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ABSTRACT

This paper reports on a longitudinal study of the incorporation of engineering design into secondary classrooms by math, science, and technology teachers who were alumni of a week-long intensive inservice course at the Thayer School of Engineering at Dartmouth College (New Hampshire). Data collection methods included observations and interviews, surveys, written materials, and site visits. Results indicate that about three-quarters of the teachers effected a full implementation of the problem-solving method during the first year following the workshop. Other findings include: (1) math teachers were less likely to have their students build concrete models and less likely to do any implementation than science teachers; (2) implementation was most common in a teacher's highest-ability class; (3) some teachers were genuinely surprised by the resistance that students expressed to doing the projects; and (4) teachers were candid in admitting that they did not cover subject matter content that they had covered previously in their teaching. It was concluded that engineering design is good science education as it incorporates imaginative views on teaching about technology and society and can engage students in sociologically authentic science. However, engineering design is also revolting, since its implementation requires that teachers rethink what it means to teach science. Contains 27 references. (JRH)

# Engineering Design in the Classroom: Is it Good Science Education or Is it Revolting?

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The title of this paper is loosely based on Edwin Layton's (1986) book, The revolt of the engineers: Social responsibility and the American engineering profession. Layton's revolution concerns an historical tension between two views of engineering: a view emphasizing the important scientific and managerial roles that engineers played in businesses, versus a view emphasizing the professional compact between engineers and the public. In the former view, engineers' loyalties were to their companies and their companies' interests. In the latter view, engineers were asked to recognize their obligation to practice with a view to the common, public good, and to concern themselves particularly with the *social impacts of technology*; their loyalties were supposed to transcend company interests. The "revolt" in Layton's history was a painful shift within the profession from one view of engineering to another.[2]

Parallels to this tension exist in the history of the science curriculum. Should the chemistry curriculum, for example, concern itself primarily with chemistry as a structured body of scientific knowledge (the "company loyalty" model, where the "company" is the academic discipline of chemistry) or with the social consequences of the application of chemistry, chemical technologies, or technologies that have chemical impacts on society (the "public interest" model)? Although these two views of science education--disciplinary science versus science applied toward (nonacademic) public needs--have had periods of both ascendancy and decline (Bybee & DeBoer, 1994; DeBoer,

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[2] The first edition of Layton's book focused on American engineering between 1900 and 1945, and documented the growth (and subsequent decline) of an ideology of the engineer as social change agent. In the second edition, Layton updated his analysis to the near-present, and left us at the dawn of modern scientific engineering, where engineers are taught in university programs that begin with intensive study of calculus, physics, molecular biology, and other sciences. This more recent change might be viewed as a second revolution, the replacement of engineering by engineering science, a revolution that is still taking place.

1991), for most of the past three decades, notwithstanding efforts like Science for All (UNESCO, 1983) and the Science-Technology-Society movement (Solomon & Aikenhead, 1994), the disciplinary view of science education has largely held sway.

Today, the narrow disciplinary view of the science curriculum is undergoing radical revision; ironically, much of this revision appears to have been stimulated by mainstream scientific groups like the American Association for the Advancement of Science, whose Project 2061 publications provided a content blueprint for the new National Science Education Standards (National Research Council, 1996). In both 2061's Benchmarks (AAAS, 1993) and the Standards, among the central themes are technology, technological design, and the social impacts of technology. In contrast, the National Science Teachers Association's flagship curriculum reform initiative has appeared reluctant to expand its content focus beyond traditional disciplinary structures. Its first detailed curriculum guide made practically no reference to technology, for example;[3] its most recent publication imaginatively repackages the NRC's Standards so that standards concerning technology and the nature and application of technology are separated from "science subject matter" and practically relegated to footnote status.[4]

In all fairness, progressive efforts by professional science teachers' associations like NSTA have often evinced little action by teachers; as Fensham (1992) has noted:

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[3] A quick and dirty comparison on this dimension can be done using the book indexes of AAAS's and NSTA's content frameworks. Under the heading, "Technology," the Benchmarks index provides 65 different page-number citations on 44 topics. NSTA's Content Core (National Science Teachers Association, 1993) has no listings at all under "Technology," nor under "Engineering," "Design," "Agriculture," "Communication," "Computers," or "Materials"--technology-related topics frequently cited in Project 2061 publications.

