

**A COMPARISON OF CAPSTONE DESIGN COURSE CHOICES FOR
UNDERGRADUATE INDUSTRIAL ENGINEERING STUDENTS: REQUIREMENTS
AND ADVANTAGES OF THE INTEGRATED PRODUCT AND DESIGN PROGRAM
VERSUS SENIOR DESIGN PROJECT**

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A Comparison of Capstone Design Course Choices for Undergraduate Industrial Engineering Students: Requirements and Advantages of the Integrated Product and Design Program Versus Senior Design Project

Abstract

Currently all national ABET accredited colleges and universities require their undergraduate students to pass a capstone design course prior to graduation. These courses are as different as the universities that offer them but all focus on some common goals: to provide engineering undergraduate students with real-world project experience while honing their communication, teamworking, leadership, and management skills.

Students enrolled in some colleges may be faced with an intriguing decision: enroll in a one-semester, single-discipline course, or opt for a one to two semester multidisciplinary capstone course. To evaluate this decision, the following approaches to fulfilling the capstone requirement for industrial engineering students are examined: a two-semester Integrated Product and Process Design program (IPPD) using a multidisciplinary-engineering team and a one-semester single discipline Senior Design Project. Common elements shared by these courses include teamwork, time management, innovative design, and project reporting. These two courses offer a number of individual advantages that students and faculty should consider. This paper may be used to inform students of each courses' aspects and advantages in order to make an informed decision on which would best benefit the student's academic and future career-related needs.

Introduction

Students pursuing Industrial and Systems Engineering degrees at the University of Florida have two choices for satisfying their capstone design project requirement. The first is to enroll in a traditional one-semester three credit course entitled "Senior Project" (EIN 4335). The second option is to enroll in a two-semester multidisciplinary design course entitled "Integrated Product and Process Design I/II" (EIN 4912 and EIN 4913). This paper provides a comparison of the two options and summarizes factors students may use in deciding which to pursue.

To illustrate the multiple aspects and advantages of each course, this paper will center around two case studies focusing on industrial engineering oriented projects, one for Senior Design and the second for Integrated Product and Process Design (IPPD). Specifically this paper will review the course structure, project selection process, project scope, time frame, team approach, level of coaching/mentoring, and deliverables of each project with feedback from the team's respective clients.

Senior Design students complete their project over the course of one semester as part of a three-credit course offered during the fall, spring and summers semesters of the senior year. Typically 5 projects are undertaken each semester. IPPD requires engineering undergraduate students to work as part of six-member multidisciplinary project teams. Each team is coached by a faculty member and interfaces with liaison engineers from the sponsor company. Typically 25 to 30 projects are offered each project year. IPPD requires six hours of coursework and is offered as a

sequence of two three-credit courses during the fall and spring of the senior year. In comparison, Senior Design is a single-discipline team coached by the course instructor and interfaces with a company contact, not necessarily an engineer, from the business sponsoring the design team.

Course Overview

The following is a brief overview of each course.

EIN 4335 Senior Design Project

The purpose of the one-semester Senior Design Project course is to give students skills in carrying out projects. Also this course brings together many of the topics of previous courses as tools to be used in doing projects. Students also acquire additional experience in public speaking and technical writing.

Students identify a project in an industrial, manufacturing, or other business setting, and, with the help of a sponsor, formulate, analyze and solve a relevant professional problem. This work usually involves defining the present state of affairs and then developing a new system that is an improvement over the present system. Projects for faculty members are not acceptable.

EIN 4912/13 Integrated Product and Process Design I/II

The Integrated Product and Process Design (IPPD) program is an innovative undergraduate engineering education initiative first developed at the University of Florida in the academic year 1994 under the auspices of the Southeastern University and College Coalition for Engineering Education (SUCCEED) initiative that in turn was sponsored by the National Science Foundation. The pilot testing was done in the 1995 academic year, and since then the program has been offered as a two-semester course available to senior engineering and business students. The students work in five to seven member interdisciplinary teams, under the direction of one faculty member who acts as a technical coach. Each team also includes the participation of a liaison engineer representing an industrial sponsor, namely a private company, or a government institution or laboratory, which charters the design team with the task of designing and building authentic products and processes of financial or strategic value to the sponsor.

IPPD is fully institutionalized at the University of Florida, and the two-semester course serves as an optional substitute for a capstone design course and for a technical-elective course. Students gain practical experience in teamwork and communication, problem solving and engineering design, and developing leadership, management, and people skills. Teams and individuals are evaluated based on clearly defined project deliverables and on their performance in lectures and workshops.¹

Background

The following is a side-by-side comparison of the two courses focusing on the main elements: Course Structure, Assessment, Obtaining Projects, Mentoring and Project Guidance, and Deliverables.

