ENGAGING K–12 STUDENTS IN THE ENGINEERING CLASSROOM:
A Creative Use of Undergraduate Self-Directed Projects

Omolola Eniola-Adefeso
University of Michigan • Ann Arbor, MI 48109

Engineering, along with science, has been the engine that drives innovation and will continue to be important in tackling the new and unique transportation, environmental, and health problems that we face as a global society. For the United States to stay relevant in the new "global economy" we must position ourselves to take a lead in tackling these problems and the key is to maintain strength in our "human capital."[1] Yet, the United States continues to lag behind other developed nations in the quality of its workforce. For one, only 5% of undergraduate (UG) students in the United States currently receive their degrees in engineering compared to ~50% in some other countries.[1] Furthermore, nearly 62% of all Ph.D. degrees in engineering granted in the United States in 2007 were to foreign students but visa regulations make it difficult for them to stay in the United States.[2] Continuing on this course will lead to fewer engineers with high-quality skills available to lead innovation in the United States.[1]

One major contributing factor to the low number of students receiving degrees in engineering is the two decades of decline in student enrollment in engineering. While there has been some recent improvement in enrollment due to the current global recession highlighting the apparent stability of engineering jobs,[3] the United States is still projected to face a shortage of up to 70,000 engineers in this decade.[1, 4] Recent surveys by the American Society for Quality (ASQ) and the National Academy of Engineering (NAE) suggest that this shortage and decline in engineering enrollment is linked to K–12 students having little knowledge of engineering careers in addition to perceiving engineering as "boring."[5] The NAE study further concluded that the money and effort put forth by engineering organizations to combat this problem have had little impact. Overall, what is clear from the literature is that boosting undergraduate enrollment and increasing the number of graduates in engineering are two key parameters in keeping the United States competitive in the global economy of the 21st century and beyond. Thus, additional effort needs to be placed on making the new generation of K–12 students aware of the engineering profession and its versatile contributions to solving many critical global issues.

***Omolola Eniola-Adefeso** is an assistant professor of chemical engineering at the University of Michigan. She received a B.S.E. from University of Maryland Baltimore County (UMBC) and a Ph.D. in chemical engineering from the University of Pennsylvania with graduate research support from NASA GRSP. Her research interests include shear-dependent adhesion and migration of leukocytes and design of cell mimetics for vascular-targeted drug delivery.*

The two most common outreach tools used in presenting engineering to the public are 1) professional engineers or engineering faculty spending time in the K–12 classroom to talk about their profession and 2) informal educational programs (*e.g.*, tutoring) focused on improving students' understanding of math and science.[5] Visits from engineering professionals, however, often leave students unable to see a path for themselves to achieve the level of success perceived in their corporate/university visitors. Likewise, tutoring/mentoring outreach efforts often fail to connect K–12 students back to the engineering—*i.e.*, heavy focus on math and science. Presented herein is a different approach to introducing K–12 students to and exciting them about chemical engineering, where a required undergraduate chemical engineering (ChE) course project is coupled with a science fair style presentation to local high school students. Specifically, students enrolled in the Mass and Heat Transfer (M&HT – ChE 230) course at the University of Michigan (U of M) in groups of four were asked to design and present one original experiment suitable for a high school teacher to use in introducing a basic heat or mass transfer concept to his/her high school science class. Each student group was provided a $25 budget to build their experiment, and local high school students from the Ypsilanti school district were invited into the classroom to experience and judge ChE students' design outcome on its ability to engage their interest in engineering as a career choice. This paper discusses the success, benefit, and practical suggestions for replication of this unique approach to K–12 outreach.

A

ChE 342 Fall 2008
Group Project Evaluation Sheet
(High School Participant)

Group No. ________________ **Project Title** ______________________________

On the scale of 1 - 10 (10 = highest score);

How original was the experiment? (Q1)

How relevant is this experiment for introducing heat and mass transfer principle to you? (Q2)

How excited were you by the experiment? (Q3)

How engaged were you with the experiment? (Q4)

Did you learn something new? (Q5)

How successful was the experiment is getting you interested in Engineering? (Q6)

How likely are you to be able to repeat this experiment in your classroom if provided the materials? (Q7)

B

ChE 342 Fall 2008
Group Project Evaluation Sheet
(Graduate and Faculty Participant)

