

## **Getting Real: The Challenges of Using Written Products of Undergraduate Research to Achieve Multiple Educational Goals**

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### **I. Introduction**

This paper explores the frontiers of an interesting problem that is highlighted by the Engineering Criteria 2000 (EC 2000)—the need to make the written deliverables produced through undergraduate research serve multiple purposes in demonstrating that a “major design experience” has achieved a wide range of intended goals. The University of Virginia’s engineering school has both an undergraduate thesis that has been required of every student since the early 1900s and an established Systems Engineering capstone project that has been in place since 1988. Both projects treat constraints in areas such as economics, the environment, ethics, politics, sustainability, and social considerations as integral parts of engineering problem solving and decision-making. In so doing, they anticipated and reflect the integrated approach of EC 2000.

Most students who major in Systems Engineering (SE) use their capstone project as the basis for the undergraduate thesis, which is jointly advised and must be jointly approved by a faculty member from the humanities and social sciences (HSS) and the student’s capstone group advisor. Because the students must communicate and document their undergraduate thesis research in a way that satisfies both experts in their fields and non-experts, they face a task that is demanding but also quite effective in preparing them to communicate with the range of audiences they must satisfy in the world of practice. (The Systems Engineering students have a separate set of capstone deliverables that include a final group report.) Because the major thesis-related documents (proposal and final report) are bound, collected, and retained as part of our university library’s collection, they have the potential to function as a useful source of evidence that a wide range of the educational goals of our curriculum are being achieved.

Differences in the expectations, pedagogical objectives, and professional cultures of the HSS and technical advisors often become most visible as the advisors and students work together to shape the written proposal created early in the project and the final technical report that is produced at the project’s conclusion. For example, there is an apparent conflict between the HSS pedagogical objective of having students improve their communication skills through individual written and oral assignments and Systems Engineering’s and ABET’s emphasis on team work. The undergraduate thesis project has traditionally emphasized individual thought processes and independent thinking where a capstone project stresses effective group interaction, problem solving, and synthesis. A capstone project features a high level of interaction with a client

outside of a university setting, where an undergraduate thesis traditionally has tended to minimize client interaction and to take a university laboratory or library as its primary setting. A well-written thesis requires a clear focus, and so does a successful capstone project, but in the former case the students create an individual focus, whereas in the latter, they have to evolve a focus with a team and a client.

To some extent, these conflicts can be interpreted as manifestations of differences between what C. P. Snow called the “two cultures,” the humanistic on the one hand and the technical on the other.<sup>1</sup> (It is worth noting that Snow himself used “literary intellectuals” and “scientists” as labels for these two cultures.) Although our experience has convinced us that there are significant differences in professional cultures involved, one of our primary aims is to avoid easy kinds of compartmentalization,<sup>2</sup> especially those that highlight differences without resolving them. The apparent conflicts also accentuate the distinction between an approach that emphasizes contributions to knowledge (the undergraduate thesis) and an approach that focuses on solving a particular problem and producing a practical result (the capstone project). Both approaches aim at making a contribution to society, but they presuppose differences in the nature and context of that contribution.

We cannot pretend to have resolved all these conflicts, but we have gotten to know the problem well and have come to believe in the value of having to articulate and defend the tacit assumptions guiding our work. In seeking to meet competing demands, we are in a sense replicating the “real world” situation we seek to create for our students through the major design experience. This paper delineates the complexity of that situation and describes the process by which we have attempted to transform the somewhat individualized objectives of the capstone project and undergraduate thesis into a set of broad, common objectives for which the faculty involved take varying amounts of responsibility. We also offer some specific suggestions for using a single undergraduate research experience to integrate the liberal education goals implicit in EC 2000<sup>3,4</sup> and the technical goals explicit in EC 2000 as implemented in a specific engineering curriculum. We begin by describing the basic approach we have used in integrating the two projects and by outlining the objectives for the major design experience that we have worked together to develop.

