AC 2010-32: A MODEL FOR INTEGRATING ENTREPRENEURIAL INNOVATION INTO AN ENGINEERING CAPSTONE

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A Model for Integrating Entrepreneurial Innovation into an Engineering Capstone

Abstract: There are many imperatives for incorporating 'relevance' into engineering education. Among the most pressing are the culminating experience of a 'capstone' and incorporation of instruction in 'real-world' applications and in innovative thinking. This paper will examine one approach for integrating entrepreneurship, innovation and real-world design into the engineering capstone experience. The paper will report on a recent multi-disciplinary capstone course that partnered with a small business enterprise. The project enrolled senior engineering students in four disciplines, along with a supporting cast from other colleges, in design of a product to fulfill real-world needs and constraints, a production system for its serial manufacture and a business enterprise for commercialization of product and production capability. The capstone experience included fabrication and test of a prototype product and multiple entries into regional and national competitions. Concluding commentary will … offer an opinion that matters as important as innovation and entrepreneurship ought not to be relegated to only elective or extracurricular status … extract lessons learned from this and companion projects … and offer suggestions for a generalization of this experience.

The Context: One of the most important common characteristics of undergraduate engineering education is the universal requirement for a culminating learning experience. This is commonly referred to as a 'capstone', but is also often included in curricula under the older title of 'senior design'. In whichever titling, the intent is to provide senior students with an integrated experience that requires a demonstration that the learning of subject matter and design methodology intended to be imparted in the major curriculum has been, in fact, absorbed and mastered. Capstone experiences vary in length and credits, but the observed norm seems to be a two-semester experience totaling six credits. At North Dakota State University, most engineering departments opt for this model, although one department compresses the six-credit experience into one semester.

Another of the persistent imperatives that employers and accrediting agencies, and indeed the general public, insist upon is that undergraduate engineering curricula should prepare new graduates for rapid integration into the professional workforce. This requirement goes by various names, but is usually understood to encompass a 'relevance' of the educational process to performance expectations for engineers in the competitive industrial marketplace.

Equally persistent is the challenge to the professoriate to devise learning processes whereby students will master both the essential engineering sciences and their utilization in practical application. Fledgling engineers must understand the science and method in such topics as thermodynamics, electrical circuitry, structural analysis and the like. In demonstrating such understanding, they typically must master the techniques for formulating problems, assembling appropriate data and equations, and calculating predicted values of parameters that describe performance of an engineering component or system. These exercises, however, are in most cases not sufficient in the 'relevance' measure. Students must also learn to apply engineering science in the design of articles, components and systems that are characteristic of industrial and commercial products. It is rarely true that mastering the engineering science automatically leads to effective utilization of those scientific precepts in practical design application.

With somewhat less visibility than in the case for 'relevance', some further characteristics of the technological economy has been periodically urged upon the design of undergraduate engineering curricula -- that of business understanding, of innovation and invention, of entrepreneurship. Traditional curricula have not addressed these matters, and for well and tried good reasons -- to wit: curricula are over-full of credit requirements, and instruction in entrepreneurial thinking is often assumed to require new and separate courses.

A Foundation: The challenge of blending understanding of engineering science with mastery in applications in design is often approached through project work. The capstone experience is an ideal platform for cementing these matters in the professional habits of new engineering graduates. The capstone is often a design project, where individuals or student teams progress through the stages of problem definition, analysis and synthesis to create a design for an engineering article.

There are also many extra-curricular opportunities for students to learn valuable skills for integrating learning of fundamentals with applications in design. Such national projects as steel bridge, concrete canoe, mini-Baja, mini-Indy, quarter-scale tractor and similar activities are very popular and serve valuable purposes. Some universities incorporate projects of this sort into the capstone experience; others do not. Likewise, other universities sponsor entrepreneurial clubs that also provide valuable experiences for students.

The atmosphere of entrepreneurial interest on and around the North Dakota State has been supported through a Center for Technical Enterprise, which acts primarily as an incubator for fledgling technological companies. As part of its charter, this Center engages the campus and surrounding communities in dialogue about and various forms of support for innovators, inventors and entrepreneurs. For several years, the Center also sponsored an after-hours seminar-cum-networking event for active and would-be entrepreneurs, the "5:01 Society".

As the spectrum of challenges outlined above was being examined, the author drew several conclusions from his prior experiences both in various industrial positions and in the professoriate. The epiphenomic conclusion is that something as important as entrepreneurship ought not to be relegated to only extra curricular status. In the Industrial and Manufacturing Engineering Department, nearly every course is taught through the method of team-based projects. Students are challenged to apply fundamental principles through open-ended projects, and by the time of graduation every student will have experienced at least a dozen design-oriented projects of durations varying from a month to a semester. What has been missing is an extension of the blending of fundamental engineering science with component and system design to also encompass the tenets of entrepreneurialism.