Group No. ________________ **Project Title** ______________________________

4 = Excellent; 3 = Good; 2 = Partial; 1 = Attempt made; 0 = Absent

Creativity (Q1)					
Does the group project or display demonstrate ingenuity in the design and development?	4	3	2	1	0
Has the students shown creativity in the design	4	3	2	1	0
Scientific Thought (Q2)					
Is the experiment appropriate for the study of heat and mass transfer principles?	4	3	2	1	0
Is the experimental goal clearly stated?	4	3	2	1	0
Has appropriate controls been made?	4	3	2	1	0
Were the observations and information gained clearly summarized?	4	3	2	1	0
Does the data collected justify the conclusion made?	4	3	2	1	0
Thoroughness (Q3)					
Is the project the result of careful planning?	4	3	2	1	0
Does the project indicate a thorough understanding of the chosen topic?	4	3	2	1	0
Does the experimental design/setup reflect students' originality?	4	3	2	1	0

On the scale of 1 - 10 (10 = highest score);

How relevant is this experiment for introducing heat and mass transfer principle to high school student? (Q4)

Can the proposed experiment be easily reproduced in a high school classroom/laboratory setting? (Q5)

How safe is the proposed experiment for a high school classroom/laboratory setting? (Q6)

How economical is the experimental setup? (Q7)

Figure 1. *(A) High school student survey and (B) faculty, teacher, and graduate student survey.*

METHODS

Project Description. For their course project, students enrolled in the M&HT course at U of M, in groups of four, were asked to design an original experiment that would be suitable for a high school teacher to use in introducing a mass or heat transfer principle/concept to students in her/his class. Students were assigned to groups semi-randomly where self-selected pairs were randomly matched to form groups of four. Groups were asked to design their experiment such that it can serve to attract high school students to ChE. Experimental design was subject to the following constraints: i) experiment must be feasible; ii) materials/setup cost for the experiment must not exceed $25; and iii) designed experiment must be easily set up in a high school classroom. Each group was required to present an in-class demonstration (demo) of their experiment at the end of the semester to a diverse audience composed of local high school students and teachers and chemical engineering graduate students and faculty. Groups were also required to submit a five-page comprehensive written description of their design.

Project report. For the written project description, groups were required to include a rationale for the design, a detailed list of required materials, and a description of the experimental setup. In addition, groups were asked to include any experimental measurements taken during the design process, describe all relevant mass/heat transfer equations, and include their expected experimental outcome(s) and conclusions.

Project presentation. The in-class demo format was less stringent; groups could have one demo that is reused for multiple sets of judges or multiple disposable (inexpensive) setups. Furthermore, in-class demos could not include the use of any hazardous materials (*e.g.*, organic solvents) or high temperature/pressure experiments. Groups were provided a budget of $25 (see project description) to obtain materials for their in-class demos and given access to a senior engineer within the department to provide guidance on setups and choice of materials.

Grading. Projects were graded on originality, feasibility for reproduction in a high school classroom, and the quality of the in-class demo. The written report counted for 75% of the total project grade and the in-class demo for 25%. Total project grade was given on a 100-point scale and represented 10% of the final course grade. The project presentation grades were derived from surveys (Figure 1) administered to guest participants that included high school students (HSS), their teachers, and ChE graduate students and faculty. The survey to HSS focused on evaluating the ability of ChE student-designed experiments/demos to excite and engage HSS about chemical engineering, and the survey to the faculty team (including HS teachers and ChE graduate students) focused on evaluating the creativity, scientific thought, thoroughness, and the fitness of the demos for a high school audience. To ensure that each student group gets an adequate number of HSS viewing their demo during the presentation window (2 hours), HSS were given survey sheets prefilled with ChE group numbers, and each HSS was required to visit at least five teams.

Recruitment of High School and ChE participants. High school participants were recruited from the Ypsilanti local school district via the University's Office of Engineering Outreach and Engagement – (OE).[2] The group consisted of 15 10th–11th graders enrolled in the general chemistry class and their teachers (2). Participating HSS were only required to have a B average in the chemistry course. Graduate students (4) and faculty judges (5) were recruited within the Department of Chemical Engineering via e-mail solicitation.