## II. Basic Approach and Objectives

Our most important assumption is that our experience with the undergraduate thesis project and the capabilities of our TCC faculty put us in a good position to do something distinctive and valuable in providing an integrated major design experience for our students. It is important to note, however, that the basic approach we describe does not require that each student write an undergraduate thesis. Our approach does require that each student produce some independent written deliverables and that technical and HSS faculty collaborate in shaping and guiding projects.

## Basic Approach

Four key features define our approach.

1. Achieving efficiency and depth of learning by using a single major design experience as the basis for both a team project and an individual thesis
2. Producing multiple deliverables from a single body of research and experience
3. Requiring each thesis to be independently written and presented orally
4. Requiring each thesis to take an independent and distinct approach to some aspect of the team project using one of the following approaches in which the thesis reports and **reflects on**
  - a particular task within the group for which the student was primarily responsible
  - a particular aspect of the work to which the whole team contributed but which is analytically distinct
  - the process that the group followed or its product
  - an issue that is tangential to the team project, typically using the team project as a case study in that issue

The words “reflects on” in item #4 emphasize the central role that individual reflection plays in achieving the HSS goals of the major design experience. The students need not only to produce and report but also to think critically and independently about their experience.

## Objectives for the Major Design Experience

The objectives we seek to achieve through the major design experience build on the ABET requirements that pertain to major design experiences but go beyond those to define objectives that grow out of our particular mission as an engineering school. We do not expect the major design experience to carry the full burden of achieving all of these goals but rather that it will contribute significantly to achieving all of them.

## ABET Requirements

These are drawn directly from EC2000 documentation. The phrases in *italics* denote objectives that are consistent with but not explicitly mentioned in EC2000 and that reflect our ability to achieve integration and add value in distinctive ways. To meet these requirements, any particular design project must be conceived as a case study in the wide range of technical and non-technical competencies the list encompasses.

- prepare students for engineering practice
- draw together earlier coursework and knowledge

- incorporate engineering standards
- incorporate realistic constraints, including most of the following
  - \*economic
  - \*environmental
  - \*sustainability
  - \*manufacturability
  - \*ethical
  - \*health and safety
  - \*social
  - \*political
- demonstrate the abilities to
  - \*function on multi-disciplinary teams
  - \*communicate effectively *with both expert and non-expert audiences*
  - \*identify, formulate, and solve engineering problems *and think critically about the process of problem definition*
  - \*design a system, component, or process to meet desired needs
  - \*understand the impact of engineering solutions in a global and social context *and use that understanding in the formulation of engineering problems, solutions, and designs*
  - \*understand professional and ethical responsibility *as it applies to particular engineering projects*

#### Other Objectives Growing Out of Our Particular Mission

- demonstrate the ability to **function effectively in both group and individual contexts** by having students
  - \*produce both a group report and an individual thesis
  - \*immerse themselves in group interaction, problem solving and synthesis while also exploring the value of individual thought processes, independent thinking and reflection, and individual writing and speaking
  - \*formally compare the two experiences
- demonstrate the ability to **treat ethical and professional ideals as creative and enabling** factors in addition to recognizing them as legitimate constraints
- demonstrate the ability to **see the ways that aspects of cultural context** (i.e., shared values, changes in widely held beliefs, or changes in political or economic structure) **provide an impetus** to technological development and **serve as a resource** for engineering designers
  - \*as they define new directions for technological development
  - \*as they attempt to persuade others of the value of new ideas

### III. Historical and Institutional Background

Our motivation for attempting to accomplish multiple educational objectives through a single undergraduate research experience grew out of a number of positive features of our situation. We had two established and successful “capstone” experiences, one a group project organized by a technical department (Systems Engineering/SE), the other an individual thesis project required of all students by the School of Engineering & Applied Science (SEAS) and administered by the SEAS humanities and social science faculty (Technology, Culture, and Communication/TCC). As mentioned earlier, both experiences emphasize the integrated, comprehensive approach favored by ABET as reflected in EC 2000. The similarities suggest opportunities for maximizing student learning and overall efficiency by using written products of undergraduate research to achieve and document the achievement of multiple educational objectives. Moreover, the two groups of faculty have a history of successful collaboration at the graduate level<sup>2</sup> and had worked together from the beginning to design the capstone project to be compatible with the undergraduate thesis project.

