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Engaging Students with Great Problems

Kristin K. Wobbe
Worcester Polytechnic Institute, kwobbe@wpi.edu

Brian J. Savilonis
Worcester Polytechnic Institute, bjs@wpi.edu

David Spanagel
Worcester Polytechnic Institute, spanagel@wpi.edu

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Wobbe, K.K., Savilonis, B.J. and Spanagel, D.
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Abstract

The Great Problems Seminars were designed to bring first year engineering students into meaningful contact with current events, societal problems, and human needs. Key learning objectives include: introducing project team work and developing writing and presentation skills. Each seminar has focused on a large global issue: food and hunger, energy and its utilization, health and healthcare delivery, the NAE Grand Challenges. Seminars are co-taught by an interdisciplinary pair: one natural science/engineering instructor and one humanities/social science instructor. The first half of the two-term course sequence explores the depth and breadth of the problem; the second half is devoted to project work. Focus group assessment demonstrates that the GPS courses achieve the original course objectives. Student course evaluations indicate high satisfaction despite requiring significantly more work than traditional first year offerings taught within the disciplines. Comments by former GPS students demonstrate that they value how these courses prepared them for their futures.

Introduction

Listing the inadequacies of traditional engineering education programs, Edinburgh environmental engineering professor William Turmeau threw down a serious challenge: "Engineering today involves more than the solution of technical problems, more than the design of advanced technological devices, more than the pursuit of pure research, and engineering courses must be reviewed and revised to ensure that engineers, once again, play a role in the wider issues concerning society." [1] This challenge has been addressed by a series of curricular innovations undertaken by leading institutions of engineering education around the world. Specifically, within the United States, a national trend toward more active, project-based learning in engineering education has been gaining momentum for more than 40 years.[2] A widely publicized illustration of the trend was the establishment in 1997 of the Olin College of Engineering, an institution which promised integrated project work in all four years of its curriculum.[3] Before and since, and in many places besides Olin, promising engineering students have been enticed to attend a variety of innovative technical education programs that promise real-world experience, training in widely applicable communications skills, and an impeccable foundation in the principles of design and professional standards of practice.

For example, our institution, a primarily science and engineering school, placed project-based learning at the core of its academic program in the early 1970's when it redesigned its graduation requirements to include two major projects.[4] One project undertaken within the student's major field of study is usually completed during the senior year. Another project is usually completed during the junior year, but this one challenges students to work on an interdisciplinary problem located at the interface of science, technology, and societal needs. To better prepare students for a world like Turmeau's, practical and cross-cultural engineering elements were increasingly incorporated into the interdisciplinary junior-year project experience. After several decades of implementation, a steady state has been achieved in which approximately half of all students (about 400 students each year) now satisfy this requirement by devoting one academic term to work at one of 23 project centers located around the world.[5]

Initiated at our new President's request in 2005, faculty-led conversations about the first year educational experience resulted in critical observations about the overall program of project-based learning. Despite the strong institutional consensus that project-based learning is an essential component of what makes our college unique and successful, extensive project work typically has not been available to first year students. Moreover, traditional coursework in the first year had not adequately prepared all students for their project work in the junior and senior years. A multidisciplinary task force resolved that a new first year experience needed to be developed at our campus, to bring meaningful problem-based project work into the earliest stage of a college student's education.

Focus on the importance of the first year is not limited to engineering education. Many colleges have developed new first-year programs designed to smooth the transition from high school to college. Some focus on study skills and transition issues, others use learning communities to build a network of social support for the academic mission, and yet others build first-year seminars connecting students with faculty research interests.[6] Among engineering education programs, however, freshmen seminars typically focus on bringing engineering and design into the curriculum earlier, largely to spur student motivation, retention, and assistance in choosing a major.[7,8,9] These first year engineering seminars often introduce ethics and professional responsibility and cover some study survival skills. Intimacy of small group settings is preferred to provide student-faculty interaction. In rare cases, the seminars may have a liberal arts or interdisciplinary backdrop. Stengel,[10] for example, describes a Princeton seminar on space flight which exposes liberal arts students to details of technology and engineering students to societal impacts of technology. Tryggvason and Apelian[11] have argued that the engineer of the 21st century will be redefined. Advances in information technology have made all information available to everyone everywhere with almost infinite speed and ease. A paradigm shift in education is indicated. Now, rather than merely to deliver content, our task as educators is to challenge students to work on real problems, to develop their own capacity to find the knowledge that they need when they need it, and to understand the difference between posing a trivial or dead-end question and posing a fruitful one.

