Evolution of the Freshman Year Engineering Core

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Abstract - The engineering core curriculum at Stevens Institute of Technology is built around an eight-semester “Design Spine”. The Design Spine in the Freshman Year is a key means to engage students early and to initiate a number of threads that build both technical and so-called “soft” competencies. In the first semester, Engineering Design I is linked with courses in Engineering Graphics and Computer Programming. Engineering Design II in the second semester builds on the first semester experience. In this paper the recent evolution of this sequence is discussed, including the integration of a more systems-oriented approach and the impact of evolving computer-based tools. A first semester engineering seminar course has also evolved to one in which students can select from a series of events offered over both semesters.

INTRODUCING A SYSTEMS APPROACH

One key change has been to introduce concepts associated with systems thinking from the start of the design sequence. The curriculum review highlighted the need for this, as engineers are called upon to practice in a global socio-economic environment increasingly dominated by engineering systems and the design of engineering systems. Engineering curricula, with their focus on the disciplinary contributions to design, encourage a mindset in which students seek technical solutions often rooted in a specific engineering discipline with little regard for the context in which their product, system, or service may be deployed, the societal or business need it may fulfill or even its relations to all the other engineering, business or ‘environmental’ domains that can contribute to success.

To address these issues of “partial design” it was decided to introduce the comprehensive design approach known as Total Design, after Pugh [2]. “Total Design” is the systematic activity necessary from the identification of a market/user need, to the selling of the successful product/process/service to satisfy that need – an activity that encompasses product, process, people and organization. In fact, total design encompasses approaches, methods and tools of system design and systems engineering as illustrated in Figure 1. The major aim of systems engineering is to develop an operational model of the system for all phases of the life cycle, the model is then used as a basis for detail design. It is this top-down approach to design that has been missing from engineering curricula and that will be increasingly needed in the design of future systems.

Engineering Design I and Introduction to Programming

The goal is to develop the total design approach through the Design Spine, with many of the basic concepts introduced in the Freshman year to establish the foundation, recognizing that they may not resonate with students there but provide the needed basis to revisit through the sequence to capstone design. In Engineering Design I the second week includes a product disassembly exercise using a cordless screwdriver. This now provides the vehicle to introduce the first steps in developing total design by consideration of market needs and
stakeholder requirements. A detailed overview and linkages of the total design process appears in Figure 2. Each phase in the life cycle of a product, system or service, as shown in the sidebars, would include essentially the same ten steps. Students are given an overview of the complete process in Week 2 of Engineering Design I and then asked to address the first two stages in the context of the cordless screwdriver, for example, by being asked to identify the stakeholders and their requirements, something that presents them a challenge if they are pushed to go beyond the customer/user.

These first two stages are reinforced in the context of the major design project that occupies Weeks 6-14. This project is an autonomous robot, which gives students an early example of a system; one that combines various disciplinary aspects such as mechanical design, electrical circuits, sensors and programming of a microprocessor. In this project they also engage in the third stage of the total design process, namely concept generation, but this is not developed in a systematic manner. It is revisited in more depth in Engineering Design II. More detail on the total design process and the initial experience in implementing it in Design I is described elsewhere [3].

It should also be noted that the robot design project provides a link and a context to concurrently build on the Introduction to Computer Programming course that is also taken in the first semester. The programming course uses C++ as the language, although it is mostly focuses on procedural aspects of programming within this environment. In the design course robot project, students use a PIC microprocessor (Microchip Technology Inc.) on a Steven-designed circuit board. The board has pre-wired interfaces for two motors, a number of sensors and micro switches and a set of additional analog and digital I/O connections. The PIC can be programmed in C++. In the design laboratory the student groups undertake a series of programming tasks early in the project that are common sub-programs for the project.
irrespective of the final design, such as motor control and bumper response. This provides a means to link knowledge from the programming course to real applications in a project-based learning mode in the design course, with instructor and teaching assistant support. These sub-programs then help in building the final software design.

**Engineering Design II**

Engineering Design II was completely revised and now focuses on sensors and data acquisition. This is accomplished using the graphical programming language LabVIEW™ that is employed to connect sensors to the students’ laptop computers via a USB data acquisition module (National Instruments). Students learn to program in LabVIEW via assignments to connect to and calibrate a light sensor and to perform motor speed control using a perforated disc and optical interrupt sensor. The students apply this knowledge to their group’s choice of one of three projects that require use of sensors, acquisition of sensor data and its use for a simple control function(s). Students are also required to develop a ‘dashboard’ on their laptop in LabVIEW to display the sensor data, etc. All students are required to develop a LabVIEW program and so it is not just left to the “programmer” in the group. LabVIEW appears to provide a more intuitive route to programming, especially for students who were either not adept at C++ or not interested in programming in Term 1.

