A Coordinated Design Course Sequence to Integrate Mechanical Engineering Capstone Design Experience

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Abstract

Modern engineering practitioners are generally involved with product development of tools, devices and systems with increasing complexities. Their tasks include multi-faceted roles to employ a holistic design process including market analysis, research and development, design execution, prototype fabrication, quality control, testing and certification of the related products. Accounting for these aspects in the modern engineering world, traditional in-class teaching methods may need to be modified to adequately prepare students to be competent in today's industry. Therefore, there is an increased emphasis in providing design experience through integrated project-based learning throughout the engineering curriculum. In this paper, we will present our recent efforts at the Department of Mechanical Engineering of the Florida Agricultural and Mechanical University-Florida State University College of Engineering (FAMU-FSU COE) to develop a coordinated and integrated three-semester course sequence to the capstone experience. The broad aim is to introduce the overall design process through project planning, management, and product development with an emphasis on creativity. In the first class, Engineering Design Methods (EDM), junior-level students are taught various collaborative learning strategies as well as a formal design process including all necessary design tools. They are also required to engage with capstone design teams which have been working on their capstone design projects in the Senior Design Project (SDP) course during the same semester. The EDM students acquire skills in preparation for their capstone experience while rehearsing these design skills by shadowing SDP teams in a virtual design mode. In the subsequent two-semester SDP course, senior level students are grouped in teams working on externally-sponsored projects while applying skill sets learned from EDM and other core engineering courses. Most of the SDPs are real-world inspired projects, which are externally sponsored by industry and government agencies, and many of them are multidisciplinary in nature involving engineering as well as non-engineering students. In addition to carry out these design tasks, they are also required to interact with students in the EDM class and provide feedback to their junior-level peers while enhancing their skills in communication and design implementation through reflective learning. Pre and post-class surveys and feedback sessions are conducted to not only gain inputs from students to improve the coordinated learning process, but also to engage them in self-reflection for continuous learning. The crux of the effort here is to develop an extendable and streamlined methodology that achieves a wholesome learning experience from the students' point of view, while adhering to syllabus and ABET guidelines. We will also report our recent efforts in coordinating multidisciplinary, cross-institutional and international design projects since they serve to expand our students' communication and collaborative skills from both technical and non-technical perspectives. Finally, this paper will report experience learned from our initial implementation, assessment of student learning and their perception of the process, with recommendations to further improve the coordinated learning model.

I. Introduction

I.A. Capstone design curriculum development across universities

Capstone design has arguably been the most important professional development course for an engineering student which combines project-based learning and the real-world practice of a formal engineering design process. Early efforts in the past as well as currently ongoing have emphasized on improving the overall capstone experience for students as well as the enhanced engagement by design instructors. Banios [1] outlines a capstone design course following closely real-world engineering practices. The paper summarizes a two semester capstone design curriculum making students work as part of teams to design projects first at a proposals stage and then follow it in the second semester with a pilot model realization. An important mention in this work is that the team structure applied to environments comprising of a democratic or committee nature while going through the entire course.

As pointed out by Chung et. al. [2], the most important attributes of a capstone course are [2] that students in general should:

1. Have an insightful design project to be done as a team.
2. Be required to focus on knowledge gained throughout the curriculum.
3. Solve problems that represent real-life engineering.
4. Acquire an understanding of the professional aspects and culture of being an engineer.
5. Learn and practice project proposing, planning and control.

The same paper also outlines efforts to understand how students perceive their capstone course through the use of surveys that employ knowledge mapping. This method has limitations of being too complex for students to understand. On the other hand, an easy tool such as a belief-based survey that adjudges students' knowledge levels offers a more direct measure [3]. When combined with the pre- and post-test survey [2] , this tool could potentially provide a better mapping of students' natural interest areas within the broad engineering spectrum.

In general, team-work based design is the norm for capstone curriculums. An additional interest to satisfying student learning outcomes is the need to integrate a wider range of technical skills such as presentations, report writing, requirements analysis, and programming [4]. These skills serve to increase marketability for engineering graduates and ideally must be included at the sophomore or junior stage prior to actual project-work in the capstone course year. To support this pedagogical approach, a sophomore-level capstone course [5] aims to improve computer-lab based experimental skills of students on the verge of entering their senior year. Here, as in other publications, the importance of working in teams is instilled.

By default, the concept of team-based learning [6] seems an obvious choice to groom engineering students to be part of their professional careers. In addition to this, efforts have been done to incorporate a collaborative learning approach [7]. A dedicated method known as the meeting-flow approach [8] to actively monitor progress and quality of project work shows promise in terms of making students understand the importance of the benefits of a systematic team environment, which is then analyzed using surveys. A third teaching strategy known as competitive learning has been used through making junior level students participate in engineering design contests [9]. However, it has been noted that the intensity of being part of a contest often makes student concentrate less on the actual lesson to be learnt [9]. Finally, while a myriad of course planning, teaching and assessment strategies are prevalent, it is important to follow closely the Accreditation Board for Engineering and Technology (ABET) guidelines. Individual topics in the design curriculum as well as assigned mini-projects could be made such that they adhere to the ABET leaning outcomes from a moderate to a strong level of contribution [10], [11].