[4] The NSTA publication (Aldridge, 1995) divides NRC's "Content Standards" into two parts. Part One, titled "Science Subject Matter," is 128 pages in length, and expands NRC's Standards B-D, which concern the traditional physical sciences, biology, and earth and space sciences. Part Two, titled "Science Applications and Processes," is 12 pages in length, and covers NRC's Standards A, E, F, and G. Thus, the book's relative treatment of "traditional" and "applications/ process" subject matter is 128 pages to 12, or more than 10:1. In contrast, the NRC doesn't distinguish between science "subject matter" and its application: all are considered content. Nevertheless, if one maps NSTA's distinction onto the NRC Standards, explanations of "tradi-tional" subject matter and "applications and processes" are given about 20.5 pages and 25.5 pages respectively, a ratio of 4:5! (Vignettes were ignored in page counts, because they referenced multiple standards, and I only included the NRC sections concerning grades 5-8 and 9-12).

> Many of their members are more ... comfortable with the traditional types of elite curricula for which their own socialization in science has equipped them. There is considerable evidence of this conservatism among science teachers, and it is a definite brake on the prospects for curriculum reforms. Teachers trained well in one discipline of science are usually loath to teach across the disciplines. (p. 798)

In studying and evaluating our own efforts to promote interdisciplinary teaching among science teachers (in the context of aquatic environmental science), we have come to view this hesitation as a problem of teacher subject-matter knowledge. Teachers often view science in narrow, disciplinary terms; asking them to build bridges between the sciences and between the sciences and society is to directly challenge their conceptions of their subject matter, and teachers' status as subject-matter experts is integral to their authority as teachers. We have found that teachers who innovate are likely to be teachers who clearly understand that science includes sociological and technological dimensions (Carlsen & Cunningham, 1993; Cunningham, 1995). From this perspective, the challenge of implementing the new science reform initiatives is in large measure a matter of changing science teachers' beliefs about what science is. History suggests that this change will be resisted. One likely form of resistance is to reassert a demarcation between science and technology, maintaining a disciplinary focus on traditional science content and dismissing design, technology, and engineering to the "extrascientific"--content better left to the industrial arts classroom.

Science education today faces a problem similar to the one with which engineers struggled mid-century; to what should it be loyal: its historical disciplinary patrons--the scientific disciplines--or a public increasingly concerned with the relationship between science and technology, and the social impacts of science and technology? To choose the latter, many teachers believe that they must revolt from a view of science that is familiar, straightforward, and true, to one that is messy and tainted with economic, political, and psychological complexity. In this paper, I argue that this is a false choice, not because the new societally and technologically imbedded science is as sociologically pure as teachers' views of science, but because science is not as sociologically pure as it is typically portrayed. If that is recognized by teachers, there is good reason to believe that they can and will incorporate into their teaching substantive attention to issues like technology, design, and the social consequences of technology. Evidence for this claim is provided from an ongoing longitudinal evaluation of a science inservice program that teaches engineering design.

## Conceptual Framework

The general conceptual framework for this work is an evolving perspective of science education based on contemporary sociology of science, which rejects both a view of science based exclusively on philosophical criteria and a sociological view based on ideology. A contemporary sociological view of science, which we have outlined elsewhere (Kelly, Carlsen, & Cunningham, 1993) asserts the centrality of human interactions in scientific work and scientific argument, hopefully without falling into the trap of substituting for a naive philosophical view one that attributes scientists with superhuman dispassion, altruism, and benevolent skepticism. Although we have only outlined this view, it describes several sociological phenomena, three of which are used in my subsequent analysis here. They are the sociological problems of secrecy and ownership, social persuasion and the status of facts, and the relationship between money and science. These problems are briefly sketched below, along with some provisional speculations on teachers' views: we are currently developing strategies for assessing these more systematically using new technology.[5]