The NDSU College of Engineering and Architecture has been experimenting with methods for integrating entrepreneurial thinking with engineering instruction since 2004.[1] These efforts have been primarily focused in extra-curricular teams that bring together students at every level for participation in a topic related to a professor's research. While these 'scholar teams' were (and are) extra-curricular, it was hoped that they would spawn capstone projects that would extend the work into design of commercially-useful products. The motivation included the observation that a certain fraction of capstone projects normally will evolve designs of significant commercial potential. It was further observed that our college houses about one hundred team-based capstone projects each year, and it was speculated that if only a small fraction of these teams could be encouraged into an entrepreneurial extension immediately after graduation, the regional socio-economic impact would be very substantial.[2]

The scholar-team movement inspired a parallel activity, starting in Autumn 2007. In that term, a for-credit activity was launched as a multi-disciplinary, multi-level, multi-year team project with learning objectives to develop skills and competencies for … translating laboratory research into commercial products and processes; creating and maintaining intellectual property; utilizing micro-technologies in medical and dental applications. These objectives are pursued through a project -- currently development of a new concept in bone scaffolding.[1,3] This activity is known as the Bison Microventure (or Bμv) and is repeatable for credit by the students. At the time of this writing, the Bμv is in its sixth semester, with the leading students in their sixth and fourth repetitions. In its six semester history, the Microventure has enrolled twenty-seven students from eight majors in five colleges, with an average of about nine students per semester. The Spring 2010 enrollment is 12. The majority of students are majoring in Manufacturing Engineering or Zoology.

An Approach to Blending the Capstone Experience with Entrepreneurial Opportunity: Because of the author's association with entrepreneurial activity, an opportunity presented it self in Spring 2008 that grew into a multi-disciplinary capstone innovation team. As it happened, the College of Pharmacy at NDSU had been researching means for bringing professional pharmacist service to remote rural areas.

The pharmacy study began in 2002 with the objectives of devising methodology for providing pharmacist care to underserved rural communities, using telecommunications technologies. The study focuses on operational and regulatory issues, with some essential emphasis on drafting model laws to permit telepharmacy operations at the state level. By Spring 2008, seventeen states had enacted legislation that permits remote operation of pharmacists, and fifty test sites had been established for the College of Pharmacy study, primarily in North Dakota and Minnesota. All of the test sites had been equipped with one-of workstations, assembled individually at each site by a private company working in partnership with the Pharmacy researchers. All of these workstations had been assembled from components available through retail outlets. The parts lists had, of course, evolved over the term of the project, and consequently, the workstations varied in their capabilities. Likewise, several operational problems had become apparent, particularly in regard to system stability and to communications security. These workstations were collectively referred to in project work as 'Model 1'.

An assessment of this experience by the principal investigators of the research concluded that the project status in Spring 2008 justified the development of a workstation expressly designed for telepharmacy operation and that such a purpose-built product was necessary if widespread utilization of this method for serving rural communities were to become widespread. The private company partner is a small business that does not have the staff to devote to new product development, and the research funding is not adequate to pursue development through other, more traditional means. At the same time, the author was known to be active in product innovation. Accordingly, the author was invited to offer project concepts for development of a purpose-specific workstation.

The project was defined during an afternoon meeting in mid-July between the Dean of Pharmacy, the Director of the Center for Technical Enterprise, the President of the private company partner and the author. A contractual statement-of-work was drafted and agreed to between the small company research partner (as the project sponsor) and the author in about two weeks. A full written contract was prepared by the NDSU Sponsored Programs Office and was signed by all concerned within another three weeks, ready for the project start on 1st September 2008.

Project objectives were defined as … [1] product: design of a purpose-centric workstation that could be brought to market within one year of project completion (i.e., on or before May 2010), plus definition of 'ideal' workstation capabilities that could serve as guidance for subsequent development of new models; [2] production system: design of a complete factory for serial manufacture of commercial telepharmacy workstation products; [3] business: design of a viable business enterprise that could operate the designed factory and manufacture and distribute the workstations. The entire project was subject to explicit cost and time-to-market constraints.

In parallel, student recruiting was launched. The original plan called for a team of six students: one undergraduate each from Manufacturing Engineering, Industrial Engineering and Management, Computer Engineering and Electrical Engineering, plus one graduate student each from the Master of Business Administration and Doctor of Pharmacy programs. In practice, the project team was slightly different: one senior each from Manufacturing Engineering, Industrial Engineering and Management and Computer Engineering; two seniors from Electrical Engineering; one MBA student; one advisor from the DPharm program.