A more holistic approach to teach design, the so-called design spine [12], [13] has been implemented by several institutions by introducing the design concepts starting from the freshman year and systematically integrating more sophisticated design tools onward until the culmination of a capstone project. It combines project management and engineering subjects into an integrated science curriculum having many distinct parts accounting for all eight semesters in a complete undergraduate experience. The application of an integrated course structure firmly coordinated with project design related subjects throughout an undergraduate engineering curriculum [14], [15], while adhering to ABET guidelines, also inspires the developmental efforts presented in our paper. A representative design spine-like curriculum in our department is shown in
Figure 1.

In summary, from past efforts in the arena of capstone design curriculum development, the following general aspects are noteworthy:

1. Importance of student working in teams, formed through a mix of knowledge and interest.
2. Project topics that represent real-world situations.
3. Division of the design course into a more theory learning phase the project execution phase.
4. Systematic structure with an emphasis on professionalism and ethics.
5. Analysis of student learning through surveys.
6. Application of pedagogic strategies such as team-based, collaborative and competitive learning.
7. Adherence to ABET guidelines.

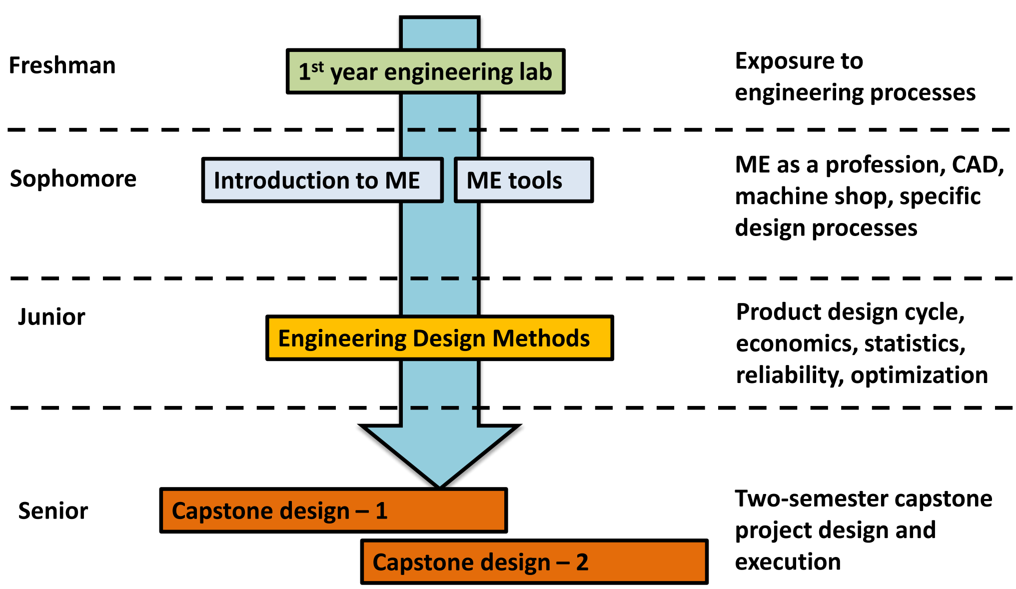

Figure 1. Integrated design curriculum in Mechanical Engineering

I.B. The current design curriculum

It is well accepted that the most important component of any engineering education as a whole is the capstone design, which exposes students to real-world application of the fundamentals they have learnt. All engineering departments need to provide ample design problems and hands-on projects of increasing complexity throughout the curriculum to the students before they graduate. It is critical to coordinate these design-relevant activities to maximize students' learning. Our program adopted an integrated design curriculum in the late 1990s and continued to improve it over the years by introducing various design activities throughout the core curriculum.

The design experience culminates with a capstone one-year senior design project in which students work in teams tackling engineering problems, the majority of which are provided and sponsored by industrial partners. These design projects meet real industry needs and provide the students with interaction with practicing engineers. In order to prepare the students for these challenging industrial problems, the design components have been woven throughout the core curriculum as represented in Figure 1.

Most of the coursework undertaken during the junior year involves design activities and instruction, and students are assigned individual or team design problems on subjects related to the course content. For instance, in the Thermal Fluids course, the assigned project may involve applying first principles to design and build a sub-scale solar collector, while in the Mechanics and Materials course, the project might involve the design of a chair or some other product requiring application of strength of materials principles. Typical projects for the Mechanical Systems course involve the design of a linkage mechanism, or a cam driven system. In each case, the students must go through a process of synthesis and design tied to the application of fundamental knowledge and principles. A major component of design training in the junior year is a semester-long course in EDM. This course is the formal lecture component of the ME department's integrated design experience that prepares students to enter SDP.

As part of the continuous assessment and improvement process, we have always attempted to integrate the course content of EDM to SDP courses. Over the years, we have continued to make improvements to the course contents of EDM and made several attempts to integrate it with the SDP activities. Initially, the capstone design course, included the concept of "just in time" teaching to integrate the theoretical learning part and the project management part [16]. Observed mismatch and a general rushed nature over a two semester design course led to a revised format starting fall 2008. One of the major adopted changes in the curriculum is the transfer of EDM from senior year to junior year. The first EDM semester entirely covered theoretical components and introduction of tools relevant for engineering design with regular lectures. Then two successive semesters of SDP were dedicated to the complete capstone design projects. This was done to not only expose students to the fundamentals of the design process before embarking upon capstone design, but also to not divert their concentration from the project work.