Course Structure

The completion of either capstone design option should provide the student with an equivalency of preparation for professional work. One way to insure this preparation at least has a chance to occur is to guarantee that by the time of completion of either option, the students will have the same prerequisite and co-requisite courses finished. Currently this is not the case; however, based upon recommendations from a recent ABET review, this equivalency policy will be implemented. A comparison of the course structures is provided in Table 1.

Table 1 Course structure comparison of Senior Design and IPPD

Element	Senior Design	IPPD
Duration	1 semester	2 semesters
Pre-requisites ^a	EIN 3314C (<i>Work Design and Human Factors</i>) EIN 4365 (<i>Facilities Planning and Material Handling</i>) ESI 4221C (<i>Industrial Quality Control</i>) EIN 4523 (<i>Simulation</i>)	<u>IPPD I:</u> EIN 4354 (<i>Engineering Economy</i>) EIN 4365
Co-requisite	EIN 4333 (<i>Production and Distribution Systems</i>)	<u>IPPD I:</u> ESI 4221C
Other requirements	Senior standing in ISE	30 hours or less to graduate Must apply to program and be accepted
Course credit	3 credits hours	3 credits each semester
Texts	None; handouts provided	<u>Required:</u> <ul style="list-style-type: none"> • Ulrich, K. T. and S. D. Eppinger, <i>Product Design and Development</i>, third edition, McGraw-Hill/Irwin, 2004 <u>Reference:</u> <ul style="list-style-type: none"> • The Team Memory Jogger, GOAL/QPC and Oriel Inc., 1995 • Sommerville, I., <i>Software Engineering</i>, sixth edition or later, Addison-Wesley, 2001 • Otto, K. and K. Wood, <i>Product Design</i>, Prentice Hall, 2001 handouts provided

Table 2 Course structure comparison of Senior Design and IPPD (cont'd)

Element	Senior Design	IPPD
Major topics	Project planning; team dynamics; report writing; presentation techniques; professionalism and ethics; review of industrial and systems engineering concepts and methodologies as needed. Additional lectures on the many aspects of engineering professional practice, expectations post-graduation, IE job types, and professional licensure	Customer needs, product specifications, concept generation and selection, project management, project economics, product architecture, component design specifications, software life cycle, test planning, manufacturing, quality, system level design, and entrepreneurship
Major Deliverables	<ul style="list-style-type: none"> • Final 1 hour formal presentation to peers & instructor • Final formal presentation to client • Final submission of engineering project report 	<ul style="list-style-type: none"> • Preliminary design report and private presentation to sponsor (mid October) • System level design report and public presentation to sponsors (December) • Final report and project documentation (5 volumes) and public presentation to sponsors (mid April) • Design (patent) notebooks • Prototype systems
Class attendance frequency	1 day lecture 2 days team project updates	2 to 3 days of lecture 1 or more meetings between faculty mentor and project team
Class size	30	15 to 20 ISE plus 135 to 150 from other disciplines
Team size	5	6
No. of teams	6	25 to 30
Faculty mentoring	1 faculty member Plus ad hoc members for specific project aspects	20 to 25 faculty mentors Plus ad hoc members for specific project aspects
Client interactions	Not formal, only when team engages on an as-needed basis;	Liaison engineer assigned by project sponsor; minimum of one hour per week;
Project scope	350 to 450 student hours with 10 to 20% contingency	600 hours for experienced engineer; student hours of 1500 to 2500 hours are typical
Time commitment for students	10 to 13 hours per week including class time	10 to 15 hours per week including class time

Assessment

To insure that a capstone course is adequately addressing the needs of all the stakeholders—students, faculty, sponsors/clients, and administrators—it is important to provide a comprehensive assessment approach. Table 3 summarizes how the Senior Design and IPPD courses handle assessment.

Table 3 Course assessment comparisons for Senior Design and IPPD

Element	Senior Design	IPPD
Project	20% grade based on project presentation 35% grade based on final report	80% of grade; based upon faculty coach assessment with input from sponsor
Client	ABET form ^b Letter of Transmittal (required for course completion)	ABET form Feedback to faculty coach and IPPD director; No direct link to student grades; Industry feedback session after final reviews; some direct communication between sponsor and IPPD director
Peer	2 peer evaluations, averaged 10% of final grade	4 to 8 team member self-evaluations over 2 semesters; coach considers this input in grade determination; opportunity to individually speak with low performers; some coaches write up performance reviews at mid-semester
Faculty	Registrar form ^c Sensing session with students	Registrar form Coach evaluation administered 2 to 8 over 2 semesters
Student Grade Summary	10% for project proposal and presentation 10% professionalism attendance evaluation by instructor (includes professional conduct, class participation, and attendance) 10% evaluated by team members (“peer” evaluations) 10% for bi-weekly status briefs 5% for Hotwash 20% for final presentation 35% for final report with sponsor endorsement.	20% for lecture/workshop performance (attendance, preparation, participation, class assignments) 80% for project performance (team grade) <i>Note: each team considered individually; average individual grades cannot be higher than team project grades; individuals must provide faculty coach with evidence of performance; monthly peer evaluations</i>

