A SERVICE LEARNING PROJECT ON ALUMINUM RECYCLING

Developing Soft Skills in a Material and Energy Balances Course

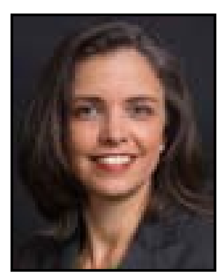
Christy Wheeler West
University of South Alabama • Mobile, AL 36688

In the core courses of a chemical engineering curriculum, the bulk of technical and scientific content that must be covered imposes time constraints that can inhibit addressing the professional skills employers want and ABET requires.[1,2] Accomplishing this in a meaningful way can be especially challenging in the introductory material and energy balances course, where class sizes are typically larger and students' engineering knowledge is limited. Attempts to assess teamwork in the course are often restricted to standard group homework assignments, and students do not yet have sufficient engineering knowledge for in-depth technical communications assignments. Furthermore, without that foundational knowledge, how are they to develop an understanding of contemporary chemical engineering issues or the "impact of engineering solutions in a global and societal context"?[3]

Service learning offers a means of enriching student learning by application of academic knowledge to fulfill a community need.[4] Service learning provides an opportunity to engage students in activities outside the classroom to reinforce learning and to develop professional skills in communication and teamwork. The connection between learning and community service is fairly clear for courses in social science and health. Recognizing that engineers also work to serve the public good, service learning in engineering courses provides a platform to address those more abstract educational objectives of societal responsibility and global impact.[5,6] In the past 10-15 years, the engineering education literature presents numerous examples of service learning projects in civil, mechanical, and electrical engineering.[7-9] These examples are mostly employed in first-year experience classes or in capstone design courses.[10] Even in comprehensive, college-wide initiatives, it is more difficult to find examples that incorporate core chemical engineering principles with service learning.[11] A recent report addressing the use of a Chem-E-Car program for STEM outreach discusses the benefits of service learning for both the undergraduates involved and the public image of the chemical engineering department.[12]

In the project described here, students studied the processes associated with mining and refining aluminum and compared them to those involved in recycling aluminum. Each group used this information to prepare a presentation on the impact and importance of aluminum recycling, suitable for a lay

***Christy Wheeler West** is an associate professor in the Department of Chemical and Biomolecular Engineering at the University of South Alabama. She earned her B.S. degree from the University of Alabama, and her Ph.D. from the Georgia Institute of Technology. Her research interests include heterogeneous catalyst synthesis and phase-transfer catalytic systems.*



audience, and delivered their presentation to a chosen group in the community. While this is somewhat outside the vein of traditional service learning, where students often work hands-on with volunteer organizations to address acute needs, it clearly offered the students an opportunity to see the integration of their basic chemical engineering knowledge with a societal issue, and strengthened their engagement with that knowledge by immediate responses from the groups with which they interacted.

Even in an introductory chemical engineering course, the students were able to perform basic calculations to compare the energy requirements for refining and recycling aluminum. They could calculate energy requirements to heat and melt an aluminum can—the basic energy requirement for recycling. They could also use heats of reaction to obtain a minimum energy needed to manufacture that can from bauxite. Internet research provided them a more realistic comparison given process inefficiencies, but these primary calculations based on material they learned in the course gave them the foundation to understand the differences from the standpoint of chemical and thermophysical properties.

PROJECT ASSIGNMENT DESCRIPTION

This project was carried out in a 4-semester-hour sophomore-level material and energy balances course in which a total of 48 students were enrolled. They were divided by the instructor into 12 teams of four students each, ensuring a range of background experience and abilities.[13] Prior to the first project assignment, there was an in-class discussion of teamwork. The students also read an article about potential problems with student teams, and wrote a short reflection on it.[14]

With the first assignment, the students were provided an overview of the entire project, including the following list of objectives:

- *To apply material and energy balances to a relevant contemporary issue*
- *To exercise oral communication skills to convey technical information to a lay audience*
- *To use engineering knowledge to affect attitudes and behavior with regard to aluminum recycling*
- *To develop a foundational understanding of an engineer's professional responsibilities to society*
- *To develop teamwork and project-management skills*

Assignments were made in four phases, as shown in Table 1 and discussed in detail below. The first phase was assigned in the third week of the semester, and the others at three- to four-week intervals, with completion of the final phase required before the start of final exams. At the end of each phase, a one-page memorandum was submitted. Depending on the phase, the memo was to summarize results obtained and/or accomplishments toward the goals and to note any group challenges and their solutions. Calculations, PowerPoint slides, or any other deliverables were included as attachments to the memo. Based on the information provided in the memo, the instructor followed up with the teams to address any specific and major teamwork problems that needed to be addressed. The calculations and PowerPoint slides were also evaluated, and corrective feedback was provided as needed.

TABLE 1
Assignment tasks by phase

Phase I • Make preliminary task assignments • Sign up for football game tailgate recycling • Study the aluminum refining and recycling processes
Phase II • Calculate and compare the energy requirements to reduce aluminum ore versus melt aluminum • Choose external audience and schedule presentation date
Phase III • Calculate five "energy equivalents" • First draft of PowerPoint slides
Phase IV • Deliver the presentation in class • Deliver the presentation to your chosen external group

Phase I

The first phase of the project involved planning the project and obtaining background information about aluminum manufacturing processes. A preliminary task-assignment grid shown in Table 2 was provided to the students with the initial project handout to assist the teams in dividing tasks. They were to fill in assignments based on individual strengths and interests, and to make sure tasks were shared evenly between the four group members. In the final assignment, they were to once again submit the grid, edited to reflect any changes based on the actual execution of tasks.

