AC 2007-869: INTEGRATION OF A WIND POWER ASSESSMENT PROJECT THROUGHOUT THE UNDERGRADUATE CURRICULUM

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Integration of a Wind Power Assessment Project throughout the Undergraduate Curriculum

Abstract

In the summer of 2005, simultaneous with the initial admission of a freshman class to a new general engineering program at the Polytechnic campus, ASU entered into an agreement with the Hopi nation in northern Arizona to assess the potential for development of wind energy resources on Hopi land. This provided a unique opportunity to involve students at the freshmen level in a problem based learning experience as they received one credit for assisting with the initial phase of the project, which included the erection of a 50 meter instrumentation tower on the reservation. At this point (January 2007) approximately ten month's worth of data has been obtained, and the analysis of this data is proceeding. Consequently, since the *analysis* of wind data requires substantially more technical maturity than that which was required for the first phase, there is another opportunity to involve students, but this time at the sophomore level. In this paper, the ongoing problem based learning experience based on the Hopi wind assessment project at ASU Polytechnic is described.

The series of annual time scales necessary to complete wind power assessment and development projects serendipitously coincide with academic time scales. In addition, if the data indicates that wind power development is economically and environmentally feasible on the Hopi reservation, the project will have entered the development phase as these students approach graduation. As a result, simultaneous with increasing levels of engineering ability, these students have the opportunity to be involved in an applied research and development effort at correspondingly increasing levels of technical responsibility throughout their undergraduate experience.

Introduction

Beginning in the fall semester of 2005, an multi-disciplinary engineering program was initiated at the Polytechnic campus of Arizona State University. A key feature of this program is the emphasis on a Problem Based Learning (PBL) approach to engineering education. Under this pedagogy, students are assigned engineering projects that are carefully planned by the faculty so that their completion requires mastery of specific sets of traditional engineering topics. Whenever possible, needed topics are presented by faculty members on a "just in time" basis throughout the curriculum, so that students immediately apply theoretical knowledge to real world engineering problems. This paper presents an example of the implementation of this pedagogy in a course designed to involve students in an ongoing research project.

In the fall of 2005, a project to assess the possibility of wind energy development on the Hopi nation in Northern Arizona was initiated in partnership with the tribe.[1] The location of the Hopi nation is illustrated on Figure 1 by the green outlined area in the northeast portion of the state. As figure 1 also illustrates, macroscopic evaluation of the climate for wind energy in Arizona is not promising. However, microclimates caused by the rugged topography of the high desert on which the Hopi reservation is located do have such promise, and this project seeks to accurately evaluate this potential.

This project has provided an opportunity to involve students in ongoing problem based learning activities. In the fall of 2005, a one credit elective class was added, and 22 freshmen students took the course. Lecture topics covered during this course included basic physics of wind energy, wind statistical characteristics and evaluation, instrumentation for the measurement of wind, basic principles of wind turbine performance, all of which were supplemented with PBL experiences. However, the primary task during the 2005/2006 academic year was the erection of a 50 meter wind measurement tower on the reservation to begin the accumulation of data on wind speed and direction. Raising and deployment of the tower required an analysis of the forces that would be encountered during the erection process, analysis of the loads that would be generated on ground anchors and other structures, and a thorough understanding of the construction procedures. To better understand this task, the students successfully analyzed, designed, manufactured and raised a ten meter tower using the same techniques that would ultimately be necessary in the raising of the larger tower. In March of 2006, the students then traveled to the Hopi nation, and participated in raising the 50 meter instrumentation tower.

At the present time (January 2007) approximately ten months worth of data has been collected from the tower, and analysis of this data is proceeding. The successful construction of the measurement tower and both the collection and analysis of measured data has resulted in another opportunity to involve students in more advanced problem based learning activities, this time at the sophomore level. In this paper, the methodology and results of this effort will be discussed.

