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A Community-Engagement-Based Design Project in Introductory Environmental Engineering

Dr. Mary Cardenas, Harvey Mudd College

Dr. Mary P. Cardenas is the LaFetra chair in Environmental Engineering at Harvey Mudd College at Claremont, Calif. Dr. Cardenas earned her B.Sc. in Aerospace Engineering from Iowa State Engineering. She joined Rocketdyne as a propulsion engineer and worked on the Space Shuttle Main Engines, Atlas Engine, and the X-30 propulsion system. Dr. Cardenas received her M.Sc. and Ph.D. in Environmental and Mechanical Engineering from the University of California, Santa Barbara, studying the transport and fate of PCBs and sediments in the Saginaw River. She has been a member of the Engineering department at Harvey Mudd College since 1995, and has served as associate dean of Faculty for Academic Affairs. She is the co-author of the Journal of Engineering Education paper, ”Use of ”Studio” Methods in the Introductory Engineering Design Curriculum” and co-developer of the sophomore-level rocket-based experimental engineering lab course at HMC. Dr. Cardenas is currently exploring novel pedagogy for Introductory Environmental Engineering courses.

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Abstract

A collaborative, community-based design project was implemented in the upper-division undergraduate technical elective Introduction to Environmental Engineering at Harvey Mudd College. Students worked with multiple stakeholders in order to design a debris flow barrier for a wilderness land parcel acquired by a local conservancy group. The Rosemont Preserve is a wilderness area preserved in 2012 by the Arroyos and Foothills Conservancy. The Conservancy is working to steward the land and to produce programs for the local community. The ecological resource is co-managed by LA County Public Works. After the 2009 brushfires, the County installed concrete K-Rail barriers to protect residential areas from potential debris flows from fire-denuded hillsides. As part of the wilderness land preservation, the Conservancy is interested in the design of a more-aesthetically pleasing debris flow barrier for the Rosemont Preserve.

The conservancy board of directors served as liaisons for the design project, provided background material and the project statement to the student team, as well as answered questions and provided guidance during the design process. Local residents (serving as volunteers for the Conservancy) also served as resources for student questions. LA County Public Works oversees the placement, maintenance, and removal of K-Rails. The student team characterized the wilderness site; acquired relevant GIS data; studied the physics of debris flow and examined previous debris flow barrier designs. The team produced alternative designs for the barrier and chose the best design by applying design metrics. The alternative designs and rationale for the chosen design were presented to the board of directors of the Conservancy.

The design project included a significant tie to a community involved with stewarding and managing an ecological resource, and engagement of the students with that local community. Most importantly, the resource was co-managed: it involved multiple stakeholders, sharing power and collaboratively engaging in the decision-making process for the ecological resource. Co-managed projects can provide opportunities for a richer, more complex educational experience for undergraduate students, and one that is representative of how natural resources are currently being managed.

This paper summarizes previous community-engagement learning, particularly in the context of undergraduate engineering education; argues that co-managed ecological resources provide good opportunities for increased student engagement with communities; describes an undergraduate engineering design project involving a co-managed resource; and presents assessment data on the educational effectiveness of the design process while working with a co-managed resource.

In conclusion, the co-managed project provided richer and increased communication between the multiple stakeholders. However, some students expressed frustration with the difficulties of getting a good communication flow with particular stakeholders, and pointed out how this changed their approach to certain aspects of the design process. For future co-managed projects, it is recommended that more work be done beforehand to get all stakeholders on board in order to improve the student experience.

Background

One characteristic of community-centered instruction is that the students learn from others, often in a group setting, where students are encouraged to be active participants. The definition of ‘group setting’ suggests constituents such as teachers, family members, and members of the outside community. There are many reasons to engage in community-centered instruction: to expose students to real-world ethics and government policy; to practice communication with people outside their own academic and social community; to promote student reflection on how their work affects their community and how community affects their work; to provide a benefit to the community (a design of a useful device, information gathering and analysis); to engender a sense of professional responsibility; to provide a cultural context for their work, and additional focus on social issues. Experiential clinical and service-learning programs involving local communities have been performed in the health professions[1], public health[2], and social work[3], as well as in engineering education.

