and composite student grades in appropriate courses. Faculty evaluation of outcomes takes place at two levels. Faculty members conduct course effectiveness session to review engineering courses taught in the program. The primary function is to improve course outcome delivery; however the integration of the courses across the curriculum is also discussed. The second review is via data gathered for each Program Outcome.

Attributes	Absent (0)	**Novice (1):** some of the elements are present.	**Intermediate (2):** most of the elements are present	**Proficient (3):** all elements are present
Use of structured problem solving techniques: created multiple options, implemented and explained evaluation of options, used evaluation for decision making and improvements				
Appraise the needs of clients: identify customer/audience, incorporate needs into design decisions				
Produce product/project definition statements: quantitative and qualitative documentation of acceptance criteria				
Propose appropriate engineering solutions: justified technical/practical/allowable solution to stated problem at correct level of detail for the stage of the project.				
Total Score: Expect 6 for Sophomore class, 8 for Junior Class and 10 for Senior Class				

Table 5: ABET Criterion 3(c) Rubric

The most important measure of student performance is through the evaluation of collected student work. The assessment rubric for Criterion 3 (c) is shown in Tables 5 above. The same rubric is used for all years of student evaluation, allowing the comparison of varied levels of professional competence as students progress through the curriculum. The expected Total Score indicated at the bottom of either rubric table changes, reflecting the increasing expectation for student performance as they move through the elements of the integrated Professional Component.

For each sample of student work, faculty members independently assign scores of 0 – 3 (absent to proficient) for each attribute component in the rubric. The sum of these scores for all attribute components becomes the total score. Freshmen and sophomores are expected to attain a novice to intermediate level, while seniors are expected to attain an intermediate to proficient level. The average values of student performance, assessed by several faculty members provide the basis for the student work evaluation used in the Professional Plan reports.

Rubric-based assessment of representative student work, coupled with assessment of student extra-curricular activities, student exit interviews and composite student grades provides the basis for the ME faculty members to evaluate the overall student progress in the Professional Plan, and adjust the delivery of the components as necessary.

Conclusion

Four years ago, the implementation of the WKU ME senior project sequence was modified from a single project executed throughout the entire year, to a two project sequence involving a design-only project in the fall, and a design-build-test project initiated at the end of the fall semester and completed at the end of the spring semester. A Professional Component Plan has been in place for the WKU ME program since the first cohort of graduates left the program in 2004. The plan has enabled us to successfully offer a strongly project-based education experience to our graduates. Assessment of student work and regular faculty review of course effectiveness indicted an opportunity to adjust the projects required in the junior and senior years, and hopefully improve resulting student experience.

When the senior year project modification was debated and then started in 2009, the anticipated benefits that we hoped to reap included:

- Better student experience in the junior design class – enhancing student project competencies (both in the junior and then the senior years)
- Better execution of the design-only external projects now in the fall senior course
- More efficient (independent) execution of the design-build-test capstone projects by the seniors
- Potential flexibility in converting design-only fall projects into design-build-test spring projects (or to decide not to do this)

Now that three or four cohorts of juniors and seniors have passed through this sequence, the following conclusions can be made regarding the students:

- The Junior Design course is a more reasonable experience for the students, allowing more time for the competition project and better develop of project execution skills
- Junior ME student attitude is improved regarding the competition project
- There is better carryover of student project management practices from the senior fall to spring course than from the junior spring to senior fall
- There is some dislike with a modest number of seniors when they are reassigned to a new project team at the end of the fall semester, but this has not impacted team effectiveness
- There has been only minor sentiment with students that the time to execute the design-build-test project in the spring is insufficient
- Faculty have been able to accommodate students pursuing smaller research projects into the senior sequence as a spring project, with the students participating in a team design activity in the fall project

And from a faculty perspective, the following conclusions can be made:

- The Junior Design course is more reasonable to supervise, due in part to greater time available for students as well as improved student attitude regarding the competition project
- Senior execution of the capstone project is typically more autonomous, with improved carryover of student project management practices from the senior fall

- Selecting potential projects for the fall senior design-only project is made easier with the flexibility to wait until mid-semester to decide to continue/stop a design-only project into design-build-test projects
- There is greater complexity in managing potential senior projects, which takes more faculty preparation time in the summer and into the fall; greater attention is needed to lessen the risk of problems that might arise with the shorter schedule of a one-semester capstone project
- It is easier to make use of student efforts to accommodate faculty research projects into the senior sequence with the split sequence

Final conclusions recommending the WKU hybrid single-semester vs. year-long capstone project implementation cannot be made. The WKU ME faculty do not even agree. Single-semester projects with a preceding design-only project do not seem to harm either the student experience or the project success. When industry-based projects with maximally self-sufficient student performance are a priority, the single semester approach becomes increasingly preferred. When faculty interaction with students in research or industry-sponsored projects, and results and timing have a greater priority, a year-long approach gains preference.