There were some complications, however. For example, although the two faculties loosely coordinated their efforts, there was no clear, formalized understanding of the relationship between the two projects. More significantly, while the educational objectives of SE and TCC are similar and compatible in many ways, they are not identical. Differences in the expectations, pedagogical objectives, and professional cultures of the TCC and SE faculty often become most visible in the written documents that students are required to produce throughout the two semesters each project occupies. The key question we have had to address, then, is: how to build on the existing common ground and deal with the differences in the most constructive way?

#### The Undergraduate Thesis Project

The SEAS undergraduate thesis project has been a school-wide graduation requirement since the early 1900s. For most of the early history of the project, all theses were read and approved by the dean. As the numbers of students grew, the school developed a separate HSS faculty (now called the Division of Technology, Culture, and Communication/TCC) who manage the undergraduate thesis project for the school. From its inception, the undergraduate thesis has been conceived as a “capstone” project in the sense of drawing together all the threads of a student’s undergraduate education. It is also rooted in the tradition of proving one’s fitness for graduation by demonstrating both subject matter competence and the ability to express oneself effectively in writing. In surveys of graduates conducted by SEAS, graduates have identified the undergraduate thesis project as the most valuable single educational experience they have at SEAS. The undergraduate thesis requires students to produce two major individually written products—a proposal and a technical report (thesis), with ethical and social impacts integrated into the proposal and also reflected, though to a lesser extent, in the technical report.<sup>5</sup>

Thus, in addition to providing students with the occasion to demonstrate their technical competence and ability to communicate, the undergraduate thesis is also designed to serve as a case study in a range of HSS issues. For example, the introduction and review of literature in the

proposal require the student to locate the problem the project seeks to address and the knowledge that will be used to address it in an historical context. The impact assessment that is included in the proposal requires students to look more deeply into the values underlying the project and to speculate about a whole range of issues that will arise during implementation and long-range management of project results, including human factors (cognitive and emotional), regulatory and legal issues, environmental factors, and ethical dimensions. The proposal requires students to think in terms of engineering as social experimentation.<sup>6</sup> In other words, they are asked to think of the introduction of any new technology and their project in particular as an experiment on a social scale that is characterized by a certain element of risk and uncertainty. The proposal also requires the students to use moral imagination both to critique their own mental models and to appreciate the perspectives of a variety of stakeholders who may view the project quite differently than the experimenters and to anticipate potential risks and negative impacts.<sup>7</sup>

All undergraduate theses are written for a combined readership of expert and non-expert audiences. The student must provide the detail and precision necessary to satisfy an expert audience and provide the context, motivation, and other background that will make the project intelligible and persuasive to a non-expert audience. Writing for non-expert audiences requires students to articulate assumptions, values, and other dimensions of the project's broader context that might go unarticulated in an expert context. Content and the ability to communicate it effectively in writing and in speaking are treated as theoretically distinct but practically inseparable aspects of quality.

To achieve all these goals, each student requires two advisors, a TCC advisor who is the student's instructor for the two semester-long courses in which the project is undertaken and a technical advisor who is usually from the student's major and whose involvement will be more or less intense depending on a range of factors including how closely related the project is to the technical advisor's research.

### The Systems Engineering Capstone Project

The Systems Engineering capstone project has been required of all SE students since 1988. It was explicitly designed as a "capstone" experience to meet both the department's own sense of what its students needed and the engineering education community's sense that a major design experience was an essential culmination to a student's education.<sup>8,9,10</sup> Shortly after its inception, the SE capstone project received one of only four innovation awards given by ABET. The project has been well received by students and has enjoyed growing participation of industrial sponsors. In terms of written products, the capstone project requires students to produce individual monthly progress reports and a group report at the end of each semester.