Data Analysis. The University of Michigan Internal Review Board approved all surveys used in assessing the outcome of the course project. Numerical values from surveys were converted to a 100-point scale and averaged over all surveys submitted for individual groups. Significance of data was assessed via a student's t-test with p value < 0.05 considered significant.

RESULTS

ChE student project outcome. There were 115 students enrolled in the Fall 2008 M&HT course; thus, a total of 29 teams participated in the class project. Group assignments and the project description were available to students by the third week of classes. Groups had the freedom to select any mass or heat transfer principle as a basis for their design and were encouraged to consult with the course instructor on the scope, scale, and feasibility of their projects. About a third of the groups based their experiments on mass transfer principles, and two teams attempted experiments involving both mass and heat transfer. Ten teams consulted with the instructor on various aspects of their designs prior to the in-class presentation. The average written report score for teams that sought instructor input was not significantly different from the average for teams that did not—92.9% vs. 94.2% ($p = 0.46$). Similarly, the average presentation score for groups that consulted with the course instructor (78.6%) was not significantly different from the average for groups that did not (80.9%). There was also no significant difference in the presentation scores (average of all surveys) between mass or heat transfer based experiments.

Overall, many student groups offered a unique and fun take on several mass and heat transfer principles. For example, the team with the highest project score designed a simple, yet effective, experiment to illustrate the basic principles of conductive heat transfer. Specifically, this group set up a station for HSS to cut through ice using body heat that was delivered to the ice via a heat-conducting material. By varying the type of material used (graphite, aluminum, and plastic) and contact area between the body and the material (one vs. two fingers), the group was able to explain Fourier's law for heat conduction to 10th-11th graders. For instance, a deeper cut into the ice by a particular material would suggest to the HSS that the material has a higher heat conductivity compared to other materials. The fact that many of the HSS (and at least one ChE faculty) expressed their surprise that graphite conducted heat much faster than aluminum highlighted the success of this particular demo in achieving the project goal. Table 1 lists titles and topics of other noteworthy student-designed experiments. Details of these and other successful projects with instructions for replication in the high school classroom can be found at <http://che.engin.umich.edu/people/eniola/projects.html>.

There were two major drawbacks to the science fair style project presentation: 1) the large class size made it difficult to set up demo stations in a way that allowed easy access for judging and 2) the large number of demos requiring access to electricity. These two issues led to brief periods of chaos during project presentation.

ASSESSMENT

High school student (HSS) survey outcome. Fifteen HSS from the YPSD school district participated in the project presentation. Of these, 10 were female and eight were African-American. The average overall GPA of the group was 3.0 with seven of the students having their GPAs below 2.0.

The judging process required that each HSS fill out a survey immediately after each demo viewed to ensure an accurate representation of their opinions. Four key questions were used on the HSS survey (Q3 - Q6 in Figure 1A) to gauge how successful a group's demo was at introducing and engaging

TABLE 1
Sample Project Designs by ChE Student Teams

Group Project Title	Heat/Mass Transfer Concept Presented
The Reindeer Effect	The experiment demonstrates the ability of a microwave to provide heat to a system through electromagnetic radiation
Molecular Diffusion Through a Porous Medium	Dependence of mass diffusivity on temperature
"Once You POP, You Can't STOP"	Dependence of mass transfer flux on temperature and convection via carbon dioxide in liquid soda pop (visual demonstration of transfer using balloons)

HSS interest in chemical engineering. Figure 2 summarizes the level of excitement and engagement reported by the HSS. About two-thirds of the HSS' encounters with demos resulted in the HSS feeling fairly to highly excited about or engaged with the viewed presentation. More importantly, 83% of encounters resulted in the HSS feeling they learned something new. Overall, nearly 70% of encounters left HSS feeling fairly to highly interested in engineering.