Total design is revisited early when a commercial fire alarm system (multiple units – one per group – connected across the lab. to a master monitoring panel) is evaluated and then the individual alarm units disassembled to reveal their sensors (temperature and optical smoke sensors). Stakeholder requirements for the alarm system are considered and then the 4th total design stage is introduced, namely Operational Scenarios, in which context diagrams and use case scenarios are developed. This requires a collection of scenarios to be established, one or more for each group of stakeholders for the particular phase of the life cycle – only the first design phase is considered in Freshman year. Each scenario addresses one way a particular stakeholder(s) will want to use, deploy or otherwise interact with the system; it defines how the system will respond to inputs from other systems to achieve the desired effect.

The design projects are also used to reinforce the total design approach. Each project is presented in the form of a commercial Request for Proposal (RFP), groups choose an RFP to which they will respond. The projects include a search and recovery robot, which is based on the platform from Engineering Design I. This robot (not autonomous) is required to locate simulated victims (infra-red sources) in a debris field and place markers at a fixed distance from each. Infra-red and proximity sensors are used; many groups also use Bluetooth™ to provide wireless control of the robot via a joystick using an RS232 port on the custom circuit board used in the robot.

The second project involves a gantry crane (built from LEGO). The project is posed as a retrofit with sensors for remote control. The team is required to use limit switches and sensors to remotely control, from a laptop computer, crane movement through a defined angular range, hoist movement and the lateral positioning of a counter weight to balance the hoist. The third project is a compact, deployable, environmental monitoring system that can link to a wireless network and includes monitoring of temperature, wind speed and direction and a simulated hazardous gas (carbon dioxide).

Each of these projects is viewed as a system and groups are required to proceed through the first four stages of the total design process, developing context diagrams and use cases on their selected concept.

**FIGURE 3**

**ENGINEERING DESIGN II CRANE PROJECT**

For the conceptual stage, the use of a systematic evaluation of their ideas is encouraged through the use of a Pugh Matrix [2] in which concepts are plotted versus customer acceptance criteria and are each rated based on an assessment of whether the concept can meet, exceed or does not meet each of the criteria. The fifth stage would be to develop system specifications to guide the physical realization of the design. However, this has been limited to a basic response in the context of the RFP due to time limitations.

It should be noted that students are assigned to the groups in both Freshman design courses to provide a diverse mix of disciplinary interest and background skills. Particularly in Design II, there is a focus on developing effective teaming skills with associated group and individual assessments.

Assessment of learning outcomes associated with the total design process in the first iteration has shown that students grasp some of the concepts well but particularly stakeholder requirements are difficult for incoming freshmen to grasp [3]. Some modifications to how this is presented are to be tried next time.

**ENGINEERING GRAPHICS**

The Engineering Graphics course is taught concurrently with the first semester Engineering Design I course previously.
described. Graphics has followed a standard approach based on 3-D solids modeling using SolidWorks™. The course has leaned heavily on associated tutorial materials. In keeping with the changes to Freshman design to promote concepts of total design and a systems approach with increased emphasis on analysis of customer requirements and use aspects, it was recognized that Graphics should be broadened in scope and better integrated into the early design pedagogy. This objective is to expose students to the range of graphical communication in engineering from three-dimensional hand sketching to virtual reality as well as broach contemporary aesthetic design, a topic missing from the traditional approach but critical from a customer needs and product success perspective in many applications.

A pilot has been conducted with three (of ten) sections of the first semester Graphics course. The primary course outcomes were kept the same as those for the other sections. SolidWorks™ was also kept as the primary tool. However, the syllabus was revised to include the introduction of a broader set of digital design and visualization tools. The revised Graphics syllabus now looks to address a wider array of user needs and customer requirements associated with the various engineering disciplines. Design tools, such as rule-based modeling, advanced replication, virtual reality and scripting environments, tools that did not exist as recently as 10 years ago, are now introduced in the context of contemporary product design and engineering.

The course commences with 3-D free hand sketching of contemporary objects with complex surfaces. The goal is to use the sketching exercises to help students think through how they will tackle the graphical representation of complex three-dimensional objects before they turn to the digital tool. This approach contrasts the normal teaching of free-hand sketching based on simple geometries. Students from the outset were instructed to sketch in three-dimensional space as opposed to more traditional two-dimensional orthographic projection methodologies. This fosters a stronger understanding of the relationships of directional surface geometries. It is intended to promote an intuitive and creative mindset in the students work, as opposed to a focus on the mechanics of orthographic projection.