Secrecy and ownership. To what extent is science predicated on free and open communication and sharing of the results of scientific research? We suspect that many teachers see a clear distinction on this dimension between science and technology, perhaps akin to the following claim in the National Science Education Standards:

> Technological knowledge is often not made public because of patents and the financial potential of the idea or invention. Scientific knowledge is made public through presentation at professional meetings and publications in scientific journals. (National Research Council, 1996, p. 193)

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[5] We are developing a World Wide Web version of a computer-adaptive test of teachers' and students' beliefs of the nature of science, based on the VOSTS paper instrument (Aikenhead & Ryan, 1992; Aikenhead, Ryan, & Fleming, 1989). We will be demonstrating a prototype of this online test in Session 42.02 at the AERA annual meeting in New York City on April 11, 1996. The first round of actual testing will be done in July, 1996.

The idea that scientific knowledge is freely disseminated through publications and professional communication is routinely modeled in science classrooms through student lab reports and presentations. The idea that scientific knowledge belongs to the entire community of scientists and is freely exchanged is the scientific norm that Robert K. Merton called communism. It is, however, sociologically problematic; Mulkay (1991) calls it an ideology, rather than a norm. Work by Mitroff (1974) and Edge and Mulkay (1976) have shown a number of ways in which secretiveness is actually adaptive for scientists. Some of these reasons are financial (improving the reputation of a research group and its ability to obtaining funding), but others are not (e.g., preventing the media from distorting results). Intellectual property issues, of course, are increasingly leaking into the most basic sciences, like mathematics and molecular biology, creating incentives for secrecy that are rarely discussed in classrooms. The idea that secrecy and ownership are problems of technology, rather than science, is sociologically untenable.

Social persuasion and the status of facts. The construction of facts in the laboratory and beyond is an important theme in sociology of science. Perhaps the best known text addressing this topic is Laboratory Life (Latour & Woolgar, 1986), which provides an anthropologist's view of endocrinological research at the Salk Institute. Laboratory Life describes the process of fact-making in endocrine research as one in which claims about the products of complex technological procedures are progressively decontextualized through the removal of modalities (qualifying statements). Although interpretation and reinterpretation occur at many levels, including public disputation with competitors in other laboratories, the facts that result from research have been stripped of human action, time, place, economic concerns, and other social contingencies. The process that is described in official accounts rarely references the struggles that occurred during the fact-building process.

Turning back to the science classroom, we see young scientists' first socialization to this form of argument: laboratory reports are written in the third person (or, more commonly, are personless) and the adequacy of empirical work is evaluated by teachers from these (sanitized) written accounts. Social persuasion is rarely modeled; facts are ontological, not rhetorical. Yet histories and sociologies of science provide many examples of scientists using their status as experts and demonstrable technologies to convince scientists (Schaffer, 1989) and nonscientists (Gieryn & Figert, 1990) that something is a fact.

The relationship between money and science. The relationship between money and science may be the most glaring component of the null science curriculum today, and in textbooks, is usually reduced to a page here and there on science-related careers. Science today is clearly dependent on and influenced by public and private capital, and research programs respond to the political economy (Dickson, 1988; Remington, 1988). Economic considerations do more than just attract scientific interest; they act to reshape scientific values:

> Indeed, the commercialization of science ... may involve a normative shift in attitudes toward intellectual property so that the ethical presumptions of science themselves get redefined by the social actors involved. Even scientists who believe that direct involvement in commercialization is improper because it might compromise the openness of research are pushed in that direction. ... The norm of ''capitalization' has displaced 'disinterestedness' as adherents, agnostics, and opponents of the legitimization of intellectual property regimes in the university all fulfill its requirements through a variety of available modes, ranging from filling out an intellectual property disclosure form to organizing a firm. (Etzkowitz & Webster, 1995, p. 503)

Money--or the lack of it--even plays a role in fact-establishing: scientists can and do strengthen their claims by making it prohibitively costly for their competitors to rebut them (Latour & Woolgar, 1986, p. 241).