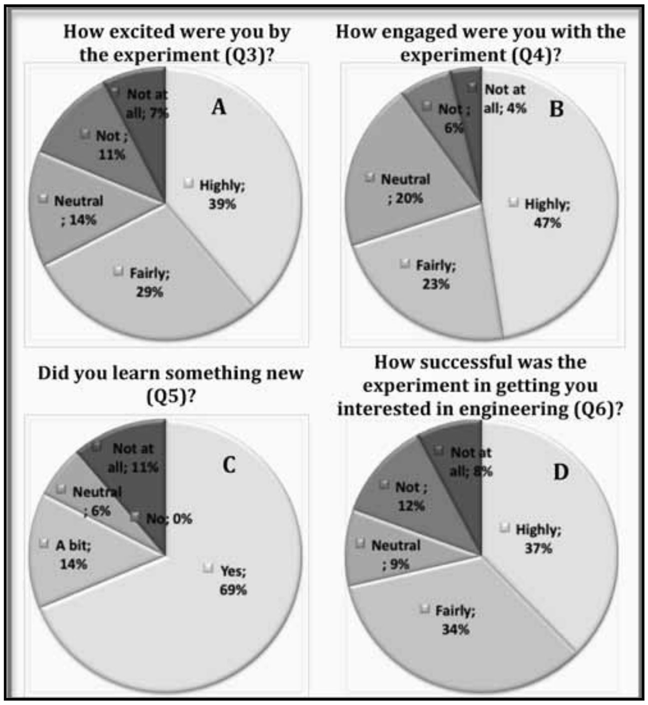

Figure 2. Summary of high school student survey on excitement and engagement rated on a scale of 1 –10. Highly (Yes) = 9 – 10; Fairly (A bit) = 7 – 8; Neutral = 5 – 6; Not (No) = 3 – 4; Not at all = 1 – 2.

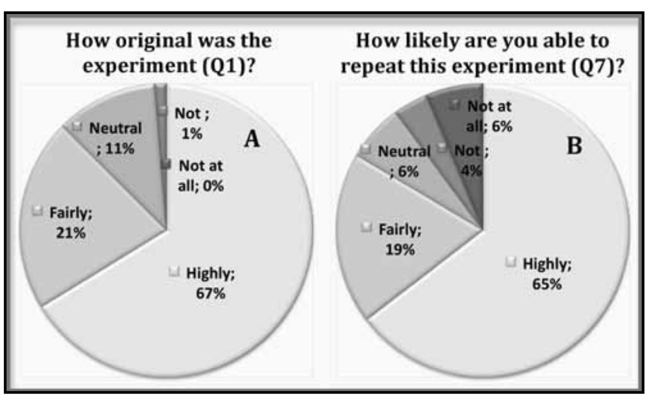

Figure 3. Summary of HSS survey gauging how well ChE designs adhered to the project statement. Highly = 9 – 10; Fairly = 7 – 8; Neutral = 5 – 6; Not = 3 – 4; Not at all = 1 – 2.

Questions 1 and 7 on the HSS survey were used to gauge how well ChE student designs adhered to the project problem statement and imposed constraints (see the section on "Methods"). Figure 3 shows that 88% of HSS encounters resulted in a "fairly to highly original" rating of the viewed demo, and 84% of encounters resulted in a "fairly to highly likely" rating on HSS perceived ability to repeat the viewed demonstration in their high school classroom.

Faculty team survey outcome. Graduate students, high school teachers, and ChE faculty members were invited to evaluate the technical aspect of designed experiments and their fitness for the high school classroom via the survey shown in Figure 1B. Only two HS teachers participated in the project presentation survey. The responses to Q1-3—focused on evaluating ChE student designs for creativity, scientific