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Appendix – Catalog of *Western Kentucky University* ME Senior Capstone Projects

Year	Sponsor	Deliverable	Team Size	~Budget	Faculty Comments {Industry Evaluation}
2003-04	Industry	Transmission Tester	4	$5k	Good result, on time/budget {very positive}
2003-04	Industry	Printer lifter prototype	4	$1k	Poor result, on time/budget {very negative}
2003-04	Industry	Air flow calibration system	4	$5k	Good result, on time/budget{very positive}
2004-05	Industry	Torque indicator prototype	4	$5k	Decent result, on time/budget{positive}
2004-05	University	ATV automation	5	$15	Decent result, on time/budget
2004-05	Engr. Dept.	Autonomous vehicle platform	3	$1k	Decent result, on time/budget
2004-05	University	Soil compaction tester	4	$5k	Good result, on time/budget
2005-06	Engr. Dept.	Vibration lab tester	3	$1k	Good result, on time/budget
2005-06	Industry	Conveyor test system	4	$5k	Decent result, on time/budget{positive}
2005-06	Grant	Air flow test system	3	$5k	Good result, on time/budget
2006-07	Grant	Pump demo system	3	$5k	OK result, late/on budget
2006-07	Industry	Quality control calibrator	3	$10k	Good result, on time/budget{very positive}
2006-07	University	Greenhouse heating system	4	$10k	Good result, over time/budget
2006-07	Engr. Dept.	Carburization furnace design	2	$1k	OK result, on time/budget
2006-07	Industry	Washing machine gear prototype	3	$5k	Good result, on time/budget {positive}
2006-07	University	Water filter test prototype	2	$10k	Good result, on time/budget
2006-07	Engr. Dept.	Automated fabric cutter	2	$2k	OK result, on time/budget
2006-07	Industry	Refrigerant heating prototype	3	$5k	Good result, on time/budget {positive}
2007-08	Industry	Brake drum tester system	4	$10k	OK result, on time/budget {acceptable}
2007-08	University	Biodiesel facility phase I	5	$60k	Good result, on time/budget
2007-08	University	Greenhouse heating system	2	$5k	Weak result/on time/budget
2007-08	Industry	Printer switch tester prototype	3	$1k	OK result, on time/budget {positive}
2007-08	Industry	Quality sample tester loader	4	$10k	Good result, late/on budget {positive}
2008-09	Industry	Brake drum quality system	3	$5k	Scope changed to design/concept {acceptable}
2008-09	Grant	Vehicle cooling prototype	3	$5k	Scope changed to design/concept
2008-09	University	Biodiesel facility phase II	3	$15k	Good result, on time/budget
2008-09	Grant	Roof Cooling Prototype	3	$5k	Weak result, on time/budget
2009-10	Industry	Air Filter Test System	5	$10k	Good result, on time/budget{very positive}
2009-10	Industry	Oil Filter Test System	4	$10k	Good result, on time/budget{very positive}
2009-10	Engr. Dept.	CNC Mill Upgrade	3	$5k	OK result, on time/budget
2009-10	Industry	Filter paper cutting system	4	$1k	OK result, on time/budget {positive}
2009-10	Industry	Quality sample tester loader	4	$10k	Good result, on time/budget { positive}
2010-11	Industry	Crane safety system	3	$1k	Good result, on time/budget {very positive}
2010-11	Industry	Assembly automation system	3	$10k	Good result, on time/budget {positive}
2010-11	Industry	Printer punch prototype	3	$2k	OK result, on time/budget {positive}
2010-11	Industry	Filtration system upgrade	3	$5k	OK result, on time/budget {positive}
2010-11	University	Greenhouse heating system	3	$5k	OK result, on time/budget
2010-11	Competition	SAE Baja	7	$10k	Weak result, late time/on budget
2010-11	Competition	NASA Lunabotics	3	$15k	Good result, on time/budget
2011-12	Competition	SAE Baja	9	$10k	Good result, on time/budget
2011-12	Industry	Process cutting prototype	4	$10k	OK result, late/on budget {positive}
2011-12	Industry	Filter media drying system	4	$0k	Scope changed to design/concept {positive}
2011-12	Industry	Touch screen sensor tester	4	$25k	Good result, on time/budget {very positive}
2011-12	University	Biodiesel facility phase III	3	$10k	Good result, on time/budget
2011-12	Engr. Dept.	Airflow test system	1	$5k	Good result, on time/budget

Table A1: Summary of *Western Kentucky University* ME Senior Projects