Following sketching with a brief introduction to 2-D vector graphics (AutoCAD™) immediately exposed the limitations of an important and pervasive digital graphics tool. However it also showed the applicability of vector drafting to certain engineering applications. This is important because as a core undergraduate course for all disciplines, students can appreciate tools appropriate to not only their discipline but also individual tasks at hand. Here, the future electrical and civil engineers sit side by side with mechanical engineers for whom a sole focus on solid modeling may seem more appropriate.

Solid modeling then forms the core of the revised course and occupies the majority of time in the semester, with part modeling, assembly modeling and interactive 2-D drawing generation being the key components. Although the content here was similar to that of the other seven non-pilot graphics sections following the existing curriculum, the pedagogy was focused on a workshop approach rather than a lecture/tutorial environment. In this regard the time spent working through the tutorial material was significantly reduced compared to the other sections. This recognized that students could easily revisit this on their own once they were aware of the topics and techniques. This change freed up time, particularly later in the course, to apply what had been learned to individual project work of the student’s choosing. In so doing, it raised the level of engagement and enthusiasm for the course.

At this point, in the tenth week of the semester, fluency in solids modeling was apparent and the tutorial workshop was replaced with individual student projects. This was a departure from the existing curriculum by not trying to be exhaustive in the exploration of the capabilities of SolidWorks™. Short demonstrations were given on select advanced topics with the expectation that students would see the applicability and need for these methodologies in their individual tasks. For example, building on the sketching exercises in which Bezier-based geometries were introduced in an intuitive manner to deal with complex geometries, their need was now demonstrated in applying the digital tools to advanced surfacing. In Figure 4 the connection of orthogonal circle and rectangle elements in (a) would typically be limited to application of a simple lofting as in (b). In contrast the use of tangency has been explored in the pilot sections to create aesthetic shapes such as (c).

The importance of the individually selected projects cannot be understated, as there are generational and gender issues in interest and environment that are not reflected in standard texts and associated examples. These contemporary objects are in turn a reflection on contemporary design and manufacturing methodologies. A counter point is the hand-
held screwdriver exercise typical of a final examination in the existing syllabus. This contrasted with the more dynamic geometries of cell phones, gaming consoles and skateboard surface and truck assemblies in the modified syllabus. At a point in which the traditional graphics section typically exhibits stagnating student interest, the proprietary interest associated by the student to his/her project became a reinvigorating factor in the latter part of the semester.

Figure 5 shows an example of applying advanced surfacing as the most appropriate method of modeling complex geometries.

Having now used SolidWorks™ in depth to meet the majority of the course outcomes consistent with what was expected in the existing syllabus, the final two weeks provided a further enhancement by exposure to the power of digital tools to go beyond three-dimensional modeling to analysis, kinematics and virtual reality. COSMOS™, an enhanced module for SolidWorks™ was introduced in the context of finite element analysis (FEA) to show the stress distribution in an object created in SolidWorks™. So while FEA was not taught at this point, the power of linking advanced engineering analysis and visualization within the design environment was a glimpse of how modern digital tools have shaped the engineering profession.

Demonstrations using CATIA™ provided awareness of advanced topics such as advanced replication. The opportunity was taken to also demonstrate the use of kinematics in design. While aspects of this can be done in SolidWorks™, the example was a sophisticated one developed as part of a Graduate design program to demonstrate leading edge design.

The course culminated with a glimpse into the power of virtual reality as a means of communicating not only the hyper visualization of design as an independent endeavor, but also the value of human interaction with the design. To achieve this, students were taken to a virtual reality theater where a stereoscopic projection system was used. A SolidWorks™ assembly file, after conversion through EON Reality™ V.R. software, was made to appear with the object floating and assembling in the three-dimensional space of the room.

Assessment by the standard survey of the student evaluation of course learning outcomes revealed no significant difference between the responses from the students taking the modified syllabus and those on the original. This was not too surprising as a primary goal was to expand the perspective of the students in the revised syllabus while meeting a common desired set of outcomes for all students.

In order to gain further insight into the impact of the syllabus revision, we conducted an additional survey in which the questions probed students’ perceptions. One key question asked students to rate their interest level at the beginning, middle and towards the end of the course. This showed that interest levels were similar at the beginning and middle of the course for both groups but diverged toward the end. Those in the modified syllabus indicated an increased interest while those on the original syllabus showed no increase. Student comments indicated that the increased interest was especially associated with the individual projects using items of interest to the students.