Obtaining, Defining, and Managing Projects

Gathering appropriate projects for capstone design courses is a recurring, labor-intensive activity. The process is complicated by issues such as whether to charge a fee for the projects, ownership of intellectual property, and the required time and effort required to solicit, qualify, and “close the deal” projects. Table 4 summarizes approaches used to obtain projects—distributed in Senior Design (no fee charged) and centralized in IPPD (\$20,000 fee).

Table 4 Comparison of how projects are obtained, funded, and scoped, and how clients interact with project teams for Senior Design and IPPD

Element	Senior Design	IPPD
Project Solicitation and Sponsorship	Students cold call local industry; instructor contacts; contacts through Dean’s office; former or current employer of student (internship/co-op)	Director recruits projects from: <ul style="list-style-type: none"> • Past sponsors • Leads from faculty, administration, and Foundation officers • Cold calls to industry executives • Referrals from past sponsors • former or current employer of student (internship/co-op), or student family member • Course website yields cold call from industry Over two-thirds of projects come from repeat sponsors
Project funding	Unfunded	\$20,000 per project plus prototyping expenses if costs exceed \$1000 threshold; additional costs if graduate student involved
Interaction with clients	Student-organized and driven Contact frequency, meeting times, and site visits. E-mail in use frequently	Weekly telecom with sponsor liaison, site visits arranged by team with client—within 3 weeks of project launch, for the Preliminary Design Review, and for final project handoff. Other travel as needed. Teams maintain web sites (authentication required). E-mail in use frequently
Intellectual property ownership	No formal process	Sponsor owns the design

Table 5 Comparison of how projects are obtained, funded, and scoped, and how clients interact with project teams for Senior Design and IPPD (cont'd)

Element	Senior Design	IPPD
Defining project scope	Projects must employ a minimum of three core industrial engineering competences, such as facility design, financial analysis (ROI), simulation, forecasting, operations modeling, work design, energy management, etc. Teams are required to generate a project contract which contains scope and project duration ranging from 350 to 450 student hours with 10 to 20% contingency	Projects should include design and manufacture of a prototype system. The projects fall in one or more of the following categories: electronics, machines and components, software, and processes (i.e. manufacturing, business and chemical). The initial project scope of 600-800 hours for experienced engineer is worked out between the faculty coach and the sponsor. Student hours of 1500 to 2500 hours are typical for the successful completion of the project. The sponsor provides a project summary sheet defining expectations. The project summary sheet template is available on the web. Project scope is reevaluated during project execution with major opportunities to rescope during the preliminary design review and the system level design review.

Mentorship and Project Guidance

The process of defining the project requirements begins before project execution and frequently continues throughout the development of the requested solution. The nature of technical projects is such that as new information is uncovered during research phases, often the project scope must be renegotiated. Constantly changing requirements, known in industry as “scope creep,” jeopardizes satisfactory completion of projects. In order to mitigate the risks associated with scope creep, it is important to practice effective project management and have processes in place to deal with the effects. Table 6 summarizes the project management practices in place to handle scope changes and client interactions.

Table 6 Comparison of how projects are tracked and managed for Senior Design and IPPD