Project Operation: All students were registered into generic 'Engr' courses, rather than the regular departmental capstone courses. Our college has had a placeholder for interdisciplinary capstone projects for some time under an 'Engr' designation, and that mechanism was used for the undergraduate students. The graduate student was registered into an 'independent study', which was applied as an elective in his curriculum. The undergraduate courses were established at three credits per semester, the graduate courses at two credits.

Project operation followed a model familiar to engineering projects in industry. The author applied an operational methodology used during his employment in the late 1990's in the automobile parts industry. The fundamental structure clearly defined the students as the designers and developers; the professor's role was that of mentor and design guide. This was very definitely <u>not</u> a case where the students obtained their technical information from the professor.

The team met every Thursday afternoon, initially for three hours. During the first meeting, the tasking to be accomplished by each member of the team was identified, with particular attention to the interfacing between each person. The first assignment was the development of a work breakdown structure for the entire project. This task occupied two weeks, with the intervening weekly meeting devoted to an in-depth discussion with the sponsor to establish the required and desired functionalities for the product.

It was quickly discovered that routine meetings could be conducted more efficiently if scheduled for two hours. The format of the routine weekly meetings followed a common pattern: [1] each person reported on the tasking he or she had pursued during the previous week, citing accomplishments, difficulties, resources employed or still needed, and other significant matters; [2] the team discussed each individual report, with emphasis on the impacts of one tasking on the responsibilities of the others; [3] an assessment by the entire team of the resources needed for the next steps; [4] a clear tasking for each team member for the forthcoming week, recorded in writing by the team mentor.

The sponsoring company is located some 300 miles form the NDSU campus, requiring some innovation to achieve frequent communication. There were two face-to-face meetings with the sponsor -- in week 2 and at the very end. All other interaction was achieved through video-conferencing -- arranged and managed by the student team.

Product Design Phase: Planned activity for the Autumn semester was to complete the product design phase, creating designs for a product that could be made commercially available within the one-year time constraint (designated as 'Model 2') and specifications for the functionalities for an 'ideal' product to be evolved over time (designated as 'Model n').

The analysis began with a thorough examination of the needs and wants of the customer for functionalities to be realized in the workstation product. Means for achieving these functionalities were then researched, and the slate of potential functionalities expanded as the student team uncovered new applications of relevant technologies through their search. Choices were then made amongst potential functionalities and means on the basis of the time-to-market constraint -- if an attractive possibility could not be confidently projected to be incorporated into the workstation in time for a May 2010 product launch, it was assigned to the Model n listing of potential product improvements.

The subsequent steps in product design were carried out in the sequence portrayed in Figure 1. This is a well-worn path in product development, and the students developed strong skills in the methodology and mind set. The product was parsed into subsystems, both for clarity in work assignments and for simplicity of manufacture. It was anticipated from the start that product manufacture and assembly would rely heavily on subsystem delineation and kitting of parts. At virtually every step, the student designers encountered the necessity for making choices and developed experience in making the trade-offs between new and innovative applications of technology and the constraints of cost and time-to-market.

The work of product design indicated to the team that a prototype article would be highly beneficial, although not included in the original contract with the sponsor. Accordingly, a proposal was prepared and presented to the sponsor in early December. The proposal included design specifications, an evaluation plan, cost projections and a time line.

Competitions: During this project phase, an element that is not normally a part of the product development process was introduced. The student team, partnering with the private company sponsor, prepared the documentation necessary to enter various state and national competitions.