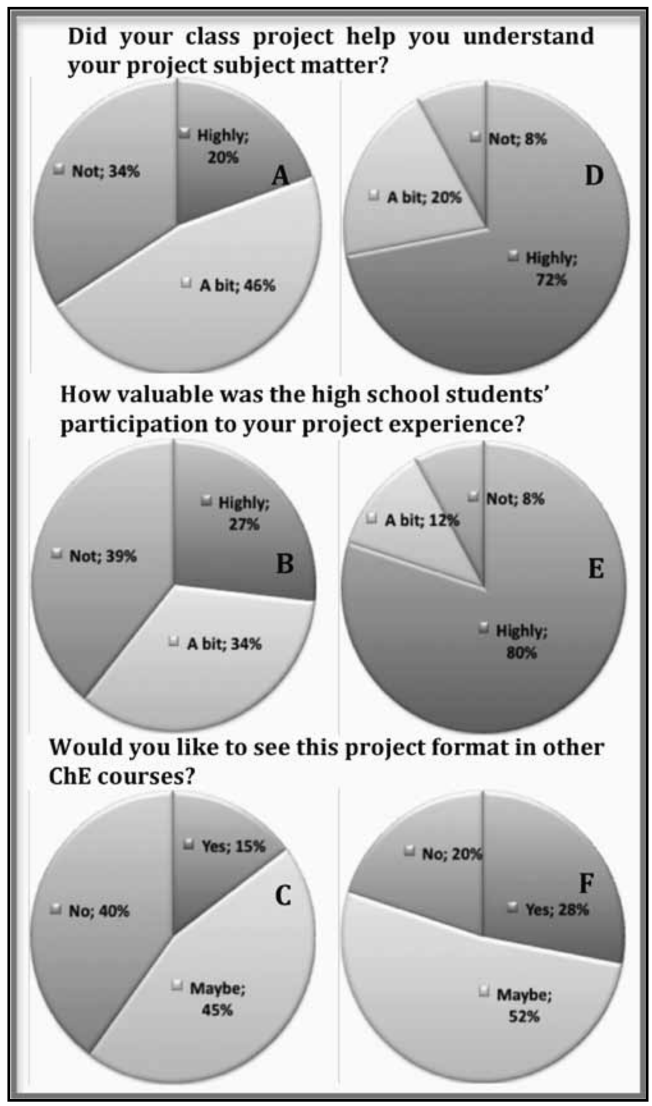

Figure 4. Summary of ChE student end-of-course (A-C) and post-semester (D-F) surveys scale.

TABLE 2
Faculty Team Survey Result for Q1 – Q3

		Excellent	Good	Partial	Attempt made	Absent
Creativity	Does the group project or display demonstrate ingenuity in the design and development?	41.9%	41.9%	16.3%	0.0%	0.0%
	Have the students shown creativity in the design?	41.9%	37.2%	18.6%	2.3%	0.0%
Scientific Thought	Is the experiment appropriate for the study of heat and mass transfer principles?	62.8%	32.6%	4.7%	0.0%	0.0%
	Is the experimental goal clear?	65.1%	27.9%	7.0%	0.0%	0.0%
	Has appropriate control been made?	46.5%	34.9%	18.6%	0.0%	0.0%
	Were the observations and information gained clearly summarized?	48.8%	32.6%	18.6%	0.0%	0.0%
	Does the data collected justify the conclusion made?	46.5%	30.2%	20.9%	2.3%	0.0%
Thoroughness	Is the project the result of careful planning?	37.2%	46.5%	11.6%	4.7%	0.0%
	Does the project indicate a thorough understanding of the chosen topic?	53.5%	25.6%	20.9%	0.0%	0.0%
	Does the experimental design/setup reflect students' originality?	44.2%	34.9%	20.9%	0.0%	0.0%

thought, and thoroughness—are summarized in Table 2. Overall, faculty responses to Q1 – 3 were mostly "good" to "excellent" (79 – 95% of the time). About 82% of the faculty team's encounters with demos resulted in a "fairly to highly relevant" rating in response to Q4 of the survey. Furthermore, over 90% of the time, the faculty team responded to Q5 through Q7 with a "fairly to highly likely" rating, suggesting a general feeling that most student teams were successful in designing an economical experiment that is safe and can be easily reproduced in a high school classroom (not shown). The two HS teachers that participated in the project presentation were also asked to respond to Q7 on the HSS survey. Of the six demos they viewed, the two teachers felt that they could "fairly to highly likely" repeat three in their classroom, they were neutral on two, and felt they were not likely to be able to repeat one in their classroom. Interestingly, the experiment rated low on adaptability to their high school classroom was also rated "neutral" on originality and "not at all" on whether they learned something new or its ability to engage their interest in engineering. Thus, it is possible that their perceived inability to repeat this particular experiment in the classroom is linked to their lack of excitement for the demo.