Element	Senior Design	IPPD
Update requirements and examples (how changes and progress are communicated to the client and instructor)	Bi-weekly project update <ul style="list-style-type: none"> • Updated problem statement • Accomplishments since previous • Analyses completed • Upcoming events/next steps • Barriers • Gantt chart review Hotwash—"Eleventh hour" review of all engineering analyses prior to final project presentation	Weekly status memo <ul style="list-style-type: none"> • Accomplishments • Plans for next week • Open issues • Project status Weekly teleconference and e-mail communication Feedback from client and coach during development of deliverables Random in-class presentations of deliverables Faculty panel reviews <ul style="list-style-type: none"> • Project plan review • Prototype review
Project management	Internally performed by the team utilizing Gantt charts and other tools that are reviewed and approved by the instructor initially and then updated biweekly	Teams transform a roadmap into a detailed project plan. Oversight is performed by the faculty coach and the liaison engineer. Tools such as action registers, team web sites, and Wikis are used to communicate and share project status
Client interaction	Exclusively handled by student team. Team leader is internally appointed typically is the point of contact for communications with the client. Travel to client is done on an as needed basis during the course of the semester. Students are responsible for all travel arrangements and mode of travel. Teams travel to client a minimum of three visits to secure project commitment, sign off on the project contract, and final presentation at the end of the semester. Generally teams will visit the client an average of seven times for meetings and data collection events.	Teams travel to sponsor site within three weeks of project launch to meet with project liaisons. Teams travel again for approval of the preliminary design report in mid October, and typically at least one more time for implementation and handoff. Travel is handled centrally and expenses for car rental, gas, hotels, meals, and airfare are covered by the program. Weekly teleconferences are held with the liaison engineer. The faculty coach attends this teleconference. E-mails and ad hoc phone calls are utilized as needed.

Deliverables

In both courses, the project teams create a series of deliverables that are provided to the sponsor either during the course of project execution or at the project conclusion. These key technical work packages pace the project teams through the process of creating value for their clients. Table 7 summarizes the deliverables for each course and the transmittal process.

Table 7 Comparison of project deliverables how the deliverables are transmitted to the client for Senior Design and IPPD

Element	Senior Design	IPPD
Final project presentation	40-minute formal presentation utilizing PowerPoint covering the following elements: <ul style="list-style-type: none"> • Project background • Objectives • Methodologies • Recommendations • Financial value-added impact 	20-minute formal presentation utilizing PowerPoint to a mixed audience of industrial sponsors, faculty and peers covering the following elements: <ul style="list-style-type: none"> • Introduction, Purpose, Scope of Report • Project Overview • Hardware Design Description • Operational & Programming Characteristics • External Interface Spec. • Operating Environment • Software Design Description • Software Functional Desc. • Software Interface Spec. • Material • Quality/Reliability Objectives and Plans • Manufacturing Plan • Product Verification • Issues, Concerns, Risks and Opportunities
Final project report	Formal engineering report encompassing all elements listed for final project presentation with the addition of detailed appendices showing details of all calculations, analyses, and research	Six volumes: Volume 1:Final Report Volume 2:Product and Process Documentation Volume 3:Acceptance Test Results and Report Volume 4:Product manuals Volume 5:UP-TO-DATE Deliverables of entire Project Volume 6:Design Notebooks

Table 8 Comparison of project deliverables how the deliverables are transmitted to the client for Senior Design and IPPD (cont'd)

Element	Senior Design	IPPD
Other deliverables	Project primer (by week 2) Project contract and initial Gantt chart (week 3) Other tools prepared for the client (week 16): <ul style="list-style-type: none"> • Databases • Drawings • Decision making tools 	Deliverables are generally split between hardware or process-oriented projects and software-oriented projects. <u>Hardware/Process project deliverables</u> : <ul style="list-style-type: none"> • Product specifications* • Concept generation, evaluation and selection • Product architecture* • Prelim. design report* • Project plan* • Analytical and exp. plan • System level design report* • Detailed prod./proc. design • Prototype results and report* • Acceptance test report <u>Software-oriented deliverables:</u> <ul style="list-style-type: none"> • Config. Mgt. plan • Prototype plan • Comprehensive test plan • Code/unit test/build & integration • Product verification *common to all project types.
Handoff to client	<ul style="list-style-type: none"> • Formal project presentation • In-class and/or at client facility • Deliverables in electronic and hardcopy format • In some cases students will train client to use decision-making tools developed as part of the project. For example, inventory management databases or electronic staffing applications 	<ul style="list-style-type: none"> • Formal project presentation • In-class and/or at client facility • Deliverables in electronic and hardcopy format • In some cases students will train client to use decision-making or other software tools developed as part of the project. Training in use and maintenance of the hardware prototype system may also occur. Occasional implementation assistance is provided for installation of student-built equipment.

Case Studies

Below are the Executive Summaries of two projects completed at the close of the Spring 2007 semester, one from Senior Design and the other from IPPD. The goal is to illustrate the project scope and outcomes for a similar project. The EIN 4335 project team was composed of 5 Industrial Engineers, while the EIN4912/4913 project team included two Industrial Engineers, two Mechanical Engineers, an Electrical Engineer, and a Computer Engineer (software specialization).

EIN 4335

“Gator Motorsports²”

The Society of Automotive Engineers participates in a national competition annually based around the design and performance of a Formula-1 style race car. This competition has multiple components of judgment ranging from drag racing, endurance racing, and cost-effective construction. What the Senior Design team focused on was the aspect of the competition known as the production plan. The production plan stipulates that the team must design an operation that manufactures four cars/day for 250 days/year producing a minimum of 1000 cars annually. Cost is a major factor; the production cost for each car may not exceed \$25,000.