The capstone project emphasizes real design problems and working with real clients in a client's setting as opposed to a university setting. It is organized so that the students participate in the specifications setting process with the client rather than beginning once the specifications have been established. The project has three key objectives:<sup>11</sup>

1. To combine the elements of systems engineering and practice
2. To conduct design and experimental work such as that expected by practicing systems engineers
3. To give the students a hands-on experience on a real systems design problem

Like most major design experiences, the capstone project emphasizes teamwork. But it also has several features that distinguishing it from many other senior engineering projects. For example, it is client centric rather than technology centric. In other words, it focuses on meeting a client's need rather than on exploring or demonstrating the usefulness of a particular technology. It also treats modeling as an art to be cultivated through experience and thoughtful, often creative, application of fundamental principles. Its comprehensive scope includes economic, social, ethical, aesthetic and economic impacts in addition to considerations of feasibility, reliability, and maintainability.

A project from the 1999-2000 school year illustrates these principles. Pacific-Sierra Research Corporation of Veridian, Incorporated of Arlington, Virginia, hired the SE department to help develop a messaging system for verification of the Comprehensive Nuclear Test Ban Treaty. Four undergraduates (John Green, Brian Hashemi, Robert Rauschenberg, and Christopher Stacy) worked with two faculty members (Donald Brown and Stephanie Guerlain) and a client advisor (L. Roger Mason) on the project. They analyzed the current system for treaty verification, set objectives for improving it (e.g., reducing the time needed to send messages related to verification), designed a new system, and tested a prototype. Out of this project came an in-depth report to the client (86 pages), a journal article (co-authored by the students, the faculty advisors, and the client advisor), an oral presentation on the project to a capstone conference, and individual senior theses. In doing these tasks, the students had to master political, scientific, and technical aspects of treaty verification, analyze areas of potential improvement, develop a new system, test it, and convey their findings to faculty, clients, students, and other researchers in the field. They did these tasks orally and on paper, as a group and individually.

#### IV. Areas of Commonality: Respects in Which the Aims of the Two Projects Move in the Same Direction and Reinforce Each Other

##### Practical Factors

Most of the practical factors arise from the organizational arrangements in which we find ourselves and are the result of the fact that the capstone project was designed from the outset to be as compatible as possible with the undergraduate thesis. For example, both the undergraduate thesis and the capstone project are scheduled at the same point in the curriculum and over the same time span (i.e., two semesters in the senior year). Both are required of all students and require

students to produce written reports. Both require a technical advisor who is a faculty member and are set up so that the same technical advisor can advise both projects.

### Philosophical Factors

The philosophical factors are rooted in the basic beliefs, assumptions, goals, and values that are shared by both groups of faculty. For example, both projects are designed to help students focus, synthesize, and apply the knowledge and skills they have gained throughout their undergraduate curricula. Perhaps most importantly, both require students to meet a “**real**” need and to locate the project in a real-world context beyond the laboratory or library, i.e., both are very concerned with the wide range of technical and non-technical factors involved in the world of engineering practice. For the SE faculty, the key aspect of “realness” is dealing with an actual client to whom students are accountable in the client’s setting, with all the messiness and unpredictability that implies. For the TCC faculty, the key aspect of “realness” takes the form of clearly identified users of the project’s final product who lie beyond the community of other experts in the technical field of the thesis. (Both ways of defining realness distinguish the projects from typical course-related laboratory experiences in which students replicate work done by others not for the value of the final product but rather for educational value alone.)