An added modification to the design curriculum is the move from a single instructor, to one instructor each for EDM and SDP (from fall 2014). This division further enables concentration of resources for the design theory part (EDM) and then followed by the design execution part (SDP). In addition to the implied need to coordinate between departments and multi-disciplinary project-work, coordination and integration is also vital between the separate instructor and teaching assistants (TA) of EDM and SDP.

Specific reasons from prior experiences to ensure close coordination and overhauls are listed as follows:

- Loss of continuity due to frequent turnover of design instructors
- Ineffective and uncoordinated communication previously between separate EDM and SDP instructors
- Lack of a systematic assessment process to track the learning effectiveness and information retention when students transition from EDM to SDP.

This paper reports the experiences gained by integrating EDM and SDP to form a well-coordinated design curriculum. The study plan encompasses three consecutive semesters for most students starting at the EDM course and then progressing on to the SDP stage culminating with their capstone design projects. Teaching strategies and surveys were designed to gauge learning outcomes and knowledge retained by students from semester to semester. The following section briefly discusses the issues and prior efforts to integrate EDM and SDP.

II. Recent coordination efforts to integrate capstone design curriculum

The previous section summarized the prior efforts and motivation to integrate and develop capstone design curriculum. Issues faced in executing this proposed integrated curriculum are well documented previously [16], [17], [18]. This section summarizes the constituents and elaborates on the details of the EDM and SDP courses of the overall integrated capstone design curriculum. Details on planned activities that are aimed at integrating learning objectives from these two courses will be described since they serve two primary purposes: (1) improving knowledge retention for EDM students to ensure seamless transition to the SDP implementation, and (2) facilitating reflective learning for the SDP students who can provide relevant feedbacks and guidance to their junior peers while reinforcing their own appreciation of the integrated design experience. In the following sections, we will first briefly introduce these two classes and then discuss recent coordination efforts to further improve the curriculum integration.

II.A. Engineering Design Methods (EDM)

As mentioned earlier, EDM is the theoretical portion of the design curriculum taught over one semester. Due to the high enrollment, the class is offered in both the fall and spring semesters. Typically, advanced sophomores and juniors form the majority of the students, however some out-of-sequence seniors also take this course in the fall semester. A comprehensive syllabus comprised of mechanical engineering design case studies, research work and application forms an integral part of EDM.

Throughout EDM, industry-relevant tools are introduced to students at various phases of the classical design cycle. Some major topics and related design tools focused on in EDM which are part of the various constituent subjects of engineering design as a whole are listed in Table 1.

Table 1 Design relevant topics and tools covered in EDM

Subject	Topic/tool focused on
Engineering design cycle	Product development and design phases
Customer requirements assessment	Kano diagram, House of quality (HOQ)
Risk, reliability and failure assessment	Failure mode and effects analysis (FMEA), fault tree analysis (FTA)
Economic decision making	Net present value (NPV), sensitivity analysis, Internal rate of return (IRR), sinking funds
Concept generation methods	Theory of inventive problem solving (TRIZ), morphological chart
Concept selection methods	Pugh matrix
Design assembly efficiency	Boothroyd-Dewhurst method
Project planning	Critical path method (CPM), Gantt chart
Engineering ethics	Types of contracts, conflict of interest situations, laws and legalities
Robust design & tolerancing	Statistical tolerancing and Taguchi design of experiments (DOE)

The EDM class is divided into teams of 4-8 members (depending on class size) who can work on mock projects defined early in the class. These projects are based on prior capstone projects and are generalized to ensure a consistent array of deliverables. Such a generalization ensures that identical in-class assignments requiring outputs such as an HOQ, FMEA, Taguchi DOE etc. can be produced by competing teams.

These EDM class teams perform activities as a unit throughout the semester which also support the integration activities between EDM and SDP. A summary of the integration centered activities described in greater detail later, that each EDM team must fulfill are:

1. Shadowing current capstone projects of SDP teams
2. Peer grading both within the EDM teams as well as of SDP teams at respective project presentations

Strategies mentioned earlier such as team-based, collaborative and competitive learning are actively applied in EDM through team assignment presentations. In addition to these three strategies, a fourth, analogy based learning [19]. Analogy based learning highlights the importance of finding potential solutions in different fields which is a useful tactic when faced with solving novel and rare problems that demands creativity and innovation. These four teaching strategies employed through the EDM semester are aimed at preparing students to work cohesively and ethically as part of a design unit, while encouraging creativity and professionalism. In addition to this, teams were asked to identify specialties and expertise topics after the first half of team project presentations were completed. Out of six team presentation assignments, the first three addressed the general design cycle and the last three had more specific focus areas. The expertise areas were divided in the following categories:

1. Customer needs
2. Concept generation
3. Product reliability
4. Product architecture
5. Product robustness
6. Legal and ethical
7. Budgeting

The above mentioned expertise areas encompass the entire EDM syllabus and include the various design tools and methods covered in class lectures. The main goals for including this approach are as follows:

- Students are encouraged to not only grasp the aspects of the entire design cycle in general, but also are exposed to individual responsibility by choosing a focus area, a practice that they would take in working on their design projects.
- Teams and their leaders learn the practice of delegating effectively responsibility to individual members while maintaining team cohesion by integrating these ideas in their key deliverables.
- Teams can observe whether or not their delegated roles are successful through self-reflection, both individually as well as in a team environment.