**REPLACEMENT FOR ENGINEERING SEMINAR**

For a number of years all engineering freshmen participated in a first semester, one-credit Engineering Seminar. This course was based on the popular format championed by Raymond Landis [1] with some customization to the Stevens context. Similar courses are in effect at other schools with varied formats [e.g. 2]. The Engineering Seminar involved groups of 20-24 students meeting weekly with an individual engineering faculty member with all groups following the same syllabus. The faculty experience with this course was that initial student interest started to wane after a number of weeks. Feedback from students indicated that a quite a few resented having to spend the time meeting every week given the heavy credit load at Stevens.

In response to the above, and as part of the revision to the core curriculum to provide among other goals a more engaging and less onerous first year along with more choice, a new approach has been taken that attempts to preserve those elements of the Engineering Seminar that were valued by the students while offering a more flexible, engaging format. A two-semester sequence, E101-102 Engineering Experiences, has been introduced. The approach is to offer students a variety of experiences and events scheduled throughout the freshman year. Coupled with this new two-semester course has been a change to the advising system whereby an advisor is assigned to the incoming student based on his/her anticipated engineering discipline. The official election of a disciplinary program is still made at the end of the third semester; however it has been found that only approximately 15% of students are undecided on entering and those students are assigned to a senior faculty member and then switched to a discipline advisor once they have a clearer idea of their commitment to a particular field.

**Structure of the Course**

E101-102 Engineering Experiences is comprised of a series of events offered each week that for the most part students elect to participate in. To do so they are required to register online through a dedicated website.
A diverse selection of events is offered. Each engineering department is expected to provide orientations to their programs and organize a variety of events relevant to their field. These can include workshops, lectures; visits to research centers and laboratories; external trips; visiting speakers, including corporate events with a career focus. Where possible, departments are strongly encouraged to offer hands-on or active approaches. The events can range from lectures suitable for a large attendance to small group activities.

In addition to the departmental offerings, a number of events are organized at the Engineering School level and also through other organizations within the Institute such as Career Services and the Academic Support Center. For example the latter is responsible for several workshops on such things as: practicing good study skills, effective time management and examination technique. Career Services has offered popular workshops on resume preparation and interview technique. These are of particular significance to the approximately 40% of Freshman who will take part in the Cooperative Education program, with their first work period commencing in the summer after Freshman Year. Representatives of some of the companies that come on campus to recruit also provide seminars on careers in their fields.

A limited number of events are compulsory for all students, including a lecture at the start of the first semester that provides a background to Stevens and the curriculum. A lecture on applied ethics is also required in the second semester, that provides a background to Stevens and the curriculum. A number of the events are scheduled to coincide with the two examination techniques. Career Services has offered popular workshops on resume preparation and interview technique. These are of particular significance to the approximately 40% of Freshman who will take part in the Cooperative Education program, with their first work period commencing in the summer after Freshman Year. Representatives of some of the companies that come on campus to recruit also provide seminars on careers in their fields.

A limited number of events are compulsory for all students, including a lecture at the start of the first semester that provides a background to Stevens and the curriculum. A lecture on applied ethics is also required in the second semester for all students. This provides an important early message to the students on the significance of ethics in engineering.

**Logistics of the Course**

Many of the events are scheduled to coincide with the two assigned time slots to ensure that students will be able to attend. This also means that many of the events are given twice to reach all who may potentially be interested and certainly this is so for the compulsory events. Other events, because of the need for additional time, such as for off-campus trips or due to the constraints of the providing individual(s) or organization, may be scheduled on days/times that are not available to all students. Where possible, the organizers are encouraged to offer repeats of these events to reach the broadest number of potential participants.

The multiple events most weeks, together with the online registration system, provide students with flexibility to choose in what and when they participate. In the first implementation the students were required to attend a minimum of five events each semester, ten in total for one credit.

**Course Website and Registration System**

A key enabler of the course function is a website and a registration system that is linked to the website. The website, in addition to linking to the registration tool, provides a Schedule of Events for the current semester to allow students to preview and plan which events they may wish to register for. In addition there are links to the engineering departments and programs, to information on the engineering curriculum, and to a variety of resources on careers, professional societies, licensure, etc. and to the advising website.

The linked Registration site is a custom developed web-based application. Data is downloaded from the Institute’s Student Information System at the start of the course to build a database of enrolled students and from this the associated records of events that they register for and actually attend. The database also has information on the individual faculty or staff who are responsible for the various events. This allows them to login to view information on their specific events and record attendance.

The system provides event organizers with a listing of registered students as well as a list of who has indicated interest but could not attend. The latter allows for planning repeat offerings of popular events. The organizer can also download a pdf file that is automatically generated with the list of registered students to use as an attendance sign-in sheet for giving credit – credit is then recorded via the website.

Assessment has shown that students like the flexibility and scope of the course. Issues of providing sufficient experiences in some disciplines and getting events posted by the start of the semester to facilitate choice need attention.

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**REFERENCES**