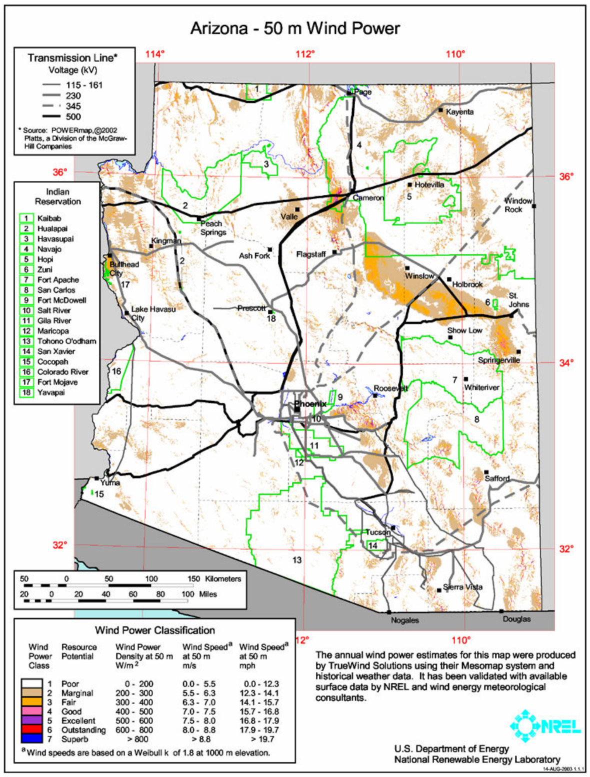

Figure 1 Wind Speed Map of Arizona[2]

Status of the Ongoing Hopi Wind Power Assessment Project

Beginning in the Fall of 2005, the wind assessment project had three specific goals as defined by the Hopi representatives.

1. Select and raise a wind assessment tower for 12 months of data gathering.
2. Prepare economic and feasibility analysis of wind power potential using the 12 months of data.
3. Establish a link between the engineering department and the Hopi Reservation High School for quarterly visits by engineering faculty and students to present educational experiences on alternative energy and recruit students to Arizona State University.

During the 2005/2006 academic year the

first goal was achieved as the tower was raised, data collection began, and the project entered into the evaluation stage. In addition, initial contacts were made with the Hopi Reservation High School, and plans were made to develop a problem based learning exercise for the high school classroom, which is presently being scheduled.

Continuing 2006-07 Goals and Course Planning for Wind Assessment

The goals for the project for the 2006-07 academic year were based both on the initial objectives and specific problems that had been encountered as data collection was initiated. Several of these challenges required increased technical maturity in comparison to those encountered in the previous year. Fortuitously, the freshmen students that were involved in the project at the freshmen level were now sophomores, and another one credit course was offered, but this time at the sophomore level. This course allowed the students that were initially involved as freshmen to remain engaged with the project.

It was decided that the course would cover several more increasingly advanced topics in wind energy, and that the students would be involved in addressing several problems that had been encountered. This was accomplished by a combination of targeted lectures, designed to build background, and problem based learning exercises. Each class was begun by stating a PBL statement that comprises their assignment for that week. A short lecture introduced the topics, followed by an overview of the problem and discussion of a solution plan. The class then worked sometimes in a team and sometimes as individuals to solve the problem. No standardized solution method was recommended. This allows the students to discover not only the information they need, but how to go about acquiring the information and forming it into a report. Some of the course goals are listed in the left column with selected topic coverage in the middle column and the encompassing problem statement in the right column:

Table 1 Course Content and PBL Statements

Course Goals	Lecture Topics	PBL Statement
Develop an energy model of the reservation	Thermodynamics, energy conversion, and energy "consumption."	1. A new Hopi village will be started on the reservation. Specify the energy requirements for a village wind turbine
Evaluate electricity demands vs. wind resources on the reservation	Worldwide energy demands and the wind resource.	2. What global effects are responsible for the wind on the Hopi reservation? How is this different from wind in Dakar, Senegal? What would you expect the prevalent wind direction to be in each place?
Match a wind turbine to the reservation needs	Wind turbine matching	3. Populate an economic spreadsheet listing all considerations important in recommending an energy solution to the Tribe.
Recommend a wind energy plan and turbine model	Wind turbine mechanical and aerodynamic design	4. Find the best material for a wind turbine blade.
Evaluate the short and long term economic effects with a wind turbine and recommend a plan of action.	Economic modeling of wind power	5. Benchmark wind energy use around the world and find a wind energy solution comparable to the Hopi Reservation.

PBL 2 required knowledge of the world's climate, especially near the Hopi reservation. The students utilized Google Earth (figure 2) and a portable GPS to identify the exact tower location to compare meteorological wind speeds.

Additional associated problems and exercises that were chosen for PBL exercises in this class were the following:

1. Debugging and repair of aspects of the assessment tower remote data transfer procedures and equipment.
2. Establishing a Data Reduction and Analysis procedure.