In even progressive science classrooms, recognition of the relationship between scientific work and capital is often reduced to simplistic assertions about the dependence of society on science, or vice versa. Except for participants in science fairs (who may have to purchase their own materials), students are usually fully isolated from the economics of the scientific work in which they engage; hence, it should not be surprising if their conceptions of science are uninformed by financial concerns. The costs of undertaking research and the potential financial benefits of successful research (to individual and to society) are facets of science practice that few students encounter.

Summary. The problems outlined above--secrecy/ownership, social persuasion, and the economics of science--are, although generally unexplored in science classrooms, important features on the landscape of contemporary sociology of science. They are not, we believe, components of most science teachers' conceptions of science, nor their conceptions of science teaching, present or future. However, these and related issues permeate the NRC's Standards and other progressive science reform curriculum documents, which call for greater attention to scientific discourse and argument, technological design, and the relationship between science, technology, and society. Implementing the new standards will require revolutionary changes in teachers' thinking and the types of experiences students encounter in classrooms. Fortunately, instructional models that support these changes are available; the rest of this paper briefly reviews one such model and reports on teachers' and students' experiences implementing it. Analysis and evaluation of the implementations suggests that technological design in science classrooms can provide a productive context for exploring the sociological problems of secrecy/ownership, social persuasion, and the economics of science.

## Engineering Design in the High School Classroom

The findings reported here come from a longitudinal study of the incorporation of engineering design into secondary classrooms by math, science, and technology teachers. The teachers are all alumni of a week-long intensive inservice course at the Thayer School of Engineering at Dartmouth College. The Thayer School's "Engineering Concepts for the High School Classroom" program is supported by grants from the National Science Foundation and other sources, and the summer course has been an annual event since 1990. The program is highly selective and admits applicants (attracted via advertisements in professional magazines, direct mailings, and other mechanisms) from a national pool. To date, more than 160 teachers from 38 states have participated. Consequently, the lessons learned from this group must necessarily be qualified as being based on the experiences of motivated teachers who were attracted to the goals of the program.

The goals and details of the program are readily available online, so only a brief description is provided here.[6] During the week-long program, teachers work in groups to complete two technology design projects, using a model developed at Dartmouth for a sophomore level engineering sciences course. The projects culminate in the construction and public demonstration of a novel technology, such as a safety device to prevent lawn tractor rollovers. The public demonstration includes a written report, hands-on evaluation of the device, and an oral presentation to a review board, which includes scientists, engineers, and other experts. Participating teachers are asked to implement the same model for design projects in one or more classrooms during the following school year.

The design (or "problem-solving") method that teachers (and later, their students) learn includes the full range of steps involved in designing, creating, and producing science-based technologies, including: problem identification and reformulation, segmentation, brainstorming, analysis of design specifications and constraints (including environmental, economic, safety, ethical, and aesthetic considerations), market analysis, patent research, device construction, testing, and evaluation by potential users.

Method

The results presented here come from an external program evaluation, directed by the author, of the Thayer project. The evaluation design includes many different components; relevant to this paper are: (1) observations and interviews with program staff and participating teachers throughout the 1992 and 1993 summer programs; (2) surveys and demographic analysis of participants in the 1992-1995 cohorts; (3) telephone surveys of a random sample of 18 teachers from the 1993 cohort (64% of the cohort), (4) written materials (project reports, student work, press clippings, etc.) submitted by teachers; and (5) ten multi-day evaluation site visits to eight schools, selected to provide a wide range of variation in community affluence, teacher subject matter expertise, geographical location, school type (public or private), and state-level curriculum

[6] Using NetScape or another browser, link to http://www.dartmouth.edu/thayer/engsconc/

mandates. Seven of the site visits were conducted in the first year following teachers' participation in the project; three visits were to teachers' schools two or three years after the summer program.