Typically, in engineering education, community engagement involves design projects for not-for-profit organizations. The “community” is often a sole liaison from the not-for-profit organization, and the students (often in teams) generally have two major times they communicate with this “community”—during the initial definition of the project and at the end of the project, when presenting the final design or product. There are projects where the final deliverable is a written report, not involving any further face-to-face communication or feedback with the community sponsor. For many of these projects, there is only one person representing the community, or if there are multiple liaisons, they are often of the same ‘type’—perhaps co-workers at the non-profit organization, who generally have the same objectives and focus regarding the direction of the project.

The Engineering Projects in Community Service (EPICS[4,5]) program at Purdue is a good example of undergraduate engineering design projects for community service agencies. The EPICS projects are multi-year projects, involving teams of 8-20 undergraduate students, liaisons from the community service agencies, graduate-student teaching assistants, and faculty advisors. The undergraduate teams are vertically-integrated; this means the teams include students from the first year through the senior level. Past project sponsors include local elementary schools, Habitat for Humanity, museums, and natural resources and conservation organizations. A number of institutions of higher education have engaged in K-12 outreach work[6]. Typically, students work with K-12 partners in order to produce curricular materials intended to introduce young students to engineering and to promote interest in engineering and science. Padmanabhan and Katti[7] described an example of a capstone project in civil engineering at North Dakota State involving community engagement. In this project, students worked with a local homeowners association to mitigate slope instabilities.

In common to these engineering projects is a sometimes limited amount of back-and-forth between the students and the community sponsors. Typically the students contact the community liaison at the beginning of the project (during initial data gathering and project definition), and then have little or no contact until the end of the project, where generally there is a final presentation or report provided to the community. The community contacts the students do have are a good learning experience, and very valuable to these types of projects, but I believe that many projects could be improved with more-integrated, continuous threads of communication between the students and the community actors.

Collaboratively managed, or co-management projects[8], involve multiple stakeholders working together. Co-management is usually described in the context of ecological resources, where community members and state agencies share in decision-making processes; in particular, co-management focuses on the *collaborative learning* and *power-sharing* that participating social actors engage in while making decisions[9]. Tensions, clashing, and conflicts can exist between various social actors in co-management scenarios; however, the recognition and valuing of potentially different objectives and concerns is paramount in co-management.

Rather than having a sole decision maker, or a top-down management approach, co-management involves multiple partners; therefore, an academic project involving a co-managed resource should benefit from the students becoming a social actor in the process—rather than simply a receiver of knowledge from a sole client with one opinion or set of knowledge--and lead to an increased level of continued involvement between the students and the community actors throughout the entire project.

Community-engagement in an undergraduate engineering design project involving a co-managed resource

E138, Introduction to Environmental Engineering, has been offered as an upper-division technical elective at Harvey Mudd College (HMC) since 1996. HMC offers a degree in General Engineering, and students often gain more discipline-specific learning through careful choice of their technical electives and capstone clinic projects. E138 has typically been taught in a lecture-based, problem-solving format. The primary purpose of the course is to introduce students to the main concepts and applications in modern environmental engineering, including fate and transport of surface and groundwater pollution (both classical pollutants and toxic substances); risk assessment and analysis; and air pollution. The students are taught integral and differential methods to describe various transport mechanisms for water- and air-borne contaminants, and solve problems to analyze time-dependent and spatially-varying contaminant concentrations in the environment. Societal factors are discussed, particularly when introducing toxic chemicals and risk assessment/analysis. The social, economic, and political factors driving contamination and clean-up are addressed using real-world examples.

For the course offering in Fall 2012, nine students enrolled in E138. Eight of the students were engineering majors; the ninth student was an Environmental Analysis major. Seven of the students were female. Two students were seniors; six were juniors, and the remaining student was a sophomore.

During the Summer of 2012, I restructured the course to include a half-semester community-based design project. Although the lecture-based, problem-solving course addressed a number of course objectives, I felt that more emphasis on the interplay between societal factors and technical work would serve the students well. Although case studies can be extremely useful, I (and others[10]) have found that students tend to learn more from problems they have taken ownership of, that involve first-hand experience wrestling issues, thus lessening the not-my-problem disengagement, inattentiveness, and indifference that can crop up during lecture-only learning. My objectives were to find a small design project for a local environmental conservation group; ideally with multiple, not-necessarily-technical liaisons; and most importantly, involving a co-management scenario. Collaborative or co-management is a term from environmental management literature[8,9], describing the management of ecological areas or resources by multi-stakeholders—often a government agency in conjunction with local residents and/or community groups. Fisheries and forests are often described as co-managed resources. Carlsson and Berkes[9] write, "Co-management of specific areas and resources is carried out with the participation of different actors that typically try to find ways to learn from their actions and adapt the behavior to the consequences of their own, and others', actions, otherwise they cannot form any collaborative arrangement." Interestingly, they further state that the ecological area or resource *itself* can be seen as an actor, reacting unpredictably and non-linearly to its own "management," and that the adaptive quality of co-management is well-suited to handling this uncertainty.