II.B. Senior Design Project (SDP)

SDP is a two semester based course which begins in the fall semester and ends in spring semester and is usually comprised of 100+ students and 25 or more projects. The two-semester based course constitutes in the culmination of four years of engineering education where students will bring together their gained knowledge and experience towards the completion of a design project. In this course teams are formed for each project and comprised of students selected on the basis of their knowledge, grades and interest. The students are expected to work as a cohesive team with the opportunity to become team leaders and learn to communicate effectively and efficiently among the team members, peers, and sponsors. During these two semesters, SDP students also attempt to participate in design competitions and entrepreneurial projects. The course also emphasizes acquiring non-technical professional skills besides the engineering concepts; such as professional code of conduct, report writing, and team management which are very critical in today's emerging global economies for a successful engineering career.

At the end of the school year, the capstone design course concludes with a one-day review event featuring a final presentation and open house. Here, all teams make oral presentations describing their projects, progress made in the given time, and the results obtained. The audience is fellow students, faculty, external sponsors, and a panel of judges comprised of the Mechanical Engineering Advisory Council (MEAC) members. The oral presentations are then followed by a poster session where teams showcase their projects and the actual prototype developed. The annual open house is adherent with our continuous assessment process to identify any strengths and weaknesses of the curriculum for modifications and improvements. This tightly interwoven relationship between the capstone course, curriculum evaluation, and MEAC participation has served the department well in many fronts such as:

- Continuous improvement of the capstone course and design curriculum
- Harvesting of relevant projects for the capstone course through strong industrial involvement
- Expanded career opportunities for our graduates

Over the SDP course, the project teams go through a structured engineering design process and are evaluated periodically. The team progress is evaluated on the basis of their design reviews, oral and poster presentations, and written reports. Besides this, individual students are also asked to evaluate their team member performance, to make sure every team member is meeting the team expectations. This aspect extends from the peer grading element of EDM.

II.C. Coordination Methodology

As outlined before, all design-relevant topics and tools are introduced in the EDM course and are expected to be used in the following SDP course. For reference purposes, these topics/tools are listed in Table 2 for both courses and, in particular, when they will be utilized during the design cycle in SDP. This correlation table is useful for students from both classes since EDM students can identify practical relevancy studying from more theoretical perspectives while SDP students can develop reflective learning by applying them first-hand to their project development.

Table 2 Integrated topics/tools between EDM and SDP

Topics/Tools	EDM Topics	SDP Application
TRIZ, Morphological chart	Design Phase/Product Development	Concept development
Kano diagram, HOQ	Customer Requirement Assessment	Project needs analysis
FMEA, FTA	Design validation and verification	Risk and failure assessment
NPV, Sensitivity analysis, IRR, Sinking funds	Economic decision making	Cost analysis and project budgeting
Pugh matrix, decision matrix	Decision making	Design selection
Boothroyd-Dewhurst method	Efficient design assembly	Prototype development
CPM, Gantt Chart	Planning and scheduling	Project management
Statistical tolerances, Taguchi DOE	Tolerancing	Design optimization
Contracts, Laws, Conflict of interest	Engineering ethics	Team work and Code of conduct

In order to effectively integrate these subjects across these two course it is critical to develop course modules that facilitates this paradigm. These modules will serve two major functions: (1) ensure EDM students retain the previously acquired knowledge and skills in preparation for the SDP class, and (2) to motivate SDP students to reflect on what they had learned previously and compare it to the outcomes from their real-life applications. This exercise can inspire a higher level of cognitive reasoning that is a critical step toward the engagement of life-long learning. Based on these considerations, course modules implemented are summarized in this subsection.

1) *Project shadowing:* One aspect implemented to introduce EDM students to the SDP is the requirement for all EDM teams to "shadow" specific projects by personal interviews of SDP team members and virtual following via web links. This is made possible by the requirement for all SDP teams to publish their design activities and deliverables on dedicated project web sites. Here, EDM students as a team during closely follow a capstone design team of their choice (assigned on a first come first served basis). The EDM team is expected to attend their shadow team's presentations (oral and/or poster), conduct an interview, and provide their observations and feedbacks of the design process as part of a graded shadow report at the end of the semester.

2) *Inter-class review of oral and poster presentations:* A supplementary aspect to collaboration between EDM and SDP students to the initial shadowing is through the attendance of project presentations. EDM students are required to attend oral and poster presentations done by their designated SDP teams. They use the same grading rubrics used in the SDP class for evaluation.

This review process is useful for EDM students since they will get a preview of what would be expected from them in the future SDP class. They can also gain a better appreciation of learning modules covered in their EDM class. Their grades/comments are collected for SDP teams to review as means for them to receive feedback from EDM students who have been shadowing their project progress.