Another important intellectual commonality is that both projects seek to avoid the compartmentalization that often characterizes technical work and emphasize the integrative and heterogeneous nature of large engineering systems. Similarly, both come out of an intellectual orientation that appreciates complexity and values multiple perspectives while at the same time providing ways of managing complexity and making reasoned decisions among alternatives. While both recognize that locating the project in the real world makes it more difficult to define and solve problems, they also see the real world context of practice as both exciting and worthwhile. Both also emphasize problem formulation as a crucial part of the intellectual work of engineering and recognize that engineers shape the world as much by formulating problems as by helping to solve them. Finally, both are rooted in the belief that the abilities to comprehend and manage the complexity of real world situations are essential for success in engineering large scale systems

### V. Areas of Divergence and Sources of Tension

#### Practical Factors

Several sources of tension arise from tendencies in student behavior. There is, for example, a tendency for students to take a “two-parent” approach that emphasizes conflicting requirements between the two advisors in order to avoid facing the problems that are inherent in the projects they have undertaken. Students also tend to want to minimize the work they have to do by expecting the requirements of both advisors to be exactly the same.



Most sources of tension in the category of practical factors arise from the sheer numbers of students who must be guided through the undergraduate thesis project. This means that the policies and organizational structure TCC uses for the thesis project must be geared to maintaining reasonable quality and meeting degree requirement deadlines for roughly 400 students a year (the entire SEAS graduating class). TCC faculty must also have a system for organizing the thesis that works for all departments in SEAS, not just SE.

Another factor is the client driven nature of SE capstone projects, which brings pedagogical advantages for the students but also introduces unpredictability that makes deadlines difficult to meet and may also create pressure to value the creation of a usable final product over the educational experience of the students. Handled properly, this tension can be converted into an educational advantage in the sense that the thesis' emphasis on individual educational experience counterbalances the client emphasis of the capstone project.

Another practical difference and potential source of tension is the difference in the size of groups with which faculty work—3-8 students per group for SE faculty, 25-30 students per class and often 50-60 students total per semester for TCC faculty. Methods for evaluating, scheduling and monitoring student work that are perfectly adequate for small groups may not be workable for large classes.

One rather infrequent but potentially quite significant source of tension arises when a student chooses to focus the thesis on an aspect of the capstone topic that does not contribute directly to the capstone group's final product. Although the student effort devoted to the independent thesis typically results in greater learning or intellectual satisfaction for the student, the quality of the capstone final product may be diminished and the effort devoted to the independent thesis may be viewed as having been "diverted" from the capstone project.

Tensions also arise in the grading and evaluation of the undergraduate thesis and capstone project. The grade for the undergraduate thesis is based on the evaluations of both advisors (SE and TCC), whereas the SE advisor alone assigns the Capstone project grade. The students tend to view their work holistically and to assume that both advisors should give the same grade on both the capstone and thesis deliverables, usually also assuming that the technical advisor's grade should take precedence.

### Philosophical Factors

The philosophical points of divergence typically are revealed as conflicts between objectives or values that are usually conceived as being in some kind of competition or antithetical relationship to each other. For example, the HSS pedagogical objective of having students improve their communication skills through individual written and oral performance is in some ways in tension with SE's emphasis on teamwork. Similarly, the value HSS places on individual intellectual analysis and the development of an individual author's "voice" is also in tension with the value SE places on teamwork and group thought processes.

SE's deep philosophical commitment to thorough exploration of the problem at hand and the value of "messy" client interaction often means that students do not define the final scope and objective of their projects until the end of the first semester. TCC's need to keep large numbers of students moving on schedule through a new and complex experience dictates that the undergraduate thesis project proposal be due a little more than halfway through the first semester to allow for evaluation, adjustments if necessary, and final approval before the semester ends. Still, it is important to remember that this early proposal deadline actually helps the capstone students get moving on a literature review. It forces them to understand the problem their client faces—in terms of the industry, in terms of ethical issues, in terms of new technologies—and involves studying the client's company in detail. The early proposal deadline thus serves pedagogical purposes in addition to practical ones.