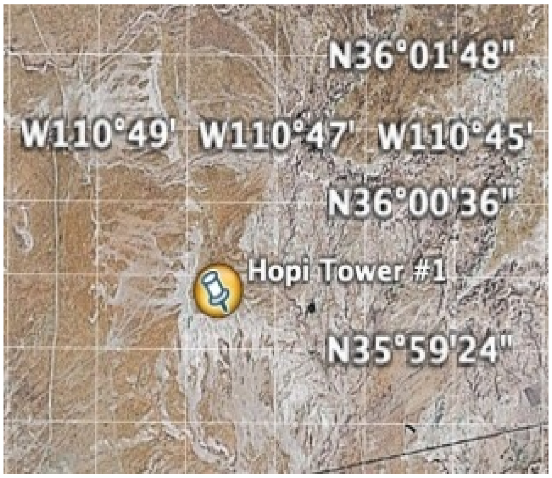

Figure 2 Location of Tower Using Google Earth and GPS

3. The development of a mock presentation to the Tribal council with a go/no go recommendation based on economic evaluations of the wind data.

Throughout this project, the theme of development of energy resources within the constraints of the Hopi culture is emphasized. Perspective on the role of sustainable energy conversion technologies is improved if students have a reasonable understanding of thermodynamics, the existing energy conversion infrastructure, and an understanding of the scales of the consumption of energy resources. In the general engineering curriculum students at the sophomore level have not yet been formally exposed to these concepts. Therefore, consistent with the just in time approach, the first lectures in the course were dedicated to an introduction to thermodynamics, principles of energy conversion, and the terminology and measurement of energy "consumption." Students then used the first law of thermodynamics and conservation of mass to develop the basic energy and power relations for wind power.

In addition to the concepts from thermodynamics, the scales of human utilization of energy resources were discussed. These discussions included the total worldwide consumption of energy resources and the distribution of this energy usage, as well as local and regional requirements. The local requirements are especially relevant when considering energy development on the Hopi reservation due to the remote location and relative lack of existing infrastructures. Consequently, technologies that are not economically feasible in developed areas may be quite competitive in locations such as the Hopi reservation, and it is important that the students understand this principle, both from a technical and an economic perspective. Some of the details for two of the above-mentioned PBL statements are given in Table 1.

PBL 4: Find the best material for a wind turbine blade.

The determination of appropriate wind turbine technology for the Hopi reservation requires understanding of the basic science. This need provided a practical opportunity to introduce basic concepts of horizontal axis wind turbine design in the class in PBL 4 (see table 1) . First, the development of aerodynamic forces on a turbine blade, how these forces work to produce torque on the shaft, and how these forces are distributed along the blade axis, was discussed. Second, the mechanical design of the blades was covered, including aerodynamic forces as well as those induced by centrifugal effects and blade twist. The result is a state of combined stress at the hub, caused by aerodynamically induced bending loads, centrifugally induced tension, and torsion induced by the centrifugal load combined with a twisted blade.

A lecture on airfoil nomenclature, the development of lift and drag by airfoil shapes as a function of angle of attack, and the concept of aerodynamic stall formed the background the students needed to understand the basic forces developed by horizontal axis wind turbine blades. After these concepts are understood, the analysis of the development of torque on a horizontal axis wind turbine is a practical application of basic vector mechanics[4]. The velocity vectors and aerodynamically developed forces are illustrated on the following figure:

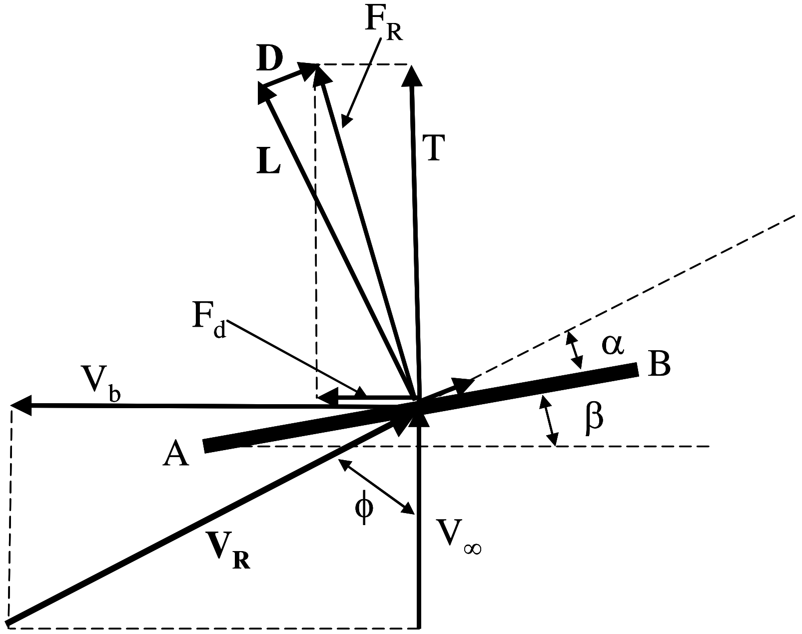

Figure 3: Aerodynamic Forces on Turbine Blade

This figure represents a top view of a cross section of a blade with the chord given by the line A-B, and with the axis of rotation being in the wind direction given by the vector V_∞. The blade "slices" through the figure from with a velocity V_b. The vectors labeled V_∞, V_b and V_R are the wind velocity, blade velocity and relative velocity respectively, and the angle β is the blade angle with respect to the plane of rotation. The relative velocity V_R impinges on the blade at an angle of attack α, developing lift and drag forces perpendicular and parallel to the relative velocity vector, and labeled L and D respectively. The resultant of the lift and drag vectors is labeled F_R on figure 3. The component of the resultant force F_R perpendicular to the plane of rotation is the thrust T along the axis, while the component in the direction of rotation is the driving force, F_d, that develops torque around the axis.

The blade velocity V_b depends on the radius from the hub. Consequently, to maintain a constant angle of attack at a design wind velocity, V_∞ the blade angle must change from root to tip, resulting in a blade twist. The calculation of this twist angle was another practical problem the students completed as part of this exercise.

This presented, at least in principle, an opportunity for practical application and reinforcement of the principles of mechanics and mechanical design. However, since the blade span is finite, the lift distribution along the span of the blade is not constant. In addition, near the hub, where the lower blade velocities result in lower aerodynamic forces anyway, for practical mechanical reasons the blade cross section transitions from an airfoil to a circular shape. The result is a relatively complex lift distribution along the blade, increasing from the beginning of the airfoil section, then falling off near the tip due to spanwise flow and vortex generation. This problem is essentially the same as that of a propeller, and the physics is well known.[3] However, in this case there was not enough time in the one credit course to develop this level of detail, and a illustrative lift distribution was provided to the students for a particular turbine geometry and operating condition. Using this lift profile, and the analysis of centrifugal forces developed by the rotating blades, the students then determined the state of combined stress on the blade at the hub. Finally, the students utilized the Cambridge Engineering Selector (www.grantadesign.com) material evaluation software package to choose suitable materials for the turbine blades.

The student results were impressive. They worked as individuals on this problem and found several ways to perform the analysis, all using centripetally induced and wind speed induced stresses at the blade attachment. None recognized a cyclical load from rotation which would require a fatigue analysis, but they did show interest when that concept was present at the end. No statistical assessment of their work is possible because of the low class enrollment. Anecdotally, most students found that carbon fiber composite would be the best material from a performance standpoint,(ignoring cost), while one student found a material with the best combination of price, strength and stiffness using the material index method found in [5].

PBL 5: Benchmark wind energy use around the world and find a wind energy solution comparable to the Hopi Reservation.

Students were also assigned the task of developing procedures for data analysis and presentation. Data, consisting of speed and directional measurements at 20 and 50 meter levels, is received daily from the measurement tower through e-mail. This data allows a realistic evaluation of the feasibility of wind power development on the reservation. The important parameters for site assessment are the wind speed distribution and wind direction, as well as the daily and seasonal variation of these factors. The most common method of presenting such results are wind speed probability plots, which illustrate the relative distributions of wind speed magnitudes, and wind rose plots, which illustrate the prevailing wind directions, including both speed and energy distributions. Examples of these plots are given by figures 4 and 5 below.