3) *Feedback, feedforward and self-reflection*: It has been elaborated earlier that EDM students learn the theory and tools of the design process which they later will apply in the SDP course. The integration across three semesters sequentially forms a design spine [12]. These two classes are so interconnected that it is logical to encourage inter-class exchanges to provide useful feedback and feedforward information loops to enhance collective learning. EDM students can gain valuable insights before taking the SDP class while SDP students can provide feedback to EDM students based on their own experience, regardless if it is positive or negative, to their junior peers. The practice of providing feedback and guidance can be a powerful means to achieve higher level of cognitive learning. For the course instructors, information conveyed through these interactions will be very useful to assess the teaching effectiveness while making necessary modifications of curriculum delivery for continuous improvements. To achieve this, we have also started to develop pilot surveys to assess students' learning outcomes which are discussed briefly in the next section.

4) *Assessment of student learning effectiveness through surveys:* Student surveys conducted across three semesters were divided into two distinct types: assessing knowledge retention and assessing knowledge application. This section summarizes survey results using two representative surveys that could provide further insight into the following two aspects.

- **Information retention:** Students who passed EDM and were now in the second semester of SDP were asked specific survey questions to check the amount of course learning materials they retained after a gap of one or more semesters. It is to be noted that we only survey the same cohort of students who took the same EDM class. This list of survey questions were extracted from test problems from the EDM class and might be presented differently based on the assessment content. Since we have done this for the first time and the results are not significant statistically, we will use the preliminary data to improve our surveys with the hope that it can be used to track the extent of information retention in EDM.
- **Knowledge retention and application:** Another aspect is how effective the retained information has transferred into knowledge and can be applied effectively in SDP. We conduct a second survey early this spring 2016 semester which is the second semester of SDP. This survey is aimed to gauge SDP students' level of understanding of the overall design process and their confidence in applying these design tools relevant to their own capstone projects. We are at the process of analyzing the results and compare to the first survey. Both surveyed results will be correlated and used for self-assessment of the effectiveness of our coordinated efforts to better integrate the design curriculum.

Figure 2 shows the active exchange of information between EDM and SDP to increase the effectiveness and coordination. As will be discussed later, we will use survey forms to gauge students' learning outcomes and their perception of learning and Figure 2 presents both assessment feedback loop within the classes and an external loop communication to the department curriculum committee for continuous improvement process as shown in Figure 3.

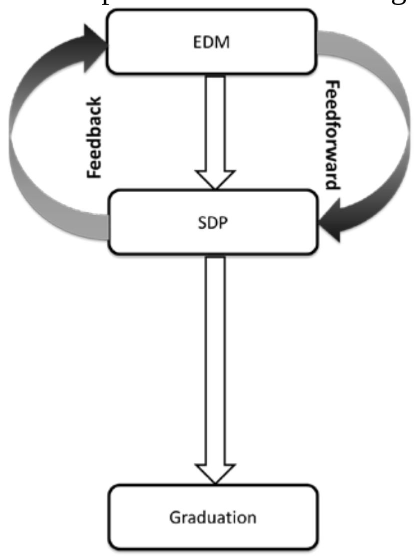

Figure 2 Feedback and feedforward of information at various stages

III. Surveys

III.A. Survey forms and their respective objective

This section briefly discusses surveys designed to gauge the following three main aspects:

1. General Beliefs (GB) – This pertains to the perceptions and thoughts of students from the learning point of view for the design curriculum.
2. Knowledge Retention (KR) – This assesses the level of knowledge retention of EDM topics when students matriculating from EDM to SDP.
3. Syllabus Focus (SF) – This pertains to more focused questions concerning the theoretical aspect of the design process and various tools as well as students' perception towards the efficacy of the teaching material. As it is directly linked to specific topics based on EDM syllabus, this survey is conducted only in the EDM class.

Table 3 shows both the timeline and specific survey forms used during the current spring 2016 semester. The GB type of survey is intended to be given at the beginning and the end of the semester in order to observe the changes in the general beliefs of the students towards each course over the entire semester. Figure 3 shows a representation of the overall availability of information across two cohorts of students who are currently in EDM and SDP courses, respectively. There is an excellent opportunity to gain valuable feedback from students and use it not only for the continuous course improvements from the department's perspective, but also provide feedback to EDM (juniors) from SDP (seniors). Since this assessment process will be integrated into the curriculum, we expect a more systematic analysis of surveyed results could be used effectively to gauge students' learning effectiveness, curricular strengths and shortcomings, and other valuable information for future curriculum improvements.

Table 3 Survey types, timeline and status

Class	Semester	Survey time	Survey type	Status
EDM	Spring 2016	Week 1-3	GB	Done (Jan. 2016)
		Week 9-10	SF	Done (early Mar. 2016)
		Week 13-15	GB and SF	Done (late Apr. 2016)
SDP	Spring 2016	Week 1-3	KR and GB	Done (Jan.2016)
		Week 13-15	GB	Done (late Apr. 2016)