In particular, co-management scenarios can be viewed "…as a means to create the political space within which communities and other groups can develop the knowledge and skills to solve their own problems." For the E138 design project, a co-managed ecological area would allow the students to become yet another 'social actor' in the management scenario, while engaging with the community groups and government agencies in order to develop alternative solutions to a problem. This type of project would stretch the students' intellectual muscles, helping them juggle potentially differing objectives, constraints, and weightings when working with the various co-management actors.

We chose a design project to investigate alternative debris flow barriers for a local conservancy group. The Arroyos & Foothills Conservancy (AFC) is an Altadena, California community-based organization working to steward the land, and provide access and educational experiences for the area residents. In June of 2012, AFC and the Crescenta Valley community preserved 7.75 acres of wilderness land, called the Rosemont Preserve. The preservation of this land effectively doubled the amount of "open space" available to the La Crescenta community.

The Rosemont Preserve is at the mouth of Goss Canyon. Goss Canyon is a 300-acre wilderness area mostly maintained as wilderness by private landowners. Directly south and west of Rosemont Preserve are residential areas of La Crescenta (Figure 1.) In 2009, the Station Fire burned 650 km^2 of the Angeles National Forest, including Goss Canyon. Due to the increased threat of mudslides from the fire-denuded hillsides, LA County Public Works (hereafter referred to as "the County") installed concrete K-rails, a type of Jersey barrier often used as a traffic barrier (Figure 2) to protect residential areas from the possibility of additional debris flow. Three years after the Station Fire, many of the K-rails have been removed, but a 48-meter-long line of them remains in the Rosemont Preserve (Figure 3.) Local residents find the K-rails to be an eyesore and detrimental to property values, and the AFC is particularly interested in working with the County to find a more aesthetically-pleasing alternative to the K-rails in Rosemont Preserve.

Two members of the AFC board visited the classroom, and presented a general project statement to the E138 students, approximately mid-way through the semester. One board member is an engineer, and the second is a flute repairman, and both are deeply engaged in the preservation and stewardship of the Rosemont Preserve. The students and the board members participated in a question-and-answer session after the project statement and background were presented. The majority of the students in E138 had taken the first-year engineering studio design course[11], which runs the students through the design process. To build on this knowledge, major project deadlines were thus based on typical design-process goals: 1) a revised project statement, and objectives and constraints were due one week after AFC visited our classroom; 2) functions, means, and alternative design concepts were due 2 weeks later; 3) design metrics and an evaluation of the alternatives designs were due 2 weeks before the final presentation; and 4) a draft presentation including final design selection was due the week before the final presentation.

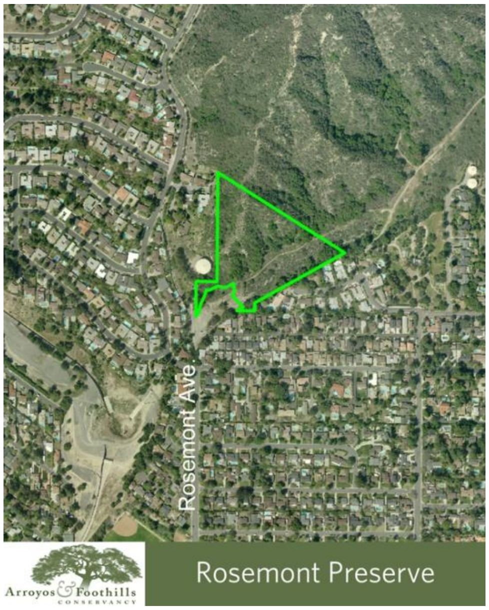

Figure 1. Location of Rosemont Preserve[12] (green triangle)

Figure 2. K-Rail being installed in La Crescenta, CA. Photo courtesy of Crescenta Valley Weekly.

Figure 3. Line of K-Rails installed in Rosemont Preserve. Photo courtesy of Tim Wendler and Paul Rabinov.