The speculative nature of impact assessment is also potentially in tension with the capstone group's need to maintain credibility with clients. From the HSS point of view, the analysis that goes into impact assessment is one of the key intellectual elements of the thesis, the area that most requires moral imagination so that they go beyond the intended and positive impacts of the project to also envision the unintended and potentially negative impacts. Impact analysis and tracing the project's history also require students to make what seem like very remote connections. In any case, this kind of analysis goes beyond what can be proved and what is obvious. From an intellectual point of view, the fact that the analysis covers this kind of territory is its most important value. In addition, a good impact statement should make the proposal more credible. On the other hand, this kind of speculative thinking may not be conducive to maintaining credibility with clients. Again, handled appropriately, the kind of outscoping that the proposal requires can support the capstone group's efforts to go beyond the client's conception of the problem to a broader consideration of possibilities, constraints, and alternatives. It is also important to note that clients cannot afford to ignore any ethical issues that may be discovered through impact analysis.<sup>12</sup>

## VI. Insights, Recommendations, and Unresolved Issues

### Insights

Our first and most important insight is that it is better to focus on achieving multiple objectives through a single research experience, rather than attempting to make a single document carry the burden of too many purposes. In other words, it is important to balance achieving multiple objectives in a single written product with creating multiple written products each of which has a somewhat distinct purpose. Having a range of written products and some that are written separately for the thesis versus the capstone can be a good thing! In our particular situation, it seems that the greatest economies come from having students use the same body of expertise, research, and design work as the subject for multiple analyses and documents rather than having the documents themselves carry the burdens of too many purposes.

Our second insight is that many of the most important HSS objectives cannot be achieved through group work alone. For example, we cannot be certain that students have learned to communicate effectively or to think critically unless we see what they can do independently. To recognize the value of individual work is not to undermine the value of group work; it is, rather, to recognize the distinctive contributions of both. Coordinating group projects and reports and individual papers can also be done in a single class, or even part of a class. For example, in an Invention and Design class at the University of Virginia, students work together in groups to produce draft patent applications, and they do individual reflection papers in which they look closely at their group and individual problem-solving processes. The goal of the individual reflection paper is to prepare students for the next group project by getting them to analyze the way they tackle problems, looking for possible improvements.

A third and related insight is that the best approach is to think of the thesis assignments as adding value to the capstone and vice-versa. For example, doing a thorough proposal and literature review makes the capstone group ready to outscope the client's problem. Doing an individual thesis makes each member of the capstone team own the project or at least a part of it and also ensures that they will gain personal, individual educational benefit. The capstone report, in contrast, focuses more on client benefits and is group written.

Our fourth insight concerns the value of having to articulate and defend the tacit assumptions guiding our work and of having to be explicit about and get a critical perspective on the mental models we are using. This is linked to the value of experiencing the kinds of conflict that often emerge in interdisciplinary collaborations. One key to managing this kind of conflict is to cultivate flexibility and open communication, which are essential for resolving differences and, where they cannot be resolved, turning them into creative tensions.

A fifth and final insight is that the "two-cultures" framework is both useful and misleading in coming to terms with the challenges of using written products of undergraduate research to achieve multiple educational objectives. It is useful because it highlights the ways in which differences in goals, assumptions, and the organizational contexts to which we are accustomed can lead to differences in our expectations for student research and the writing that results from it. The "two cultures" framework is misleading in the sense that it grows out of a presumption that one of the two cultures is somehow superior to the other and should take precedence over it. In its original context, the two cultures argument was an argument about whether scientific culture or literary culture could do more to improve the lot of humankind.<sup>13</sup> From the integrated, non-compartmentalized perspective that all of the faculty involved in this collaboration share, it seems counterproductive to frame our situation this way.

## Recommendations

1. Distinguish between tensions arising from practical factors and those arising from philosophical differences. This makes it easier to see what is at stake in the differences and to evaluate how important they are and how they might be resolved.