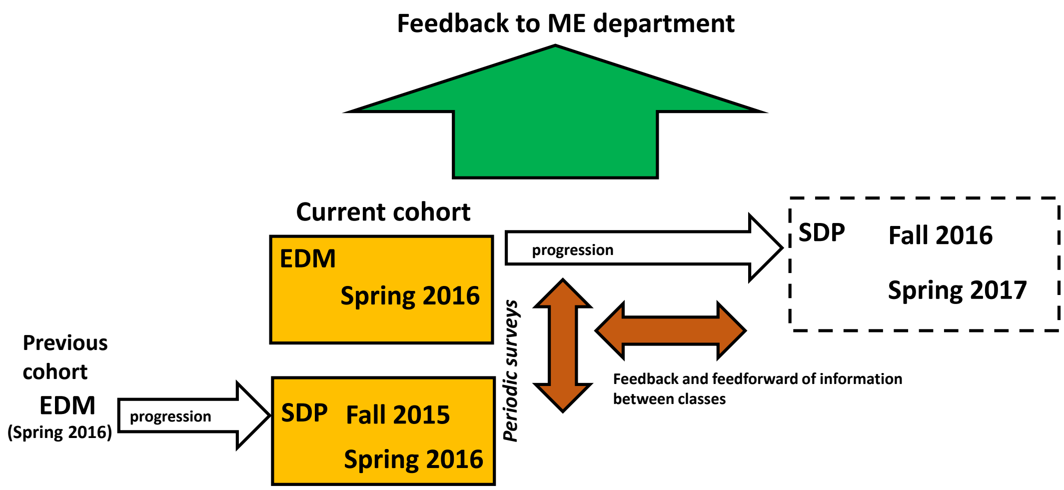

Figure 3 Periodic surveys and information loops

As discussed, two more GB surveys, one each class are planned towards the end of the ongoing spring 2016 semester and their results will be reported in the final paper. Also, it is important to note that the cohort of students who are taking the EDM class will take the SDP in the next school year and their participation through one complete cycle (EDM+SDP) will provide a longitudinal tracking of their learning efficacy and self-perception leading to more direct correlation of the effectiveness of the integrated curriculum.

III.B. Sample results

The answers for all GB type surveys range from the belief being true or false with varying degrees of abstraction i.e. extremely true to not at all true. Table 4 only shows the percentages of students who had answered either extremely true or very true for the questions asked. It is important to note here that this survey was conducted with the help of graduate students from the FSU College of Education and each GB survey consists of a total of over 80 total questions from all three categories namely: future application, self-motivation and confidence in learning outcome. Table 4 shows responses for a selected set of questions that are most relevant for the design curriculum assessment.

Table 4 Spring 2016 semester EDM and SDP survey on general beliefs of students

Survey type: General Beliefs (GB)			
Question category	**Question**	**Responses* (beginning of semester)**	
		EDM	**SDP**
Future application	1. I will use the information I learn in this engineering course in other classes I will take in the future.	69%	54%
	2. What I learn in this engineering course will be important for my future occupational success.	55%	55%
Self-motivation	3. I think the course material in this class is useful for me to learn.	61%	46%
	4. Understanding the subject matter of this course is very important to me.	56%	45%
Confidence in learning outcome	5. I'm confident I can learn the basic concepts taught in this class.	96%	88%
	6. I'm confident I can understand the most complex material presented by the instructor in this class.	80%	63%
	7. I'm confident I can do an excellent job on the work in this course.	90%	80%
	8. I expect to do well in this class.	93%	88%
	9. Considering the difficulty of this class, the teacher, and my skills, I think I will do well by the end of this class.	93%	86%
Answer range	• Extremely true • Very true • Somewhat true • Little bit true • Not at all true		
* Only shows statistics for "extremely true" and "very true" combined.			

In the last week of the spring-2016 semester, a survey of over 50 questions that asked students in both the EDM and SDP classes about their beliefs mainly about what they learnt in this semester was conducted. This survey like the previous one was conducted with the help of graduate students from the FSU College of Education. It is important to note that the survey questions shown in Table 5 intend to probe the student's confidence in his/her learning of the subject from an expertise point of view.

The comparative results in Table 5 shows a close similarity between EDM and SDP classes especially for questions 1, 3, 4 and 5. It is interesting to infer that students in SDP are more likely to allude to focusing on particular capstone project tasks within their SDP team, which makes it encouraging to further solidify the practice of allowing students to perform as "in-house experts" during EDM itself. However, it is to be noted that the current cohort of SDP students were not specifically asked to choose specialty areas when they took the EDM class from previous years (as explained in section II.A). However, the surveyed data is still useful since it allows us to track longitudinally whether there would be substantial differences toward the learning attitude between the current SDP cohort as compared to the current EDM students when the latter group taking SDP. The student beliefs related to learning through focus areas of expertise makes it a promising addition to the generic learning outcomes categorized in Table 4.

Table 5 End of semester survey on general beliefs of students related to expertise and learning outcomes

Survey type: General Beliefs (GB)		
Question	**Responses* (end of semester)**	
	EDM	**SDP**
1. I know the answers to questions in this field because I have figured them out for myself.	42%	44%
2. Sometimes you just have to accept answers from the experts in this field, even if you don't understand them.	48%	53%
3. The most important part of being an expert in this field is accumulating a lot of facts.	34%	37%
4. I am most confident that I know something when I know what the experts think.	52%	57%
5. One expert's opinion in this field is as good as another's.	36%	33%
6. Experts in this field can ultimately get to the truth.	45%	56%
7. All experts in this field understand the field in the same way.	18%	23%
Answer range: • Strongly disagree • Somewhat disagree • Neither agree nor disagree • Somewhat agree • Strongly agree		
* Only shows statistics for "strongly agree" and "somewhat agree" combined.		