The students divided themselves into three sub-teams: Geographical Information Systems (GIS) analysis and mapping; Floodplain research and solutions; and K-Rail design. The GIS sub-team of three students produced maps of the area, which helped to analyze the magnitude of the design debris flow. The Floodplain sub-team of two students investigated ways to restore the floodplain, focusing on effects of addition or removal of various plant species (invasive and native.) The four-person K-Rail design team focused on exploring the design space to produce alternative designs, and ranked the designs. All students were involved in defining design objectives and constraints, and in evaluating the designs with metrics.

The AFC liaisons provided a contact list for the students, which included LA County Public Works officials. In particular, the County is the social actor in charge of K-Rail removal and/or replacement with an alternative design, so the E138 students were tasked with determining the County's specifications for K-Rails as a debris flow barrier. This type of multi-stakeholder system is characteristic of co-managed ecological resources, and provided the students with an experience of dealing with multiple (and sometimes orthogonal) objectives and constraints, depending on which social actor they were working with.

As is typical with many community-based projects, much of the communication was done using email, and face-to-face meetings were arranged by email, rather than phone contact. In fact, the phone communications were done mainly through text messaging and private mobile phones, rather than by using institutional resources; however, this was only true of the E138 students and the Conservancy members, as the County communicated solely using official County email.

The students' initial communications with the County were promising, and the students received some answers to their questions about K-Rail design specifications, but soon all response from the County ceased. It is not clear whether this was due to the type of questions the E138 students asked, or because the County employees were not able to prioritize the K-Rail removal project. I had no contact with the County prior to the initiation of the project, and although AFC had discussed K-Rail replacement with the County, they were not told that a student group would be working on design alternatives. However, this caused the E138 students to come up with other ways of verifying the County's numbers, defining design specifications, and justifying their choices, which increased the students' learning and knowledge in a way that would not have happened had the County simply provided information. Thus, although the reticence of the County was not optimal, it was a good learning experience of real-world (lack of) communication, and how to form a useful response to such situations.

In contrast, the AFC responded quickly and thoroughly to student questions. The students were a bit perplexed with *how* the AFC responded; often, the students would write one board member, only to receive a response from an entirely new, different social actor from the Conservancy. One AFC member even visited campus after receiving a forwarded email message from the E138 students, and spent an hour answering questions; before this person visited, the students did not know this person existed as an AFC member. Interestingly, AFC only provided the students with a list of County contacts, and neglected to give the students a list of AFC members. It is likely that AFC members, being a closely-knit community, forwarded the students' email messages widely, and this may have contributed to the number of different AFC actors who became involved in the project. The varied social actors from AFC, and their different backgrounds, contributed to the desired community-engagement nature of the project. I was also pleased that the communication continued throughout the project; this was not the typical project in that the majority of the discussion occurred during the project definition stage—the students and many of the co-management community actors were engaged through the bulk of the project.

During the design-method process, the students struggled with the definition of metrics, which is typical. As part of the design process, objectives are defined and weighted. Quantifiable metrics are written for each objective, and then are used to numerically rank each alternative design. Since "aesthetically pleasing" was a main objective for AFC, the students needed to quantitatively define a metric for that objective. At the suggestion of AFC, the students investigated architecture and landscape architecture literature in order to gain direction on how to write such a metric. The students' first attempts were fairly weak, using phrases such as 'more natural colors,' and 'natural-looking materials,' but progressed to survey-based methods, and quantitative metrics, including non-linearity of color, geometric profile, geometry of faces; visual consistency; opportunity for human interaction with the design; and consistency with the environment in color, texture, locality of source material, spatial dimensions consistent with local features (Table 1.)

Another type of community engagement emerged from this metric, which I had not foreseen: the students decided to survey their own peer group (undergraduate students at HMC) in order to help rank the designs. I assumed they would survey the Conservancy board, or La Crescenta community members, but the students brought in the participation of the college community.

Table 1. The E138 students' metric for the "aesthetically-pleasing" objective.