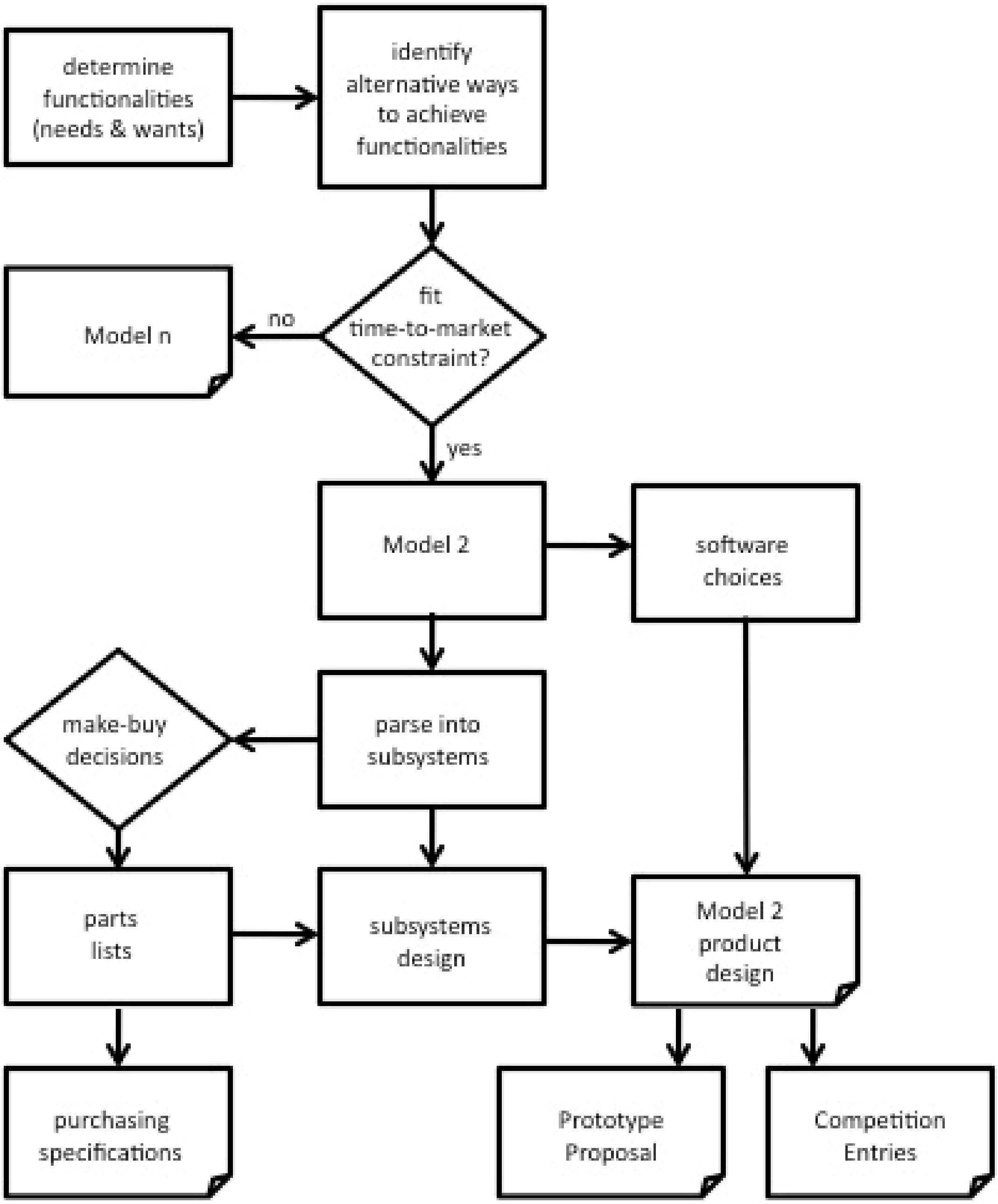

Figure 1: Product Design Phase of Innovation Team Project

InnovateND: The first competition selected was InnovateND, sponsored by the North Dakota Department of Commerce. The focus of this competition is encouragement for entrepreneurs who are interested in starting new enterprises within the state. In the 2009 competition, there were four rounds of presentation and competitive selection. Round 1 is a fairly straight-forward written proposal for a new product and new enterprise. The focus is on description of the product, its utility and its commercial potential. Round 2 is a more comprehensive proposal, elaborating on the product and presenting an outline of planning for commercial production. Round 3 adds the planning for a business enterprise. Round 4 includes both a written proposal and an oral presentation, emphasizing financial projections. The panel of judges is drawn from various sectors of the financial community, with heavy emphasis on angel investors, venture capitalists, and commercial bankers.

The Round 1 InnovateND entry for the telepharmacy workstation project was submitted in early November. The team was notified about six weeks later that their entry had been selected for Round 2. There were approximately one hundred entries in Round 1, and about 60 were selected for Round 2.

BMEidea: At about the same time frame, the team entered the national BMEidea competition, sponsored by the National Collegiate Innovators and Inventors Alliance, in collaboration with the Biomedical Engineering Society. This is a three-round competition, more strongly oriented to technological innovation. The first round is a sponsor's assessment of a short proposal for a product with biomedical applications. Round 2 is a more comprehensive proposal, and Round 3 includes both a refined written proposal and an oral presentation.

Projects selected for competition beyond Round 1 receive a small planning grant to be used for supporting the continuing work of the project. The telepharmacy team received this planning grant and the invitation to compete in Round 2 late in the project's product design phase.

Transition from Product Engineering to Production Engineering: Project activity during the Winter break was somewhat curtailed by the holiday season, but several noteworthy events occurred. Most importantly, the proposal for building a prototype workstation product was approved by the sponsor. This, in turn, led to the start of purchasing activity for OEM components, fabrication supplies and tooling. Facilities were located that provided a secure workspace for prototype assembly and test. Although fabrication work on the workstation enclosure could be completed in the open facilities of the NDSU Manufacturing Engineering Laboratory, the proprietary nature of the new product development required a more protected environment for assembly and test.