2. Deal with the tension between teamwork and individual performance by distinguishing between individual writing on the one hand versus independent technical work on the other. Most pedagogical goals of TCC can be met through individual writing without individual technical work; however, some pedagogical goals of TCC can only be met through a certain amount of individual reflection on each student's part. In those cases, the value of reflection about client needs or wants should be emphasized.
3. Emphasize to students that the evolution of problems over time is a common phenomenon in all fields of engineering. Defining the problem and what should be done about it is at least as important an intellectual task as executing the solution, but it is a process that students must pursue actively (get on with it and expect change!). It is useful for all students, including those not in SE, to understand the evolutionary nature and intellectual significance of problem definition as a part of all engineering work.
4. Emphasize to students that it is very common for a single project or body of work to be written up in different ways for different purposes and audiences. In other words, packaging the products of research in multiple ways is not only often a practical necessity but also a good way of fully realizing the value, usefulness, and implications of the work that has been done.
5. Be sure that the mutually reinforcing nature of the various "packagings" gets at least as much emphasis as the differences between them. This involves helping the students see the ways that various write-ups of a single body of work can build on each other and contribute to the student's growing understanding of the subject at hand.
6. Urge students to pursue the best solution to the problem regardless of client pressure and preferences. The two advisors can serve as an important counterbalance to each other.
7. Make the relationships between the two projects as explicit and mutually supportive as possible without either minimizing the differences or collapsing them into easy categories like "the two cultures." This entails validating the whole range of pedagogical objectives (technical and HSS) while emphasizing the ones for which each group of faculty is primarily responsible. It is essential to recognize the importance of professional cultures and the full range of objectives and tensions involved and to avoid the trap of dualistic categories. For example, it is possible that the distinction between academic and industrial cultures matters as least as much as the distinction between literary and scientific cultures.
8. Use the documents produced through the two projects as evidence of outcomes being achieved. As we have indicated earlier, it is important to be realistic about how many outcomes can be demonstrated through a single written product. On the other hand, achieving optimal levels of integration requires testing the limits of the kinds of analysis that can be drawn together in a single document. We believe that it would be very detrimental to design the written deliverables in a way that isolated or compartmentalized either the HSS or engineering disciplinary objectives. Although multiple readers and some external evaluation of written

deliverables are already built into the evaluation and approval process for theses and capstone group reports, we will need to extend and regularize the document evaluation process in order to generate the kind of data that EC2000 calls for.

## Unresolved Issues

Even after open communication and flexibility have achieved all they can, some unresolved philosophical issues remain. How to deal with the tradeoff between what can be accomplished and learned through teamwork versus individual intellectual effort and the development of a distinct authorial “voice” and perspective? How to deal with the tradeoff between the values derived from intense interaction with a client in a realistic “get it out the door” context versus the values of autonomous intellectual pursuits that emphasize student curiosity and learning over the value of final products? How to deal with the issues of evaluation and grading? In this case, there are two related issues. One issue has to do with how much effort SE faculty can be expected to devote to evaluating the technical quality of thesis work. Another issue has to do with differences in the grading criteria that each advisor uses. Finally, how do we deal with differences in how we define a “contribution to society”? In other words, how do we measure the value of the outcomes of undergraduate research?

## VII. Conclusion

Our approach to these unresolved questions is to interpret them as creative tensions that can lead to new insights and a richer understanding of engineering enterprises, not only for the faculty involved but for students as well. Approached properly, the apparently competitive objectives enumerated throughout this paper can be seen as complementary parts of a rich and productive undergraduate research experience. More specifically, the undergraduate thesis and capstone project can be seen as adding value to each other and forming together a more complete educational experience than either would constitute alone.

For example, the student who develops an individual voice in the thesis and is also part of a group voice in the capstone group report is in a better position to judge the differences in usefulness, learning, and personal satisfaction to be gained from each approach. A student who has experience of both a client driven and an autonomous approach to intellectual pursuits can weigh the relative merits of the two and see how they enrich each other. A student can pursue issues in the thesis that are not part of the client’s goals or interests and gain a broader perspective on the client’s goals and interests. A student who is graded on different occasions according to different criteria should have a more nuanced sense of the wide range of values that can legitimately be attached to one body of expertise or a single final product.