With these criteria in mind, the Great Problems Seminars were initiated in the fall of 2007. The three main imperatives that influenced the course design process were: (1) to engage first year students with modern problem-solving oriented toward social and global issues; (2) to introduce the real-world experience of working in teams; and (3) to develop each student's writing and presentation skills. The faculty who developed the seminars consequently focused on three key principles:

1. Engage first-year students with current events, societal problems, and human needs;
2. Require first year students to perform/produce critical thinking, information literacy, and evidence-based writing; and
3. Devote time and attention to nurture the development of professional skills including effective teamwork, time management, organization, and personal responsibility.

Engagement is the primary goal for the seminars. Seminars are therefore defined by problems, not by disciplines; they are interdisciplinary, not multidisciplinary. The seminar model was conceived neither to be a survey of engineering fundamentals nor an overview of how science and engineering disciplines address real problems. Great Problems cannot be adequately framed within a single discipline that offers a single solution approach; by definition they will be solved only by integrating and negotiating among many small solutions coming from disparate directions.

Seminar Details

The academic year at our institution is divided into four 7-week terms, with students enrolled in 3 courses per term. Typically, a first-year student's schedule looks like:

Calculus + Science + Humanities

Contact time for a typical course is 4-5 hours per week; students are expected to spend an additional 12-13 hours doing course-related work outside of class. This puts more emphasis on self and group- learning versus lecture digestion. By comparison, each GPS is designed as a two course sequence, stretching across two terms and earning academic credit in two specified fields.

Each seminar focuses on a large global issue. Topics include: food and hunger, energy and its utilization, health and healthcare delivery, the NAE Grand Challenges. Seminars are co-taught by a pair of faculty members drawn from disparate disciplines. The first term of the two-course sequence explores the depth and breadth of the problem, introducing perspectives from a variety of different disciplines including, but not limited to, the two disciplines represented most immediately by the instructors. Students practice using information sources, working in teams, and presenting materials, in order to learn how to perform each of these activities with increasing facility and effectiveness.

The second half of the course is devoted to project work. With faculty guidance, teams of 3-5 students perform an in-depth analysis of some aspect of the great problem, and try to frame a partial solution based on their investigations. Seminars culminate in a joint Project Presentation Day in which all groups present a poster describing their project. On Project Day, more than 200 faculty, staff and students attend the poster session. Team members are busy for the entire allotted 90 minutes explaining and discussing their project with visitors or reviewers. Each team is also required to produce a substantive written project report. Successful project teams demonstrate fluency in analyzing a technical component, as well as awareness and assessment of the socio-political circumstances and economic impact of the problem.

The problem-based course structure allows faculty members to exercise considerable flexibility in scheduling and general organization of the content. GPS faculty have road tested a variety of course delivery styles. Thus far, four different seminars have been offered.

Feed the World (FTW): Offered twice, co-taught by an education specialist and a biochemist. This Great Problems Seminar starts with questions related to the biochemistry and the physiology of nutrition and hunger, and considers cultural, policy and economic aspects of food choice, production and delivery. Student project topics have included *Food Stamp Participation in the Local Community* and *Heifer International in Namibia.*

Course delivery consisted of one 160 minute class period per week attended by all students enrolled, and then one separate meeting with each half of the class for another 50 minute period per week on another day. Both faculty members were present at all meetings of the course. The long class period was used for a variety of activities including student presentations, guest speakers, quizzes, class discussion, in class assignments. Very little lecturing was done. The shorter class periods were devoted to discussing small and large project assignments.