ChE student survey outcome. Since the class project/outreach event described herein is new to students enrolled in the M&HT course, it was important that their view of the project format be collected. To this end, the ChE students were surveyed twice—first on the last day of classes prior to the final exam and a second time at end of the Winter 2009 semester (~ 4 months after in-class presentation). Both surveys were voluntary with responses collected anonymously. A total of 100 students participated in the end-of-term survey and 50 in the post-fall semester survey (post survey). Three key questions were repeated in both surveys to evaluate potential change in student opinion over time. Figure 4 (previous page) shows pie charts comparing the outcome of questions between the two surveys. When asked if their project experience helped their understanding of their project subject matter, 72% of the post survey respondents were highly positive compared to 20% of the end-of-term survey respondents. Similarly, respondents on the post survey showed a greater enthusiasm for HSS participation in their project presentation (80% post-semester vs. 27% at the end of term). Students' feeling about having this type of project format in other ChE courses at Michigan likewise shifted in the positive direction with only 20% of respondent saying "no" on the post survey compared to 40% on the end-of-term survey. The overwhelming improvement in ChE students' attitude towards the class project in the post survey may not be representative of the entire class, however, since only 44% of the class participated in this survey compared to the 87% participation for the end-of-term survey. Thus, it is plausible that students who previously had a positive view of the class project were disproportionately represented on the post survey. Even if this were the case, however, the views of these students appear to be more positive on the post survey as compared to the end-of-term survey, *e.g.*, only 20 students on the end-of-term survey thought the project helped their understanding of their course material vs. 36 students that felt the same way on the post survey.

A set of questions was asked only on the post survey to gauge students' feeling on the impact of the M&HT project on the outcome of their winter semester courses. Of the 50 students taking the post-semester survey, 38 indicated they were currently enrolled in the junior ChE lab course, and 32% of these students indicated that their M&HT project experience was "highly" valuable to their winter lab course (Figure 5). Only 24% of all post-survey respondents, however, indicated that their ChE project experience was "highly" valuable to other courses in which they were currently enrolled. When asked how likely they were to consider participating in other K–12 outreach programs if their class project presentation were categorized as outreach, 60% of post-survey respondents indicated they were highly likely to do so compared to only 8% indicating they were not likely to participate. Overall, students who had a positive feeling about the course project on the post survey did so regardless of their course grade outcome, *e.g.*, 40% of post-survey respondents felt their H&MT grade was worse than expected compared to 20% saying they do not want to see this sort of project in other engineering courses. Finally, some ChE students offered positive opinions about the class project outside of the survey questions. For example, one student wrote "the class project showed us how diverse the things are that we chemical engineers can actually do" and another said "I got the opportunity to talk about the class project at an interview so I was glad that we did the project."

Comparison to other science fair style outreach programs. Many universities (and companies) also have on-site outreach programs that allow K–12 interaction with college students and professionals. Two prominent examples of this are: 1) the University of Illinois at Urbana-Champaign's College of Engineering annual science fair style open house aimed at "showcasing the talent and ingenuity" of their engineering students to the public,[6] and 2) the engineering expo at Kansas University. Students, student groups, and faculty across the engineering college participate in these outreach events by way of presenting demos, hosting engineering-themed competitions, tours of facilities, and informational sessions. Although the in-classroom outreach program presented herein is not meant to replace or compete with such elaborate events, it can offer unique advantages to K–12 outreach. For one, the presented in-classroom event may be a great way for a department to incorporate outreach into their program in the absence of a college-wide event similar to the ones mentioned above. Secondly, while the in-classroom event cannot reach as large an audience as a college-wide (or campus-wide) event, it can offer an opportunity for a more intimate interaction between K–12 and engineering students. Specifically, the large college-wide event can run the risk of being viewed similar to a spectator sport where the visiting K–12 students are exposed to elaborate finished products perceived to be created by incredibly bright engineering students, but are not able to see themselves with the capacity to perform at such level. In a classroom setting, the K–12 visitors are exposed to 1) all types of students and their vulnerabilities, 2) simple projects focused on showcasing engineering aspects of day-to-day life as opposed to the "cool and fancy" things engineering can make, and 3) a better sense of the engineering classroom. Moreover, the design criteria imposed on the presented in-classroom outreach (see "Methods") ensures that K–12 visitors are active participants in the experiments as a way to learn key engineering principles, *i.e.*, a successful ChE design is one that can be carried out by K–12 students in their own classroom. Thirdly, the present in-classroom project-outreach event offers the possibility of tracking impact on participating K–12 students and their eventual college enrollment since recruitment is via an official college-school district relationship. Finally, for engineering colleges that do have an on-campus outreach event, the presented outreach approach may serve as a way for departments to involve more of their undergraduates—not just the high achievers—such that they have more demos to showcase and can foster a more intimate interaction between the K–12 audience and engineering students.