A personnel complication arose during the Winter break. The MBA and DPharm students withdrew. From their curricular perspective, both had been participating as an optional, elective activity, not needed for their degree objectives. The DPharm student, in particular, had been treating the project as an extracurricular volunteer activity, which could be set aside when other, more pressing matters arose. While neither defection was crippling, a shift in workload was necessary. This was modest and easily affected by the remaining team members.

Production System and Business Enterprise Design Phase: The objectives for Spring semester had now been expanded from two to three -- design of a production system for serial manufacture of the workstation products; design of a business enterprise for commercial exploitation of the product and factory designs; <u>and</u> fabrication and test of a prototype. The tasking proceeded in parallel.

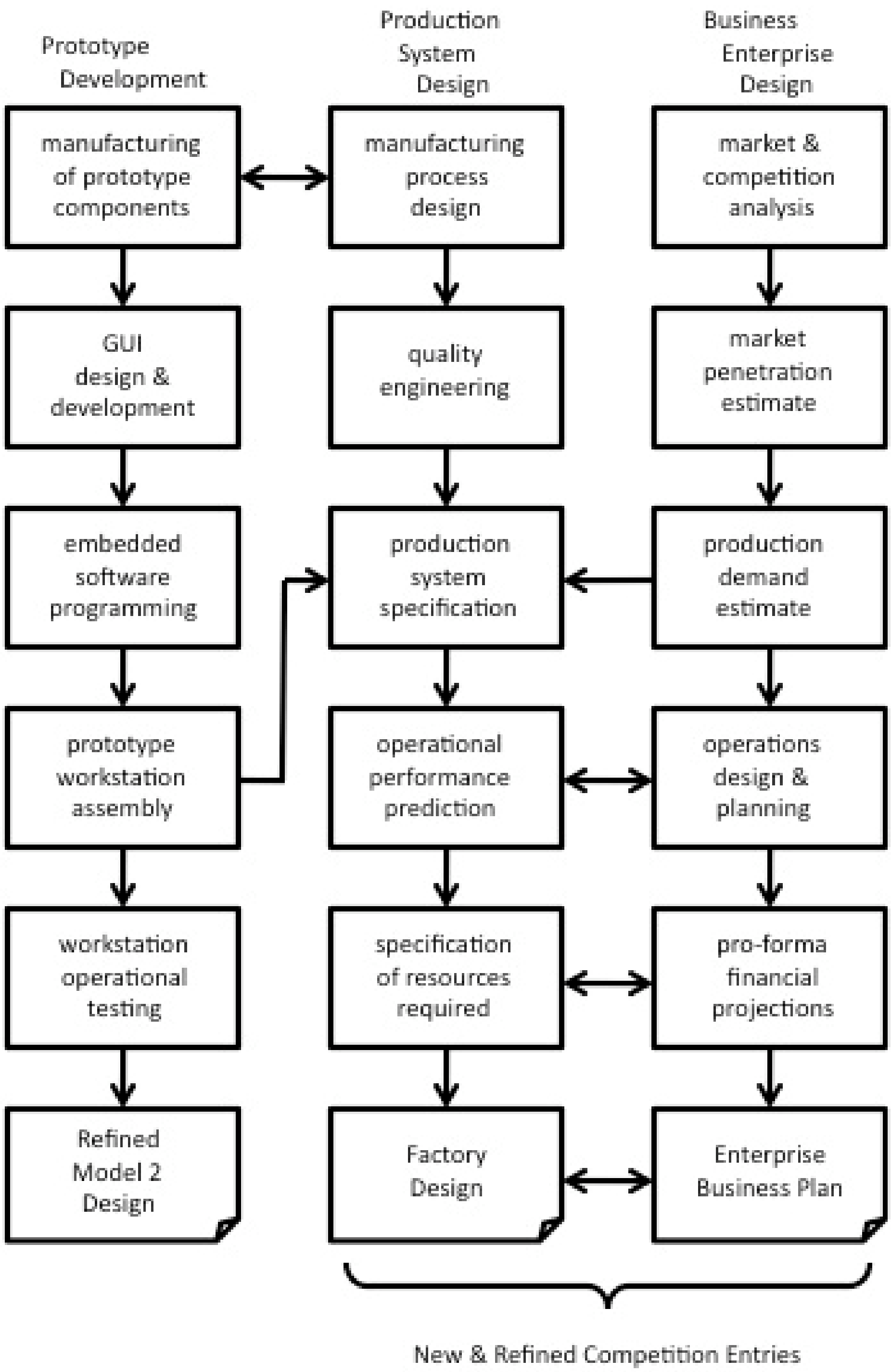

Figure 2: Production and Enterprise Design Phase of Innovation Team Project

Design of the production system followed methodology well-developed in the Manufacturing Engineering curricula. The student team member from that major led the effort to apply learning from prior coursework to this very real requirement. The same student led the productization work in prototype fabrication, again building on skill sets previously learned in coursework. The design of the business enterprise was led by the student from Industrial Engineering and Management, as that major contains a strong managerial learning component. As it turned out, this work required a more significant element of new learning, especially in the market analysis and financial planning. Unfortunately, both Electrical Engineering students dropped away from the project during the semester, citing imperatives from other coursework. This left the Computer Engineering student alone to fulfill both the software and hardware tasking for the prototype and completion of those tasks for product design.