Power the World (PTW): Offered three times, co-taught by a historian and a mechanical engineer. Early assignments develop the thermodynamics of power production and the history of energy technologies. Students explore the physics and engineering of energy production and distribution within a historical socio-economic context. Final projects have dealt with such diverse topics as: *Energy Cost Analysis of a Green Roof and Photovoltaic System for a Campus Sports and Recreation Center* to *Air Pollution in China: Is the United States Responsible?*

Each week has one 90 minute common period; this is used for lecture material (e.g. thermodynamics or the historical trends in fuel usage from wood to nuclear), guest lectures and resource sessions (public speaking, poster development, library search techniques, etc.), and opportunities for group presentations. There are also two 50 minute sessions each week (held separately with each faculty member) for seminar discussion groups; one focuses on engineering perspective and the other on socio-political questions. In the second term, these sessions convert into biweekly project group progress meetings with faculty advisors.

Heal the World (HTW): Offered twice, co-taught by faculty from biology and management. This seminar focuses on the biology of infectious disease and the management of healthcare policies; how disease spreads and how can it be controlled. Final projects ranged from *An Innovative Approach to HIV/AIDS Education in Cape Town, South Africa* and *Preventing Infectious Diseases on Campus*.

This seminar meets as a large group once a week for two hours, and then splits into two groups that each meet for an additional two 50 minute periods. Again both faculty members are present for all meetings of the course. Class activities include outside speakers, games, student presentations, in-class writing, and discussion.

Grand Challenges (GC): Offered twice, co-taught by a materials scientist and an English professor. The first term of the seminar consists of an overview of eight of the NAE Grand Challenges, including energy, water and food needs, transportation and infrastructure. The course design is more conventional than the other seminars in that it includes more lecture delivery and exams, along with essay writing and class discussion. Student projects have reflected the broad range of course topics, from *Geothermal Power in Sterling (Massachusetts)* to *Building a Better House* to *Malewa (Kenya) Clean Water Project*.

Each week consists of two 2-hour meetings as a single group. The students are divided into teams of 4 on the first day of class. There is significant opportunity for class discussion as well as required use of an electronic discussion board. Outside speakers and a field trip supplement the classroom experience.

Faculty Anecdotes

Faculty have engaged in both formal and informal discussion with current students and alumni from the seminars. Based on these discussions, several findings stand out:

- Students enjoy project work, especially the chance to choose a project that they really care about. This is the most valuable aspect of the student experience. Students demonstrate tremendous pride of ownership in their final projects. This was especially evident not only at Project Presentation Day but also at weekly group meetings.
- Students can be frustrated by the lack of traditional structure, especially in the early weeks of the program. Learning about open-ended problems is extremely challenging for students.
- GPS courses require more work than traditional courses for both faculty and students.   Some students report that GPS demanded more time than their other two courses combined. (The same students, however, also reported spending 9-12 hours per week on the seminar, which is *less time* than faculty recommend for any course.)

A wide variety of learning styles were apparent in the GPS. Some students were frustrated due to the lack of concrete answers or solutions to problems laden with complex social issues; often these are high performing students who function better with high levels of structure. Conversely, students who may struggle in lecture/examination courses have the opportunity to shine with creativity and problem-solving skills in GPS open-ended team projects. Faculty identified developing an awareness and appreciation for complexity as one of the most important and challenging components of the project experience, for all students.   It is objectively more difficult to learn how to ask a *fruitful* interdisciplinary research question than it is to find the answer to a well-defined problem presented within any given domain. A certain degree of frustration may therefore be inevitable in the trade-off between instruction that is tailored to solve predictable exercises and instruction that is intended to equip students to tackle realistic, complicated situations.

GPS Enrollment and Growth

The GPS program was piloted in the fall of 2007 as two seminars: Feed the World (FTW) and Power the World (PTW). In 2008, two additional seminars were added, Heal the World (HTW) and Grand Challenges (GC). In the third year, FTW was not offered due to increased administrative duties of the faculty involved. The enrollments in these courses are indicated in Table 1. Initial registrations were even higher for 2009, but a number of students who pre-registered chose to drop the course within the first week of classes.