The objective of this project was to create a facility that satisfies the above production requirements while keeping costs at a minimum. Parts and supplies were analyzed on a national basis to determine the most effective shipping rate and parts supplier. Production duration of each sub-assembly (brakes, engine/drive train, instruments, steering, suspension, and frame/body) was optimized using Arena simulation software. All eight sub-system production lines were run concurrently in an effort to shorten the overall cycle time. Facility design components included the number, type, and location of machines, number of workers, process flow lines, operating hours schedule, capacity limitations, and final production rates. All process time data, machine utilization data, and process data come directly from UF's SAE prototype build team.

As a result, there was a greater amount of manufacturing time as compared to parts installation time therefore dictating that the facility should be set up to first manufacture parts then place them into the cars. Upon arrival to the facility, all parts inventory is scanned into a tracking system that reports real-time inventory levels. The fabrication area of the facility utilizes cell manufacturing and an assembly line in the final assembly area. The final results was a facility cost ranging between \$540,000 ad \$750,000 and a vehicle cost of \$13,529 which was \$11,471 below the production cost per vehicle limit.

EIN4912/13

“Military Vehicle Assembly Line Design and Simulation³”

Dynamic Defense is a multi-skilled team of student engineers in their senior year at the University of Florida. This team designed and simulated an efficient assembly line that met the

expected demand for two types of military vehicles, *vehicle one*, and *vehicle two*. Due to vehicle one's smaller task list, emphasis was placed on vehicle two because its assembly line can accommodate vehicle one. Efficiency will be measured by the utilization of workers, and the minimization of overhead costs. Dynamic Defense will also model the production process using Rockwell's Arena 7.0 simulator.

The efficiency of the production process was optimized by utilizing commercially available line balancing software, Proplanner's ProBalance, to optimize the station assignments. Concepts from lean manufacturing will be implemented as to limit waste and improve worker utilization. The expected savings and improvements will be demonstrated by simulating the new production process. The sponsoring company expects a 20% savings due to efficiency increases in labor and overhead costs.

We propose two alternative solutions for the production of one vehicle per day requirement. For a simple assembly line configuration the optimum solution requires 16 stations and 42 workers in two-shift operation. For the dual assembly line configuration our proposed optimal solution requires 7 stations and 20 workers for each line, totaling 14 stations and 40 workers on both lines.

For the single line design we achieved 84% station utilization; whereas the station utilization for dual line configurations was 93%.

Our analysis has shown that the proposed line configurations will save 60% direct labor cost over the current practices. This will translate into 2047% internal rate of return and almost one day for the payback period.

Conclusion

Senior Design provides the opportunity for students to experience engineering consulting for a variety of industries such as manufacturing facilities, healthcare, and business operations. The course is offered every semester and only industrial engineering students may participate. IPPD is a two-semester commitment where multidisciplinary teams of students function in a simulated research and development environment under the guidance of engineering faculty mentors and liaison engineers from sponsoring companies. The projects cover the development of electronics, mechanical systems, software, and processes. Both courses emphasize team dynamics, presentation skills, preparation of technical and project management deliverables, including the delivery of formal engineering reports. Senior design is well suited for students interested in consulting, whereas IPPD tends to appeal to those students looking for more of a research and development experience.

Bibliography

1. Stanfill, R. K., Crisalle, O. D., "Recruiting Industry-Sponsored Multidisciplinary Projects for Capstone Design," *Proceedings of the American Society for Engineering Education Southeastern Section 2003 Annual Meeting*, Macon, GA, April 6-8, 2003, 12 pp. (CD-ROM).
2. Francis, S., Higgins, K., Rangi, K., Vinson, C., Walker II, G. "Gator Motor Sports," final report, Senior Design Project (EIN 4335), University of Florida, Gainesville, Florida, April 11, 2007.
3. Boerner, D., Colbert, R., Lee, D., Moseley, A., Perea, M., Rodriguez-Triana, A., "Military Vehicle Assembly Line Design and Simulation," final report, (volume 1), Integrated Product and Process Design (EIN 4913), University of Florida, Gainesville, Florida, April 12, 2007.

Endnotes

^a Pre-requisites and co-requisites for EIN 4335 and EIN 4912/13 are under revision such that students completing either option will have equivalent backgrounds

^b ABET outcomes a through k are assessed through a survey completed by the faculty coach and liaison engineer

^c Every course instructor for all course at the University of Florida is evaluated using a common evaluation form