Wind speed frequency diagrams are often assumed to follow a Weibull distribution[3]. This is convenient when limited data is available because if the hypothesis is true, a frequency diagram can then be constructed based only on measurements of the average wind speed. The measured frequency distributions allow students to test the validity of that hypothesis The Weibull distribution is given by:

$$P(V) = \frac{k}{C}\left(\frac{V}{C}\right)^{k-1} e^{\left\{-\left(\frac{V}{C}\right)^{k}\right\}},$$

where P(V) is the probability of the wind being at speed V. The scale parameter, k, is usually assumed to be 2, and the shape parameter, C, can be found from:

$$C = \frac{V_{ave}}{\Gamma\left(\frac{1}{k}+1\right)},$$

where V_{ave} is the average wind speed and Γ is the gamma function. If the generated Weibull curve is compared to the measured data, a test of the assumption of such a distribution is possible. The Weibull curve is illustrated on the sample wind speed probability plot in figure 4 below.

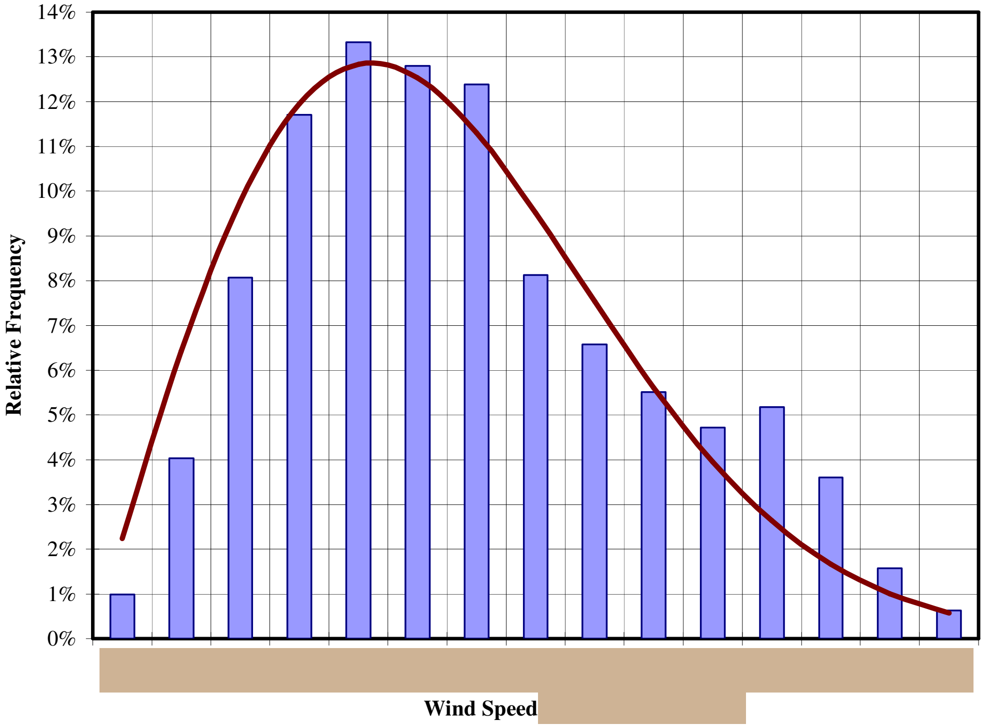

Figure 4 Example of Wind Speed Probability Distribution. The line represents the Weibull estimate for k=2.

The magnitude of the wind illustrated on figure 4 has been omitted due to the proprietary nature of the data. However, the results indicate that, at least in this case, the Weibull distribution will underpredict the available power from the wind. This example is used to illustrate to the students the advantage of thorough measurements and the need for careful assessment of the potential wind energy generation sites.

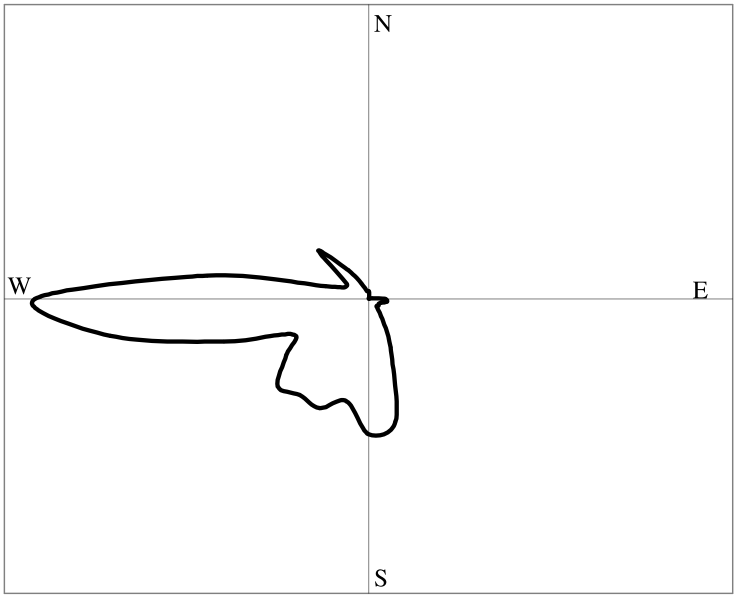

Figure 5 Example of Wind Rose Plot. This plot represents the directional distribution of the total incident wind energy.