Table 1: Course enrollments A term (B term)

	2007	2008	2009
Feed the World	38 (36)	24 (23)	NA
Power the World	63 (52)	81 (71)	57 (47)
Heal the World	NA	46 (45)	66 (62)
Grand Challenges	NA	55 (54)	54 (53)

In 2009 both PTW and GC had population limits of 60 and significant numbers of students on the waitlist at the beginning of the year. The numbers within parentheses indicate the number of students who registered for the second half of the course. The most common reasons students cited for deciding to drop out halfway through a GPS were: lack of structure, high workload, and the quantity of required writing. In general, the students who left were not students who struggled with the academic work. Indeed, some were the brightest students in the class who were more comfortable in traditionally structured courses with clear disciplinary content.

The students enrolled in the seminars represented 21 different majors. Over the past several years we have seen that HTW and FTW tend to attract more science majors and more women; PTW and GC tend to enroll more engineering majors and more men. 2009 demographics are included in Tables 2 and 3 below (FTW data are from 2007-8). Again in 2009 HTW attracted significantly more science majors, with Biology/Biotechnology majors constituting the largest group (53%). There was a sizeable fraction of Biomedical Engineers in this course, 15% of the total enrollment and about 38% of the engineering students. In contrast, GC had disproportionately more engineering majors, with the largest block of declared majors as Engineering – Undecided (28%). This was also the largest major block in PTW, constituting 15% of the enrolled students. PTW disciplinary demographics are roughly representative of the first year class as a whole.

Table 2: Student majors in Great Problems Seminars

	Feed the World	Heal the World	Power the World	Grand Challenges	First Year Class
Engineering	15%	39%	60%	77%	60%
Science/Math	80%	58%	30%	21%	31%
Other	5%	3%	9%	2%	8%

PTW was disproportionately male (77%), while GC tracked the gender ratio of the First Year class as a whole (see Table 3). HTW and FTW were disproportionately female relative to the entering class. We speculate that there are two not unrelated underlying reasons for the biases: the students select courses that reflect their disciplinary interests and/or the students choose the seminar that aligns best with the distribution requirements of their chosen major.

Table 3: Student gender in Great Problems Seminars

	Feed the World	Heal the World	Power the World	Grand Challenges	First Year Class
Male	54%	42%	77%	68%	69%
Female	46%	58%	23%	32%	31%

Internal Assessment of GPS

GPS has been assessed both internally and by external assessment experts. Part of our internal assessment is a standard course evaluation administered to all students near the end of each course. Students rate a number of items on a scale of 1 to 5 with 5 being the most positive score (significantly better). Evaluations for some key questions from the 2008 GPS offerings are found in Table 4. The GPS courses scored statistically significantly above the University means. The first year course means reported below represent a set of courses populated predominantly by first year students (chemistry, physics, calculus, intro CS), but do not include all courses that enroll first year students.

Table 4: Student Course Reports 2008

	FTW	PTW	GC	HTW	First Year Mean	University Mean
My overall rating of the quality of this course is	4.62	4.2	4.67	4.34	3.89	4.05
My overall rating of the instructor's teaching is	4.95	4.36	4.55	4.45	3.86	4.05
The amount I learned in this class was	4.68	4.11	4.55	3.89	3.71	3.83

Instructors in individual courses have also done assessment of their courses. For instance the faculty in Feed the World asked the 2008 students to assess their progress in a number of skill areas of interest. The results are shown in Table 5.

Table 5: Self-reported skill development- FTW 2008

To what extent has this class helped your	Not at all	Somewhat	Quite a bit	A great deal
Writing skills	0%	36%	41%	23%
Speaking skills	9%	5%	36%	50%
Presentation preparation skills	0%	14%	9%	77%
Team working skills	0%	14%	14%	73%

External Assessment of GPS

The seminars have been assessed from their inception by the Research & Evaluation Group at the UMass Donahue Institute. This assessment included pre- and post- surveys of students who participated in the first year, focus groups of students and of faculty from each year in the spring following the course, and focus groups of students one year removed from their GPS experience.

Assessment of 2007 Offerings: In the first year of the program, surveys were administered to all first year students. GPS students, relative to non-GPS students, reported a higher level of engagement in several important areas, including:

- Working effectively in teams
- Developing a greater understanding of contemporary and global issues
- Solving complex real-world problems
- Presenting and defending opinions by making judgments about information, validity of ideas, or quality of work based on set of criteria

Focus group assessment indicated some dissatisfaction with the GPS experience. In the first round, some student interviewees felt the courses had less structure than they were comfortable with, and others had not felt that their expectations were met by what the courses actually delivered. However, in focus group assessments done a year later with students from these same offerings, the perceived value of the courses had “improved”; no negative comments were expressed in the follow up session.