Metric	**Non-linearity**	**Visual Consistency**	**Human Interaction**	**Consistency with Envr**	**Conduct Survey**
Categories	Color, texture, geometric profile, geometry of faces	Lack of randomness, clear flow, color balanced, consistent pattern, consistent texture, consistent size		Color scheme, texture, locality of source materials, dimensions in relation to space available and nearby features	
Description	Non-linearity creates interest as well as being more "natural"	Consistency creates balance and a sense of cohesiveness	Provides seating, provides a border to a path to walk beside, etc.		Ask participants to rank all designs. Average all results. Aim for 20+ respondents
Rank 5 (Best)	Non-linear in 4 categories	Visually consistent in all 6 categories	Several intended, obvious interactions with structure	Highly consistent in all 4 categories	Best design
Rank 4	Non-linear in 3 categories	Visually consistent in 4-5 categories	Some reasonable interaction implied and intended	Highly consistent in 3 categories or slightly consistent in 4	
Rank 3	Non-linear in 2 categories	Visually consistent in 3 categories	Some logical interaction with structure intended and implied	Highly consistent in 2 categories or slightly consistent in 3	Second best design
Rank 2	Non-linear in 1 categories	Visually consistent in 1-2 categories	Minimal or non-intuitive interaction intended and implied	Highly consistent in 1 category or slightly consistent in 2	
Rank 1 (Worst)	Linear in all categories	Visually inconsistent in all categories	No interaction with the structure intended	Inconsistent in all categories	Third best design

The students' survey included representative photos of their three design alternatives, and simply had student peers rank the photos based on which one they found most aesthetically pleasing.

The student group presented three alternative designs to replace the K-Rail as a debris flow barrier, and ranked these designs based on their metrics. The designs included large woody debris; gabions; and earth berms (Figure 4.) Results from the design process and supporting analyses were presented to the AFC during the last week of the semester. Attending AFC members assessed the project presentation and designs, and the students were given a post-course assessment to evaluate the effectiveness of the design process instruction, and to survey them on the community-engagement aspects of the design project.

Designs

K-Rails

Woody Debris

Gabions

Earth Berms

Figure 4. Alternative designs for the K-Rail replacement.

Assessment

As mentioned previously, the majority of the students in E138 had been taught the design process in E4, our Engineering Studio first-year course[11]. Therefore, I was interested in the students' assessment of their skills and knowledge of the design process. Students self-rated their abilities to identify objectives and constraints, write quantifiable metrics to evaluate designs, evaluate designs based on these metrics, and present results based on the design process. A post-course assessment was administered on the final day of class; all nine students participated in the assessment (n=9). The results are presented in Table 2, based on a scoring from 1 to 5, with 5 corresponding to “strongly agree” and 1 meaning “strongly disagree”.

The students rated their knowledge and skills related to the engineering design process highly, ranging from a low of 4.22 (out of 5) regarding their skills at writing quantifiable metrics, to a high of 4.67 evaluating their skills at evaluating alternative designs. It was not surprising to see the lower score on the ‘writing metrics’ skill, as the students struggled to come up with a good, quantifiable metric for “aesthetically pleasing”, and recognized that I had to push them hard before they came up with an acceptable metric. They also noted that their survey-based results for that metric were biased by their own poor selection of photos of the alternative designs. Generally, the students finished the course with good confidence in their skills in the design process area.

Table 2. Student assessment of design-related knowledge and skills

Skill and knowledge assessed	**Average response (1-5, 5 being highest), n=9**
I can identify the clients’ objectives and constraints.	4.44
I can write good, quantifiable metrics based on design objectives.	4.22
I can evaluate alternative designs based on metrics.	4.67
I can prepare and give a good presentation on the design process and chosen design.	4.56

I was concerned with whether the students had come in with strong design-process skills, and would find the review tedious, but essay-type reflective questioning (questions 3 and 4 in Table 3) provided evidence that the majority of the students felt the project was useful: “We clearly did not remember what we had learned [in other courses] about the design process and I for one really appreciated the refresher.” “Most of the concepts of engineering design from E4 have not been used since that class. In addition, the functions, objectives, and constraints have never been applied to a project with an outside client. I feel the more practice with these design strategies, the better,” and “It was useful. Having taken E4 1.5 years ago, most of the design process was lost on me.” However, there was one student who said, “I felt it was too repetitive having already taken E4 and in my second semester of Engineering Clinic. But it is a good review for a junior not yet in clinic.”

Table 3. Questions on essay assessment form

1.) How much did community involvement affect your design process and/or design choices?
2.) If you could have changed anything about the community involvement aspect, what would it be?
3.) What aspects of the project were most difficult for you, and why?
4.) Was it useful for you to run through the design process again?