I conducted four of the site visits alone, and took one or two doctoral students on five more visits (to complement my subject-matter expertise and to help provide insights on issues of gender and racial equity). A tenth visit was made by Christine Cunningham to a school where gender was a stated concern in the teacher's Thayer-model innovation. Among the visited schools are two expensive private schools, one public school in an affluent community, one isolated rural school serving a school population with a majority of Hispanic migrant workers' children, an urban school with 100% low-income minority students, a school in the suburb of a large city, and two rural schools serving economically diverse communities. The schools are located in five different geographically distant states, with a range of state-level accountability demands. The 13 Thayer-alum teachers we visited (some schools had sent more than one teacher) had a range of teaching experience from 3 to over 20 years; most were teaching science, but the sample included two mathematics teachers and two technology teachers (both from multi-teacher schools).

During these site visits, my students and I (1) interviewed teachers, administrators, guidance counselors, and students; (2) observed classroom instruction in Thayer-impacted classes; (3) reviewed curricular artifacts (e.g., handouts, student reports, prototype devices); and, in some cases, participated in or observed summative group presentations (e.g., as a member of an external design review board). A primary concern during these visits was to try to understand the relationship between school context and the Thayer innovation. For example, we sought to determine the extent to which engineering design requires sophisticated (and expensive) instructional support facilities.

## Findings

Overall implementation. Before speaking to the sociological themes of the paper, some data are shown concerning overall implementation by teachers. These data were collected during the telephone interviews, and carefully corroborated through site visits.[7] The telephone interview was designed to take about 10-15 minutes. A typical interview lasted 20-30 minutes, because teachers volunteered many details about their activities and plans. The results are summarized quantitatively below.

| | Number of Teachers | | |
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| **Specific Implementation** | Yes | No | % "Yes" |
| **Used Thayer method in any form** | 16 | 2 | 89% |
| **Used open-ended design projects** | 15 | 3 | 83% |
| **Students explicitly redefine the problem** | 14 | 4 | 78% |
| **Used constraints and/or specifications matrix** | 14 | 4 | 78% |
| **Had students brainstorm alternative solutions** | 15 | 3 | 83% |
| **Conducted patent search** | 2 | 16 | 11% |
| **Students did telephone or face-to-face interviews** | 12 | 6 | 67% |
| **Students built actual devices** | 13 | 5 | 72% |
| **Students submitted written group reports** | 12 | 6 | 67% |
| **Used Design Review Board of any kind** | 9 | 9 | 50% |
| *External Design Review Board* | 7 | 11 | 39% |
| *Internal Design Review Board (teachers only)* | 2 | 16 | 11% |

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| **Number students affected per teacher** | mean | 40.2 | students |
| | median | 29.5 | students |
| **Number class periods per teacher** | mean | 24.9 | lessons |
| | median | 20.0 | lessons |

Several points about implementation are worth noting. First, if "full" implementation of the problem-solving method is defined as utilization of a majority of the identified "specific implementations," about 3/4 of the teachers effected a full implementation during the first year following the Thayer workshop. Second, median statistics for number of students affected and number of lessons devoted to the method are probably better measures of the extent of

[7] Because telephone respondents were from a randomly selected subset of the schools, not all site visited teachers were interviewed on the telephone.

implementation than means. Although smaller, they are less skewed by the experiences of a small number of teachers who involved a large number of students and/or lessons. Third, even using the more conservative median, these numbers document an extensive level of implementation, e.g., 20 lessons resulting from an inservice program only one week in duration. Finally, patent searches were conspicuous as the most (and arguably the only) underutilized part of the problem-solving method. Design review boards, although used by half the teachers, were the only other component used by less than 2/3 of participants.