At the beginning of the spring 2016 survey, KR survey was also conducted in the SDP class. The questions specifically linked to design topics taught in EDM and aimed to observe the level of knowledge retention for the SDP students and this was done in the second semester of the SDP cycle after they had worked on the design phase of their projects over the fall 2015 semester. The KR survey answers had a best and second best answer, Table 6 shows the response percentages for each question. Question 3 pertains to assessing customer requirements and question 4 for concept generation using standard tools. The response proportions for these two questions show poor retention of the taught material and needs to be followed up in the next EDM session. Such a KR type survey in the SDP class is useful to provide feedback into the EDM course teaching method to ensure continuous improvement.

An SF type survey was also conducted during the middle of the spring 2016 semester as well as at the end, only for the EDM class. The answer choices ranging from strongly agree to strongly disagree. Similar to the GB survey mentioned earlier, this survey too was done with the help of the FSU College of Education's graduate students and consisted of nearly 60 questions, of which selected relevant responses have been shown in Table 7. The statistical results only tally responses when the EDM students answered either "strongly agree" or "agree" to the selected questions.

Table 6 Knowledge retention from EDM to SDP, conducted in SDP class

Survey type: Knowledge Retention (KR)				
Question	**Answer choices**		**Answer weight**	**Percentage %**
1. When analyzing a product for potential risks due to faults and failures, I am aware of the following fundamental tools.	A	FMEA	Second best	41.11
	B	FTA		
	C	Both A & B	Best	56.67
	D	None of the above		
	E	My project does not need risk analysis at all		
2. In an HOQ, to better understand competitor's product(s), I am aware of two standard methods that could be employed.	A	Benchmarking		
	B	Reverse Engineering		
	C	Kano Diagram		
	D	Either A or B	Second best	15.56
	E	Both A & B	Best	66.67
3. To analyze a product and find performance related dependencies of various factors, a meticulous approach needs to be adopted. For this purpose, I am aware of the following tools at my disposal.	A	FMEA		
	B	Taguchi DOE method	Second best	0
	C	Both A & B	Best	24.44
	D	HOQ		
	E	None of the above		
4. If my project deals with an established product that needs to be modified using well understood fundamentals, I am aware of the appropriate technique to use to generate ideas.	A	Morphological method		
	B	TRIZ	Best	24.44
	C	FMEA		
	D	HOQ		
	E	Both A & B	Second best	53.33
5. To redesign a product and reduce assembly cost, I am aware of standard tools.	A	Boothroyd-Dewhurst method	Second best	43.33
	B	Hitachi method		
	C	Lucas method		
	D	Critical Path method		
	E	All of the above	Best	38.89

Table 7 Middle and end of semester EDM survey on syllabus focused learning outcomes

Survey type: Syllabus Focus (SF)			
No.	**Question**	**Responses* (beginning of semester)**	**Responses* (end of semester)**
1	The most important part of work in this subject is coming up with original ideas.	39%	25%
2	In this subject, it is good to question the ideas presented.	66%	76%
3	Principles in this field are unchanging.	40%	34%
4	Principles in this field can be applied in any situation.	60%	55%
5	Expertise in this field consists of seeing the interrelationships among ideas.	62%	85%
6	Answers to questions in this field change as experts gather more information.	69%	82%
7	First-hand experience is the best way of knowing something in this field.	66%	81%
Answer range	• Strongly agree • Somewhat agree • Neutral • Somewhat disagree • Strongly disagree		
* Only shows statistics for "strongly agree" and "somewhat agree" combined for the EDM class only.			

Table 7 results show that in most aspects, the students' responses become more favorable towards the end of the semester. The only criteria that shows substantial decrease is question 1 when students were asked whether the originality is the most important part of work in the EDM. The possible explanation could be that initially more students anticipated that the EDM course topics might focus extensively on originality, but towards the end of the semester they realized that the main emphasis was more on learning the fundamental design cycle and other design-related tools. Therefore, this drop in percentage for question-1 of Table 7 could be considered not as a less favorable response rather than as a better appreciation of the learning objectives of the class.

The last day of EDM classes consisted of a mock poster session where teams printed and presented their work done on internal project topics. SDP students were required to attend this session and provide feedback, a task that falls within the feedback and feedforward loops as shown in Figure 2. An online survey was conducted within the EDM class to assess the experience of students related to EDM-SDP integration aspects such as attending poster sessions and presentations. Results are summarized in Table 8. Such a survey offers different insights as compared to the previously mentioned GB, KR and SF type surveys and specifically caters to better integration measures between EDM and SDP.