Questions 1 and 2 (Table 3) on the reflective essays focused on the community-engagement portion of the project. Students pointed out that a major deficiency of the project was the lack of a formal site visit. AFC offered the opportunity, but neither I, nor AFC, deliberately set a date and time for the site visit, relying on the students to realize the necessity of the visit, and schedule one. However, the students did not take advantage of AFC's offer of a tour of the site, and in the evaluations, the students mainly blamed the course structure, saying an early, mandatory site visit was necessary. The most frequent response seen in the student essays was that they wished for more interaction with the County, suggesting that a pre-established line of communication with a single point-of-contact would have helped. Most students observed that communications with AFC were frequent and informative, but one wrote, "I would have increased the frequency and amount of communication between the class and individuals from the Conservancy, County, or our peer group." The same student also pointed out that major frustrations were due to communications problems across student sub-groups, and unbalanced effort levels of various students. Another student wrote, "Communication between the [student] teams also greatly improved student productivity. Having the GIS maps needed allowed for easier characterization of the design alternatives."

I also surveyed the five attending AFC members regarding their views on the student presentation and the effectiveness of the designs. Table 4 summarizes these results.

Table 4. Assessment of AFC of students' presentation and designs.

Assessment questions	**Average response (1-5, 5 being highest), n=5**
The presentation demonstrated effective organization of the material.	5
The presentation used supporting materials (graphics, etc.) appropriately.	5
The presentation included appropriate technical/engineering content.	4.8
The metrics quantifying the design objectives were appropriate.	4.8
The alternative designs met the design objectives.	4.8
The design selection was well justified.	4.8

AFC members assessed the presentation organization and use of supporting materials very highly (5 out of 5), and slightly lower on the technical content of the presentation (4.8 out of 5.) When I debriefed the members of the AFC, one member said the lower score was because the students did not do as good a job of explaining the design process, as the AFC preferred to hear more of a story on how the process proceeded. Similar scores (4.8 out of 5) were given regarding the design content of the presentation (the metrics definitions, alternative designs, and final design justification.) Again, those slightly lower scores were due to the AFC not being familiar with the design process, and with the students not focusing enough on defining the terms during the presentation. However, that said, 4.8 out of 5 indicates that the majority of the AFC scored these skills at the highest end (5 out of 5), with one member scoring these as 4 out of 5, which indicates strong satisfaction of the AFC with the presentation and the design content. In response to an essay-type assessment of the students, one student wrote, "One a side note, I have one comment to improve the presentation. I noticed that many of the people in the audience during the presentation were not familiar with functions, objectives, constraints. So, in the future, it would be helpful to explain the definitions in the context of how we use them at Harvey Mudd College." This comment and others indicates that some students were using the presentation as a learning experience, and will take away important lessons regarding knowledge of their audience.

Conclusions

This paper investigated the use of design projects involving a co-management scenario (involving multiple stakeholders) in an undergraduate environmental engineering course. An important question was whether co-managed projects would increase and richen the amount of interaction between the undergraduate students and the various project stakeholders, compared to previous single-client projects, where most of the communication takes place very early on in the project, and then dies out until the final presentation or report is due. This project involved three major social actors: the HMC undergraduate students in E138; the Arroyos & Foothills Conservancy; and LA County Public Works. I found that communication between the E138 students and AFC was increased over the typical initial project-definition and background-information exchange, and that the students benefited from interacting with a range of board members and volunteers from the Conservancy. However, interaction between the E138 students and LA County Public Works contacts was limited to a single back-and-forth email exchange. The sole email response from the County contained good, useful information, which helped the students tremendously, but the students' subsequent questions garnered no response from the County. This caused frustration to the students, who had to scramble to come up with other ways to define design specifications and gather needed information. Although this resulted in spurring even more learning in the students, the situation points out the importance of making sure all social actors are on board during a co-managed community-based educational project. Other findings included the importance of a required, pre-arranged site visit to the ecological resource, since the students did not have the motivation or time to plan such a trip themselves, even as they recognized the importance of such a visit.

The HMC E138 student team worked with the Conservancy and the County to explore alternatives to K-Rails as a debris flow barrier in the Rosemont Preserve. The student team provided three alternative designs to replace K-Rails as a debris flow barrier in the Rosemont Preserve; a characterization of the site including GIS maps and analysis; recommendations to restore the floodplain; and justification for a final design choice. The student team gained more experience and skills implementing the design process for real-world clients; wrestled with potentially-competing objectives of the Conservancy and the County; learned good communication practices between themselves and the various social actors involved in the co-managed project. The Conservancy found benefit in the proposed designs for K-Rail replacement, and are interested in continuing the work with Harvey Mudd College to further develop the designs and explore implementation in the Rosemont Preserve.

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