The second phase of the project progressed through stages as depicted in Figure 2. As expected, significant interactions amongst the major tasking threads occurred virtually daily. The value of the subsystem organization for the product that had been introduced during initial product design became very apparent. With refinements that grew out of prototype development, the product was finally defined through six subsystems -- touchscreen; still camera; video camera; audio system; computer; enclosure. All except the enclosure included embedded software, written especially for this product. The utility of subsystem definition and the companion planning for use of kitting for assembly was evident throughout the design of both production system and business enterprise. This product philosophy also was of considerable value in assembling the prototype.

Competitions: During Spring semester, the competition aspect of the project continued to receive serious attention. The partnership between the student team and the sponsoring private company extended to two new entries, plus continuation of the previous opportunities.

<u>InnovateND</u>: A Round 2 proposal was submitted in early January, with more complete description of the product and production system and an outline of the business planning. In early March, the team was notified that its Round 2 entry had been selected for the next stage of competition. Thirty-four entries were invited to offer complete business plans for consideration. This provided further focus to the enterprise design effort and emphasized the interactions amongst the tasking threads (as depicted in Figure 2). The Round 3 entry was selected as one of twenty finalists, and the team (now three) traveled to Bismarck for oral presentations at the end of May. Unfortunately, the telepharmacy workstation entry was not selected for one of the cash prizes.

<u>BMEidea</u>: The Round 2 proposal was submitted on schedule, but was not selected for the semifinals of Round 3.

<u>Innovation</u> <u>Showcase</u>: This competition is sponsored by he American Society of Mechanical Engineers, and has a strong bent to technological innovation -- much like the BMEidea competition, but with a less strong bias towards biomedical products. The telepharmacy workstation product was proposed for this competition, but was not selected for a second round.

Manufacturing Challenge: This is a competition for student chapters of the Society of Manufacturing Engineers. The orientation is primarily towards the manufacture of products by student chapters, and thus, has only a minor orientation to technological innovation. SME Chapter S291 is hosted at NDSU, and it was a simple matter to blend the objectives of the student SME chapter and the telepharmacy innovation team. Permission was obtained from the sponsor to use the enclosure for the workstation product in this competition. The Manufacturing Challenge competition consists of a written proposal, a poster display and an oral presentation -- the latter two delivered in person in Los Angeles. The NDSU student chapter secured sponsorship from local companies, and a two-student team traveled to Los Angeles at the end of March. Again, the team returned without a prize.[1]

Results: There were six distinct outcomes from this project:
[1] a working prototype: The sponsor received a working model of a Model 2 telepharmacy workstation. Prototype performance was evaluated by means of remote communication to two of the research sites employed by the College of Pharmacy, This prototype provided substantially improved insights into the operational characteristics of such systems, as well as immensely valuable perspectives on commercial viability.

Figure 3: Prototype Telepharmacy Workstation

[1] It should be noted that this competition took place during the same time period as a record-breaking flood in our region. All preparations for the competition and the actual travel took place while the university was closed for the weather emergency and the community was fighting to save itself from the forces of nature.

[2] complete product specifications: The delivered prototype included fully developed design drawings (in Solid Works), detailed purchasing specifications and an workstation operator's manual.

[3] complete production system design: Production system design is defined by specification of all processes used in manufacture and assembly, capital equipment specifications, manufacturing work instructions, facility design, production staffing plan and performance estimates for throughput, inventories (raw stock, work-in-progress, finished goods) and operating costs.

[4] complete business enterprise design: The business entity was designed as a subsidiary of the sponsoring company. The design included a market model, a marketing plan (with estimated market penetration rates), a production plan, a corporate staffing plan, and financial projections. The financial planning included three-year pro-forma projections for operating statements, cash flow statements and balance sheets, plus a capitalization plan

[5] documentation: All of the work is reported in comprehensive documents reflecting product, production system and business enterprise design, as well as the prototyping experience (fabrication and performance evaluation).

[6] student learning: The central issue throughout the project was student learning. From the perspective of the capstone experience, the purpose of the project was always focused on expansion and development of student skill sets and attitudes. By far, the most important outcome has been that the three surviving engineering students are 'scarred for life' with intellectual habits of innovation and entrepreneurialism.