Table 8 Final EDM class survey on SDP integration aspects

Question no. with choices		**%**	**Action/Remark**
1. My experience while shadowing the current senior design (capstone) project. Select all that apply.	A) It was straightforward to follow the senior design project (SDP) team's updates on the website and they did a good job of putting up information online.	53	
	B) Since I knew some of the SDP team members personally, it was easy to collect relevant information to compile a good quality report.	12	
	C) Both A and B.	26	
	D) The SDP team could improve on regularly updating information on their designated project websites to make it easier to shadow them.	18	Information sent to SDP teams.
2. My experience when attending an SDP presentation. Select all that apply.	A) I did not attend.	14	Need to enforce measures to ensure greater attendance
	B) It was helpful to see how the SDP team is judged by the audience so that I have some idea of what to expect from it when I am part of a similar team.	61	
	C) Attending the SDP presentations gave me some degree of perspective for the entire design curriculum and in turn played a positive part in my own presentations.	73	
	D) Attending their presentations was not at all helpful for me.	0	Encouraging result.
3. My experience of the SDP poster sessions. Select all that apply.	A) I did not attend.	17	Same as 2.A.
	B) It was helpful and gave me an idea of what to expect when I do the same.	77	
	C) I closely assessed their posters and the way they present it which in turn had an influence on my EDM mock-poster session.	33	
	D) It was not at all helpful.	6	
4. My preparation and confidence levels to enter senior design in the coming academic year. Select all that apply.	A) I feel extremely confident and well prepared to enter capstone design with the theory learnt in EDM as well as the SDP-integration exposure I received.	39	
	B) I feel well prepared from the EDM theory point of view, but will need more SDP related exposure to be confident about the aspects of capstone design.	61	
	C) I feel there was adequate exposure to SDP aspects, but would feel more confident having more design theory in EDM.	11	

	D) I feel I am poorly prepared with not much confidence entering capstone design.	0	Encouraging result.

IV. Discussion and conclusions

IV.A. Survey result interpretation

In section III, survey samples were briefly described with the general results. Important lessons can be learned from these surveys conducted at different times during the course and in both the classes. As explained earlier, EDM is the first semester of the design curriculum comprising of the theoretical aspect of the design process while SDP is the next two consecutive semesters of the actual capstone design project implementation. Focusing on specific questions and their response proportions, the following inferences could be drawn:

1. **Linking learning to future goals –** From the GB surveys in Table 4 and Table 5, insight into how students in general think about the future use of what they learn in EDM and SDP at the beginning of the semester could be obtained. Such information is vital to plan ahead and engage in project-centered activities such as seminars given by industry guests.
2. **Emphasis on creativity and originality –** Information in the SF survey from Table 7 provides some insight into students' views while combining creativity and originality while keeping their ideas within the boundaries of the syllabus. It further points to the need for course material to allow the development of creative thinking but emphasize specific guidelines following engineering principles and design protocols during EDM. This has been facilitated using team presentations and collaborative learning while showing encouraging results.
3. **Retaining knowledge –** Information from Table 6 shows in general the extent of information retained by SDP students who have worked on their projects over the fall semester. As mentioned earlier, the survey results reveals a seemingly lack of understanding regarding how to assess customer requirements by using appropriate concept generation techniques. Such information could be readily communicated to the instructor in the EDM class for corrective actions. This further validates the use of periodic surveys and the feedback/feedforward loops (as shown in Figure 2 and 3).
4. **EDM-SDP integration –** Insights into students' perspectives in both classes and longitudinal tracking of their learning through integration is vital to make informed decisions about future curricular improvements. Table 8 shows that the majority of EDM students agree that attendance of SDP interactive sessions help and influence their own presentations. Specific feedbacks such as that on SDP teams' websites could be imparted to further improve accessibility where possible. Another positive aspect is the reasonably high rate of attendance (>80%) of EDM students at key SDP events.

IV.B. Summary and future considerations

In summary, the efforts to integrate the capstone design experience on the introduction of design theory/tools in EDM (first semester) and the implementation of project realization in SDP (following two semesters) show promise. The emphasis on linking standard design subjects in a relevant and concise syllabus through EDM and then re-emphasize in SDP as discussed in section

II is critical to achieve curriculum cohesion and more effective learning. Several inter-class collaborative activities have been implemented for the past three semesters (section II.C.) including project shadowing, inter-class reviews of oral and poster presentations, and surveys to track students' information retention and knowledge transfer and application. Through these interactions, it is anticipated that EDM students gain better understanding of the design process as a holistic activity through the recognition of relevancy between theory/tools and the project execution.

The SDP students learn first-hand in capstone design projects, which when linked to the format and outcome expectations from EDM, ensures a seamless transition. The SDP students are positioned to provide feedback and guidance to their junior peers while reinforcing their own appreciation of the integrated design experience. This promotes not only reflective thinking to achieve effective self-learning but also facilitates information retention and improved knowledge transfer between these two cohorts of students. Active use of surveys with help from DE graduate students has assisted immensely in gaining insight into students' perceptions.

As mentioned in the abstract, the eventual aim of this effort in our department is to have a design curriculum that is adaptable and flexible while serving as a benchmark for future design courses in our college. The curriculum includes a continuously improving plan that allows for relevant changes while incorporating strategies such as analogy, collaboration, team-based and competitive learning. Periodic feedback and surveys allows us to better understand the students' perception of our efforts. The overall student satisfaction level shows a noticeable increase based on feedback received at the end of each semester as well as the unsolicited comments from recruiters and MEAC members. We plan to continue this pilot program and refine our implementation of the inter-class collaborative activities. We are grateful to graduate students from the Florida State University College of Education to improve our surveys so we can better measure the effectiveness of the integrated efforts for future improvements.

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