In addition to baseline statistics, telephone interviews provided many details about teachers' projects, such as when they were scheduled, with what types of classes, what problems were encountered, and whether projects would be continued in future years. In general, I used these comments to corroborate what was observed on site visits, where it was possible to contextualize and validate teachers' reports. Nevertheless, a few themes did emerge:

- Math teachers were less likely to have their students build concrete models or devices, and less likely to do any implementation than science teachers

- Implementation was most common in a teacher's highest-ability class (but note that students interviewed on site visits generally believed that the method would be useful with lower-ability groups)

- Some teachers were genuinely surprised by the resistance that students expressed to doing Thayer-inspired projects, but (a) were usually able to provide a coherent explanation (e.g., "these are students who are used to succeeding through individual, rather than group, initiative"), and (b) nevertheless emphatically reported that they judged that projects were valuable and worth repeating, despite student resistance

- Teachers seemed disappointed that they were not able to accomplish the patent-search step, and might benefit from either viable options for accomplishing that step or alternatives to it[8]

- Teachers were candid in admitting that they did not cover subject matter content that they had covered previously in their teaching, in order to implement the Thayer approach

- Lack of access to shops was only infrequently cited as an obstacle to implementation

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[8] Since this phase of data collection, patent searching via the Internet has become much more generally available to teachers

In summary, given the relatively short (one week) duration of the inservice program, we found a surprisingly high level of implementation by teachers: about three quarters effected a "full" implementation, and devoted an average of 20 periods of classroom instruction to the projects. This figure, one year after the focus cohort's summer program, is especially impressive because most of the school-year followup strategies used in the Thayer program (a newsletter, competitive mini-grants, a World Wide Web site, and ancillary materials including a book and a professionally produced videotape) were developed later in the program's development. Granted, the teacher population attending the program was self-nominated and competitively selected--hence, their implementations might be most appropriately seen as an "existence proof"(Lampert, 1990) of innovation, rather than a representative sample of teaching--but the scope, intensity, and enthusiasm with which teachers implemented the method extended across the spectrum of teacher experience, school affluence, and community and student demographics. Consequently, I believe that the project provides good evidence that, given appropriate training and tools, science teachers can and will devote substantial instructional time to technological and societal themes.

Secrecy and ownership. Several aspects of the Thayer problem-solving method directly or indirectly expose students to issues related to secrecy and intellectual property. The method requires that projects be novel; that is, students must develop new technologies. During the summer program, and in a minority of the school-year implementations, a comprehensive patent search was required; this step proved to be logistically onerous in 1993-94, before tools for patent searching began to become available over the Internet. One teacher, for example, arranged to transport her students several hours by bus to a regional U. S. patent library; after doing that once, she dropped the patent search requirement. Other steps in the problem-solving method, however, buttress the novelty requirement. For example, students are required to do market research through telephone or face-to-face interviews, and assessment of the novelty of design is a component of this research. Among the dozens of student projects reviewed in the evaluation research, market research interviewees included corporate engineers, public affairs spokespeople, local police officers, scientists, small business owners, and bus drivers. Because multiple mechanisms existed to ensure that students' technologies were novel, projects tended to be highly diverse in scope and students demonstrated pride in being identified with their projects during public reviews, in media coverage, and, in one case, in a scientific paper session conducted on a Friday night in a local pizza parlor! Whether effected via patent searches or market research, the requirement that projects be novel confronted students with intellectual property issues.

Curiously, the most ambitious implementations of the Thayer method were most likely to create conditions in which students became secretive. When teachers dedicated more than three weeks to engineering design, they often introduced the process with a preliminary uniform design problem, such as a challenge to design and build a device to particular specifications (such as a model bridge). These standard design projects engendered much (generally good natured) secretiveness; despite teachers' assurances that projects would not be in competition for a limited number of good grades, students interpreted the culminating reviews (often with review boards made up of other teachers or outside experts) as competitive in nature. Designs were carefully guarded until the summative evaluation was complete. In these (most ambitious) teacher implementations, the initial uniform design project was followed by a novel design project, where student groups would engineer divergent technologies. Little evidence of secretiveness was observed in these second projects. Nevertheless, other aspects of the design project exposed students to issues related to intellectual property. Patent searching and, more commonly, interview-based market research provided students with insights that they would be unlikely to encounter in most science classes.