To an overwhelming extent, the 2007 GPS alumni believed that GPS did an excellent job of introducing them to the project-intensive environment of the University. Because of GPS, these students felt they had learned how to do project and group work in better ways than non-GPS first year students. They also reported positive employment consequences that they could attribute directly to their GPS-specific experiences.

In summary, GPS alumni indicated that as a result of their experience in GPS, they had developed skills in the following:

- Project management
- Teamwork
- Time management
- Presentation skills
- Critical thinking.

Alumni felt that these skills helped prepare them for future project work both at the college and professionally. Other skills, not directly related to GPS goals, also showed up among the benefits alumni attributed to their participation in GPS:

- Assuming positions of leadership on a team
- Accepting critical feedback from others
- Having confidence to speak with individuals who are in positions of power
- Presenting one’s self professionally.

These skills fall under the umbrella of maturity. Not only did GPS serve to acclimate first year students quickly to the university environment of heavy workloads and challenging project work; the courses also accelerated their ability to manage these things well. GPS challenged these individuals to behave as professionals during their first year. While they struggled to do so (and even resented it at times), they not only met the challenge but emerged with skills that will serve them well during and beyond their collegiate career.

This year the majority of students who were in the 2007 offerings of the GPS are completing a junior year project, a university degree requirement. This project is the equivalent of three courses, and requires that students tackle problems of importance at the junction of science/technology and society. Over half of our students complete these projects at a site off campus, many at international sites. Faculty advisors are completing surveys (no indication is given to the faculty as to which are GPS students) regarding a number of areas where we anticipate that the GPS may have an impact. These include teamwork, leadership skills, independence, initiative, ability to deal with complex, open-ended problems, etc. Since these projects are completed at different times throughout the year, these data are not currently in hand but will be available in time for presentation at the June 2010 ASEE meeting.

Assessment of 2008 Offerings: Similar focus groups were held for the 2008 GPS students and faculty. Analysts concluded that all offerings succeeded at meeting the following goals of the program:

- engaging students with current events, societal problems and human needs
- encouraging students to think critically
- promoting information literacy
- producing evidence-based writing
- accepting personal responsibility for their work and to
- developing teamwork, time management and organizational skills

The biggest benefit perceived by all was that students developed significant experience, knowledge and skill in the area of teamwork. Students felt that their participation in GPS allowed them to develop competencies that they would not have developed otherwise, and they believed that these skills would serve them well in their future work.

The focus groups with students and faculty further supported these additional conclusions:

- Students are capable of meeting the significant challenges of project work and of teamwork during their first year when they are instructed as to how they might approach those challenges.
- First year students appreciate being treated as professionals and are not only capable of rising to the challenge but thrive as a result of it.
- Mentoring first year students empowers them to become agents of change.
- Skills learned by students through the GPS are immediately applicable and beneficial to students outside GPS.
- GPS is a catalyst for intellectual growth at the university.

Clearly, the second year offerings were better received by the students. The reasons for this are probably two-fold. Having been through the course, instructors were better able to communicate to the students the course objectives and how the course was structured to deliver those objectives. In addition, course format and operation were more clearly explained to the incoming students, so that their expectations would be more in line with what they would experience.

The Donahue Institute will be conducting focus groups with this cohort of GPS students this spring to identify the perceived impact of these courses a year later. These data will also be available in June.

Assessment of 2009 Offerings*:* A similar set of assessments is planned for the most recent offerings of the GPS.

Conclusion

The Great Problems Seminars were designed as an experiment to bring first year engineering students into meaningful contact with current events, societal problems, and human needs. Using global issues as a backdrop, seminars are co-taught by an interdisciplinary pair of faculty to explore the depth and breadth of the problem and to focus on active learning and group projects to link societal needs with technical solutions. Assessment demonstrates that the GPS courses achieve the original course objectives and that students clearly value how these courses prepare them for their futures.

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