Assessment: There are several measures through which to assess the accomplishments of this project. First, the suitability of innovation team projects as capstone experiences must be examined. If one looks at the project through the prism of the ABET general criteria, it will be observed that all eleven of the criteria have been addressed. A parallel and entirely compatible assessment results when the program criteria are examined. The project documentation doubles as 'display of student work' required for accreditation evaluation.

For the students who completed the project, the commonly-used mechanism of 'course substitution' provided that they received full credit within their academic majors for the capstone/senior design requirement, and all fulfilled their graduation requirements on time.

The undergraduate students who dropped out quite obviously did not complete a crucial graduation requirement and did not receive their bachelor's degree as all concerned had originally expected. Further, their course grade reflects that they did not finish. As both are in a different academic department than the project mentor, the procedure for directing them through to degree completion is not directly known.

The graduate students who faded away fared slightly differently. In that this was an elective course, not required for their respective degrees, they were simply withdrawn, and no official record of their original intent remains in the Registrar's records. Their only penalty is a zero return on their tuition investment.

ABET Criteria	Project Components
a. apply math, science & engineering	product design; process design
b. design & conduct experiments	prototype evaluation
c. design systems, components or processes	product design, process design, production system design, enterprise design
d. function in multi-disciplinary teams	project operation
e. identify, formulate & solve engineering problems	product design, production system design, prototype fabrication
f. understand professional ethical responsibility	project context
g. communicate effectively	documentation, competitions, video conferencing
h. understand interactions of engineering & society	project context
i. ability for life-long learning	entrepreneurial habits of mind
j. knowledge of contemporary issues	project context
k. use techniques, skills & tools of modern engineering	product design, production system design, prototype fabrication & evaluation

Figure 4: Matching ABET General Criteria with Innovation Team Project

Further, it is necessary to understand how such projects can be identified and actualized. It is obvious that the faculty who direct such projects must have well-developed and active communication with the broader community. It is usual to identify this characteristic as 'contact with industry'. Simple contact with various industrial concerns is not, however, quite adequate for the purposes illustrated herein. The 'contact' must be broadly based to encompass the loose community of innovators within the school's constituency. This particular opportunity arose because the professor involved … [1] had been active in the local entrepreneur's networking group (the 5:01 Society); [2] had previously mentored student projects that had [a] resulted in patent applications and [b] created a prototype of a new machine for assembly of advanced microsensors; [3] had been mentoring another multi-disciplinary innovation team for two years. This is addition to frequent and broad 'contact' with a variety of industrial firms.

Finally, the value of the designs that emerged from this capstone (a.k.a. senior design) experience can be evaluated. The objectives of the project, as modified in progress, were

[1] design of a purpose-built workstation for telepharmacy operations.

[1a] fabrication and evaluation of a prototype workstation product.

[2] design of a production system capable of effective and efficient serial manufacture of workstation products.

[3] design of a business enterprise capable of commercial marketing and distribution of workstation products.

The ultimate assessment of project outcome is satisfaction of the customer. From that perspective, the project objectives were completely fulfilled. The eventual utilization of the designs (product, production system, enterprise) completed by the student innovation team, quite obviously, rests with the sponsor. The private company that provided the funding for the project was the customer, and the designs (as well as the prototype workstation) belong to the sponsor cum customer.

Project Objectives	Performance
1. product design	complete Model 2 design Model 2 prototype revisions to Model 2 design Model n functionality specifications
2. production system design	complete production system design factory design estimated factory operational performance (throughput, inventory levels, operating costs)
3. business enterprise design	quantitative market analysis complete enterprise design (market penetration, staffing, purchasing, facilities, distribution) business plan (capitalization, pro-forma financial projections)

Figure 5: Matching Project Objectives with Project Performance

The innovation team presented a set of designs that they believe are commercially viable, and all three members of the final team roster offered to take the opportunity of building this new enterprise as their first career placement after graduation. As of the time of this writing, the customer has not made a decision on proceeding further, in part due to uncertainties in the capital markets. The business plan includes a requirement for an initial capital infusion of some significance to a small business.

Conclusion: There will certainly be other means for incorporating an entrepreneurial component with the undergraduate engineering capstone experience. The model described herein used a partnership with a small private company for development of a product that the private firm had visualized. As such, the invention component of this project was somewhat differently addressed than it might be in other circumstances. Nonetheless, it is believed that relevant conclusions can be drawn about the viability of adding an innovative and entrepreneurial element to a common undergraduate practice. The overall conclusion extracted from this experience is that combining the undergraduate capstone with an innovation/entrepreneurship project …

[1] is quite possible;
[2] is entirely consistent with all ABET outcomes;
[3] adds value to undergraduate education;
[4] holds prospects for excellent collaborations with external partners;
[5] offers potential for launch of new products, processes and/or enterprises.