Figure 5 is an example of a wind rose plot, which, for this data, indicates a prevailing west wind. This behavior may vary over short time periods, such as a few hours, and over longer time scales, such as seasonal changes. The students can use this data to develop criteria for siting wind turbines. For example, in this case it would be important ensure that the west side of the turbine site is as free of obstacles as possible.

Student performance on this problem was mixed. All students were able to retrieve and analyze tower data for wind speed, direction, energy and duration. They were all able to use the pre-packaged software included with the assessment tower [6] to generate the Weibull distribution and find the average wind velocity as well as a wind rose (Figure 5). Furthermore, they were able to select some candidate wind turbines that matched the wind profiles on the site.

The project is still continuing and the final results will be evident at the final presentation to the Tribe in June 2007.

This project has been invaluable in emphasizing problem-based learning, hands-on problem solving and social embeddedness working with the Hopi Tribe. The students have seen a diversity of culture with several trips to the Reservation and even in reading an additional literature assignment, Dark Wind, a novel by Tony Hillerman, all of whose books occur on the Northern Arizona Reservations. The novel contained Hopi terminology and a snapshot of life on the Reservation.

Comparison with ABET a-k

This ongoing course continues to support the general program outcomes as articulated by the ABET criteria for accrediting engineering programs, categories a through k of criterion 3. Specifically, Engineering programs must demonstrate that their students attain outcomes a-k, listed below.

a. an ability to apply knowledge of mathematics, science, and engineering
b. an ability to design and conduct experiments, as well as to analyze and interpret data
c. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d. an ability to function on multi-disciplinary teams
e. an ability to identify, formulate, and solve engineering problems
f. an understanding of professional and ethical responsibility
g. an ability to communicate effectively
h. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i. a recognition of the need for, and an ability to engage in life-long learning
j. a knowledge of contemporary issues
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

In addition, an engineering program must demonstrate that its students attain any additional outcomes articulated by the program to foster achievement of its educational objectives.

In support of categories a, d, e and k, students worked as a team and used their evolving technical skills to formulate and solve engineering problems at the sophomore level that they were first exposed to as freshmen. Interpretation of the wind data supports category b. The students developed and gave presentations in support of category g. The fact that this project involves the production of clean energy and integration of Hopi cultural constraints into an engineering project supports categories c, h and j.

Discussion

The Hopi Wind Assessment project described in this paper was not initiated as an educational program. However, since the timing of the project coincided with the initiation of the engineering program at ASU Polytechnic, and the time scales of the project coincides with the academic calendar, advantage was taken of the opportunity. In other words, for this project the planets were aligned. The question of whether to pursue similar opportunities for future cohorts of students will depend on the availability of appropriate projects. In particular, the project timeline must cover multiple years, and it must be possible to manage the technical difficulty of portions of the project assigned to the students so that as their abilities improve they are presented with appropriate challenges. Traditionally, through the curriculum students are involved in multiple projects of increasing difficulty that are almost autonomous, and the question arises as to whether a global project such as described in this paper is an inherently better experience. We believe that it can be *if* the project fits the constraints described above.

Involving students in multiyear projects does present significant challenges, especially in terms of project continuity, that should be taken in to account when considering implementation of these projects. For example, students do not always proceed through the curriculum as a cohort, with some making normal progress from year to year, while others may repeat courses or even take semesters off from school. As in any project, it is helpful if there is a sufficient number involved, and that specific critical expertise is not unique to any individual. (In this case, the number of actively participating students declined by 17 from the freshman to sophomore years, resulting in the loss of significant intellectual capital.) Coupled with this is the need for the curriculum to be flexible enough to accommodate elective credits so that enrollment can be more easily maintained in the course. Finally, it is important to have a team of faculty involved so that continuity of project management can be maintained as individual faculty responsibilities evolve.

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