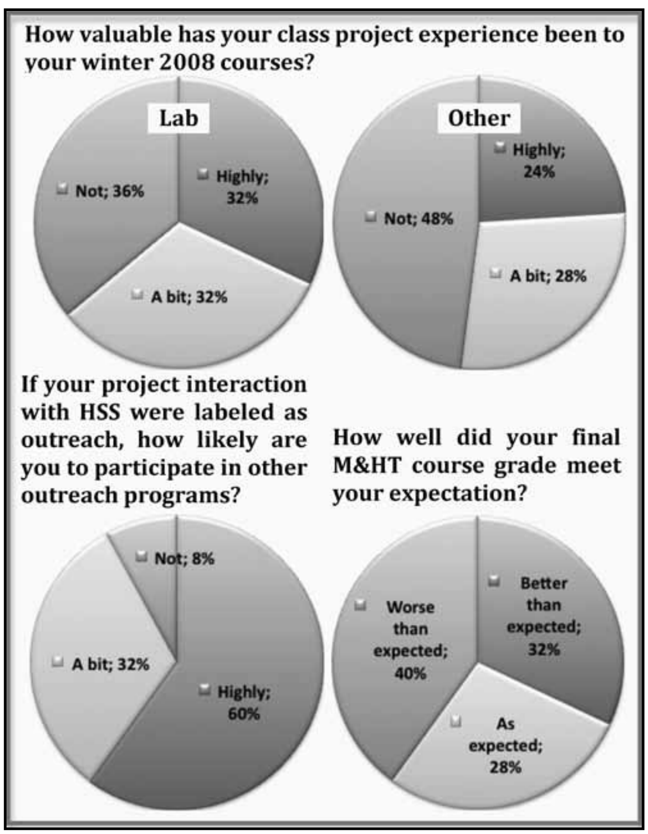

Figure 5. *Summary of ChE student's response to questions unique to the post-semester survey.*

CONCLUSIONS

Visual/hands-on demonstrations have long been an effective way of teaching scientific/engineering principles,[7, 8] and the "each-one-teach-one" approach to knowledge transfer has been proven to enhance students' learning experience. Here, we show that these two approaches can be combined to create a unique course project within the chemical engineering curriculum that allows ChE undergraduate students to enhance their understanding of key course concepts while simultaneously exposing HSS to basic concepts of chemical engineering. Both groups of students (HS and ChE) that participated in this unique project presentation/outreach format indicated a better understanding of the demonstrated engineering principles. More importantly, the HS audience (including teachers) indicated an overwhelming interest in chemical engineering as a result of their participation in the ChE course project. Overall, the incorporation of K–12 activities into the chemical engineering course curriculum overcomes the time commitment barrier that often prevents college students and faculty from participating in outreach to K–12. Furthermore, this project-outreach class presentation format likely presents engineering to high school students in a less intimidating manner where these students themselves can get involved with demonstrations of engineering principles. This conclusion is evident in the highly positive response of HSS to the survey question focused on their perceived ability to repeat ChE demonstrations in their own classroom. Bringing HSS into the engineering classroom can serve to demystify the college experience for these visitors. Lastly, while this type of class project-presentation easily lends itself to mass and heat transfer, it can readily be adapted to other chemical engineering courses, including material balance, fluid dynamics, separation, and product design. For example, the hands-on experiment for freshmen in chemical engineering developed by Prof. Hohn at Kansas State University[8] can easily be modified to include a presentation to K–12. Practical tips for replication are listed in Table 3.

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TABLE 3
Practical Tips for Project Replication

1.	Project format works best for small to medium class size (although a positive outcome is achievable with a fairly large class as reported herein).
2.	Student should have access to the project description early in the semester to allow ample time for project development.
3.	Instructor may stimulate idea formulation among students via her/his own sample in-class experimental demonstration of course concepts.
4.	Instructor should take care to invite K–12 students at the appropriate level, *e.g.*, middle to high school students are likely appropriate for participation in mass and heat transfer projects while elementary to middle school age students maybe more suitable for any project/outreach associated with an introductory chemical engineering course. Overall, desired K–12 grades can be targeted via the project description and imposed constraints.