[6] can be valuable in local economic development.

A recommendation has been offered to the engineering departments within NDSU's College of Engineering and Architecture that incorporating innovation and entrepreneurship with capstone is not only possible but highly desirable and should be pursued as broadly as possible. Decision-making on such a recommendation in a university environment must, of course, proceed with due deliberation. In the interim, the author will be seeking further opportunities to mentor similar projects in the near future.

Lessons Learned: Notwithstanding the overall positive results of this project, there were several bumps in the road from which important lessons can be drawn.

[1] The preparation of senior engineering students in market analysis and financial planning is inadequate for the design of a business enterprise. While the background of Manufacturing Engineering students is adequate for interpreting market demand in terms of design of a production system to meet those demands, the skill sets for estimating market size and devising a plausible penetration strategy are not as well-developed as is needed in this application. On the other hand, skill sets drawn from prior coursework in this major are quite adequate for providing estimates for throughput, operational inventory levels and the time elements proportional to operating costs. However, neither this major nor Industrial Engineering and Management provide skill sets for translation of these factors into pro-forma financial projections. The somewhat ad hoc instruction provided during the telepharmacy project will be replaced with purposeful instructional modules in future projects of this sort.

[2] Project participants must be selected with some care. This type of a project requires team members who are prepared to function as independent, self-motivated engineers, and it appears that this is not a universal trait, even amongst senior students. Observation suggests that because this is not a 'regular' course, the less mature students see the project more as an extracurricular activity and open to participation on a voluntary, as-time-permits basis. Such behavior is antithetical to productive teaming and cannot be permitted. This is a difficult challenge for the faculty mentor and is expected to remain a work-in-progress for at least another year's worth of experience in similar projects.

[3] Participation of non-engineering/science students has been disappointing. This observation is combined with those from experience with another innovation team that has included students from engineering, bio-science and business majors. In particular, business students in these experiences tend to treat the 'business' aspects of the project as totally independent of the technological elements. This leads to considerable mismatch in both observation and interpretation within the student team. In the next product realization project, the author intends to employ students from Industrial Engineering and Management, with suitable additional instruction, as enterprise designers.

[4] Special facilities for such projects are needed. When a team is working with products that are intended to have commercial value, it is important to keep the physical articles shielded from the casual passer-by. The openness of typical university laboratories provides for too little proprietary security. Application of nondisclosure agreements with all of the students is

effective, but secure physical facilities are still required. No problems of this sort were encountered in the telepharmacy project, because a corner of a not-yet-occupied lab was made available. However, this is a temporary solution, and better arrangements are necessary.

[5] The competitions selected for the telepharmacy project were not a good fit. The project was too technological for two of the competitions (InnovateND and Manufacturing Challenge) and not scientifically advanced enough for the other two (BMEidea and Innovation Showcase). Nonetheless, the experience for the students was of enormous value, and entry into selected entrepreneurial competitions will continue to be included in future projects of this sort.

[6] As discussed above, the background, orientation and attitudes of the supervising faculty are critical factors in attracting, framing and leading entrepreneurial capstone projects. The most important issue is that the faculty be, themselves, innovative and entrepreneurial, open to and actively seeking new ways of accomplishing established goals.

[7] Departmental and professorial cultures are also influential factors. Many professors, while espousing 'contact with industry', have never actually worked in any environment but the traditionally and heavily silo-ed academy. Such faculty and their departmental units are unfamiliar with the trade-offs necessary in product realization and tend to focus on curricular topics as entirely defining their engineering discipline. In this environment, it has been difficult to recruit students from other departments, to recruit faculty with other specialties into mentorship and to gain organizational approval for crediting product realization projects as fulfilling the capstone academic requirement.

Acknowledgements: The author is indebted to the three students who brought the telepharmacy project to a successful conclusion: Jennfier Soydara (BS, Industrial Engineering and Management, 2009) emerged as the team leader and is mostly responsible for the careful documentation; Kinsey Wallgren (BS, Manufacturing Engineering, 2009) proved to be the ultimate in resourcefulness and insured that what needed to get done got done; Aaron Axvig (BS, Computer Engineering, 2009) displayed outstanding creativity in extending his prior knowledge to innovative software design and codewriting in this project. The opportunity to work with these fine young people represents the pinnacle of the professorial profession.

Successful completion of the project also depended upon three private companies who provided financial and in-kind sponsorship: Custom Data (Dickinson, North Dakota) as the primary sponsor; Amity Technology (Fargo, North Dakota) who provided access to state-of-the-art laser cutting and powder coating machinery and offered excellent processing advice; Remmele Engineering (Brighton, Minnesota) who supported the Manufacturing Challenge competition entry.

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