Perhaps most importantly from the HSS point of view, a student who has seen that a “contribution to society” can be measured in terms of many values is less likely to accept the easy but reductionist strategy of asserting a master value that dictates all decisions and establishes a hierarchy of goals.

To fully exploit the educational value of the integrated major design experience, we are planning to have the students engage in deeper reflection on the totality of their thesis/capstone experience. Even given the broad goals that the major written deliverables are designed to achieve, there is still some important learning that is not captured in either the thesis final report or capstone group report. We will, for example, ask them to articulate what they gained from the group effort, what they gained from the individual experience, and what they are able to lift from the combined experiences. We will ask them to write anecdotally and to use specific examples from their own projects. Although our questions will guide them toward articulating the integrative features of their experience, there will also be ample opportunity to explore any tensions they experienced. For example, they might consider the broad categories of personal versus professional growth and deal with specific conflicts such as lifelong learning versus producing a product, team versus individual effort, corporate authority versus personal values/goals and contributions to society, etc. The aim will be to have the students discover a diversity of objectives and to go beyond the easy categories of thesis and capstone project. (This exploration will be undertaken in pilot form in the Spring semester 2001.)

Given the emphasis that this paper has placed on the role of institutional history and organization and other practical factors, the question might well be asked how our insights and recommendations might apply to faculty whose aims are similar but whose particular circumstances are different. There are several basic principles that we believe would apply in any circumstances where faculty sought to achieve multiple educational objectives, including HSS ones, through undergraduate engineering research.

1. Recruit faculty whose disciplinary backgrounds, pedagogical commitments, and mixture of commonality and divergence provide the basis for both effective collaboration and creative tension. Encourage those faculty to articulate their own professional standards and mental models, to engage in critical thinking, and to emphasize both common ground and important points of divergence and what they represent.
2. Select projects that offer interesting issues and problems for the full range of faculty involved. A good project need not be equally interesting or challenging to all faculty who will be involved in supervising research related to it, but it should be interesting from HSS as well as technical angles. Needless to say, projects should also be selected with student learning as a top priority.
3. Require students to produce several different written products that package the project for different purposes but avoid compartmentalizing the documents into easy categories (such as HSS or technical). One good way to do this is to design the written documents so that they are aimed at multiple audiences whenever this is practical. Even client documents, for example, will typically need to satisfy more than one audience. It may also be useful to distinguish between internal and external documents, each of which has a legitimate purpose.

4. Consider the ways that the documents can be mined for evidence of EC2000 outcomes—for example, for evidence of ethical reasoning, for improved skill in problem solving or communications, or for greater awareness of environmental or regulatory constraints.
5. Recognize that achieving multiple educational goals requires significant investments. Another way of putting this is to say that achieving multiple outcomes requires investing in multiple inputs. Engineering educators at other institutions have sometimes contended that it is difficult for other programs to implement the strategies we employ because those other programs are organized differently. We recognize that other institutions may have good reasons for organizing their HSS faculty and instruction in ways that differ from our arrangements. We strongly believe, however, that deans and others who are involved in allocating resources must recognize that they cannot realize the benefits of integrated HSS education or achieve the goals that EC2000 sought from that integration without making significant investments in integration.

To the extent that we can achieve multiple educational objectives through a single undergraduate research experience, we can maximize the payoff from the considerable student, faculty, and institutional investments that must be made in undergraduate research, especially research that is undertaken in the realistic contexts of clients and other users of the products of engineering. Achieving multiple objectives through a single research experience is also consistent with the integrated approach underlying EC2000.

Confronting the complexity of “getting real” also, and perhaps more importantly, has the potential to provide an illuminating intellectual experience both for students and for the faculty who guide their work. Integrating the HSS and technical educational objectives may be a matter as much of balance as of synthesis, and we may need to seek out the condition that nineteenth-century scientists often ascribed to the physical universe—a state of counterpoise in which the varied forces of nature balanced each other in a relationship that was both dynamic and enduring.

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