Social persuasion and the status of facts. An interesting feature of the design projects done in science classrooms was that they always shifted the focus of student work from explanation to demonstration. Final project reports, for example, whether written or oral, tended to concentrate much more on demonstration of project efficacy than on elaboration of underlying causal mechanisms. When I was conducting the site visits, I worried about this, because it appeared that scientific explanations (i.e., scientific understandings) were often being displaced by staged demonstrations of devices, absent a conventional account of the "science." In retrospect, although this concern may be justified with respect to traditional views of science curriculum, it is probably less fully supported by the history of science, which is rich with examples of demonstrations substituting for explanations, sometimes stage-managed behind the scenes (see, e.g., Shapin, 1989). A principal contribution of contemporary sociology to this picture is that its principle of reflexivity (Bloor, 1976) suggests that these stage-managed productions may be more than the exception to the rule of fact-making.

Another interesting dimension of the design projects was that the most compelling projects were almost autobiographical in nature. In stark contrast to conventional laboratory reports, students' design reports usually began, and often ended, with personal accounts related to students' hobbies, relatives, or communities. One group, for example, devoted weeks to researching, designing, constructing, and testing a device whose sole function was to squeeze the water out of a washcloth. Their final project report related that an elderly relative of one student suffered from severe arthritis, a condition that apparently has many quality-of-life implications, one of which is to make it difficult to wash. Their final report included, in addition to a demonstration of the washcloth squeezer, grateful letters of support from arthritic field testers who had evaluated the device at a regional health fair. Other projects, less socially magnanimous in nature, usually retained a strong personal dimension. For example, one report I witnessed in a southern U. S. school was of a rope-tow turn signal for water skiers: the public presentation included the device, written testimony from a boat manufacturing engineer, and a slide show of the students gleefully field testing their device on a large lake on a warm May afternoon. The contrast between reports like this and conventional lab reports could not be more striking.

One other aspect of the projects related to persuasion was striking: the use of external review boards often palpably changed the role of the teacher. In the most successful implementations--which tended to use review boards to evaluate final projects--the teacher was not commonly used as a resource to finalize a design decision. It was our judgment that, by shifting the responsibility of project evaluation to an impartial external body, students were more likely to use the teacher as one of many resources, rather than as an ultimate authority.

The relationship between money and science. Students engaged in Thayer-model engineering design projects were generally exposed to three aspects of the relationship between money and science. First, the patent and/or market research was defined as a task to determine whether the engineered device could be profitably constructed and marketed; projects were usually approved only if they were both doable and economically feasible. Second, the students were responsible for budgeting their prototypes, purchasing components, and either submitting reimbursements to the teacher or (less commonly, in the more affluent schools) convincing their parents to cover the costs of construction. In every project we observed, teachers placed a specific dollar cap on what could be spent on projects.[9] Third, a formal analysis of construction, marketing, and sales costs was a requirement in most of the projects. Review board members commonly awarded or subtracted points from their evaluations based on the quality of this analysis.

## Conclusion

The central question of this paper was, "Is engineering design good science education... or is it revolting?" My provisional answer is that it is both. Judged against the standards of the most imaginative contemporary curriculum reform proposals, engineering design is good science education. It incorporates imaginative views about teaching about technology and society in science classrooms. It can engage students in sociologically authentic science. And it can be engaging and original, for teachers and students from widely varying backgrounds. That is the "good science education" part of my question.

However, engineering design is also revolting; its implementation requires that teachers rethink what it means to teach science, and in a nontrivial fashion. Implementation of a Thayer-style project requires at least three weeks of class time, and usually requires more. This inevitably means less time addressing traditional content. Whether teachers' enthusiasm for the positive aspects of engineering design projects will, in the long run, outweigh the constraints that teachers face is a question we will be studying through further evaluative followup in the coming year.

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[9] With one exception, these limits were always under $50/group for a weeks-long project.

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