So that students were familiar with general recycling behavior and the local infrastructure for recycling, a representative from each team was required to attend the College of Engineering's football tailgate event and to coordinate with attendees from other groups to deliver the cans to the local recycling facility. This reinforced the service learning aspect of the project, ensuring that the students had hands-on experience with recycling when they went to speak to their respective external groups. Having to coordinate with other groups for transportation to the game and to deliver the cans also added an extra element of project management to the task.

The final portion of the first assignment was to perform research on the internet regarding processes involved in aluminum refining and recycling. Each student was to perform this study independently, and then the groups were to meet and create a short document listing the main points of each process, to be included in the progress report memo.

TABLE 2
Task assignment sheet provided to assist students with distribution of responsibilities

Task	Assigned to			
Engineering tasks				
Research aluminum refining and recycling	Entire team			
Energy difference calculations	Entire team			
Creative comparisons	Entire team			
Comparison research				
Comparison calculations				
Check calculations				
Communications tasks				
Making PowerPoint slides				
Edit PowerPoint slides	Entire team			
Delivering presentation				
Attend presentation (at least one non-presenter)				
Prepare progress report memos				
Organization tasks				
Schedule team meetings				
Record team member assignments				
Make sure tasks are completed on time				
Plan with other groups for tailgate and recycling				
Schedule presentation				
Submit memos				
Service tasks				
Attend tailgate to collect cans				
Take cans to recycling center				

Phase II

In this phase, students performed the basic calculations to understand the fundamental energetic differences between the refining and recycling processes. They were required to consult thermophysical property databases such as the NIST Webbook[15] or a database available via Knovel through their AIChE memberships.[16] Using heat capacity formulas, heats of fusion, and heats of formation, they determined the minimum energy associated with each process. These were treated as state functions, where the net processes could be represented as follows:

$$Al(s, 25°C) \rightarrow Al(l, 660°C)$$

or

$$Al_2O_3(s, 25°C) \rightarrow 2Al(l, 660°C) + 3/2\ O_2(g, 25°C)$$

These calculations provided insight into the ultimate thermodynamic difference between the two processes—one only a physical change, and the other also involving a highly endothermic chemical reduction.

TABLE 3
Distribution of points for each part of the project

Football game tailgate and recycling participation	10%
Completeness and correctness of calculations	20%
Creativity in energy equivalents	10%
Choice of group for presentation based on potential impact	10%
Professional quality of slides	5%
Information content of slides	5%
Professional quality of oral presentation	10%
Completed presentation to chosen group	20%
Completed project-phase deliverables in a timely manner	10%
Individual scores were scaled based on group evaluations	

During this project phase, the students also chose an external group for whom their presentation would be tailored, and scheduled a date for it toward the end of the semester. Their instructions stated that points would be allotted based on the potential impact of the presentation to that group. For example, a presentation to a single person who could exert influence on community-wide decisions would receive credit equal to a large group of university students.

Phase III

Now that the students had an understanding of the refining and recycling processes and the energy differences, the focus shifted toward communicating that information to their respective lay audiences. To make the energy difference more tangible, students were instructed to come up with "energy equivalents," comparing the amount of energy saved by recycling a single can, six-pack, or case to another familiar energy usage, such as charging a cell phone. This required that students research energy requirements for these other applications and perform unit conversions to calculate the equivalents.

At this point, the students prepared a first draft of their PowerPoint presentations, including graphics and information to be included on each slide. They were instructed that the presentations should be between 5 and 10 minutes in length.

Phase IV

Upon receiving the instructor's comments on the first draft of their slides, the student edited the slides and prepared the presentation. They were required to present it to the class at least two weeks before their scheduled meetings with the lay audiences. The class offered critiques and improvements that were incorporated in each case. Finally, the presentation was delivered to the external audience.

Grading

Students were given the point distribution shown in Table 3 with the original assignment. The final grade accounted for 10% of their course grades.

Student survey

At the conclusion of the course, students were asked to answer reflection questions regarding their experience and learning during the project. The prompting questions are listed below:

- *Did this project affect your perspective on the societal responsibilities of an engineer? If so, how?*
- *How was the experience of preparing and presenting technical information to a non-technical audience?*
- *Did this project affect your thoughts about energy on a daily basis? Do you have a more tangible understanding of energy use? Explain.*
- *How was the experience of learning about an engineering process without it being taught in the classroom?*
- *What did you learn about working in groups? Do you now have an answer for potential interview questions about solving team problems?*

A selection of student responses is included in Table 4.

TABLE 4
Sample responses from student reflections

Prompting question (Total responses)	Example responses (Number of responses with similar ideas)
Did this project affect your perspective on the societal responsibilities of an engineer? If so, how? (27)	"I learned that not only is it the engineer's job to make processes more efficient, but also to help the environment." (10) "As engineers we can use our knowledge of chemical processes to inform society about more efficient ways of doing a variety of things." (8) "The true value of energy will stick with me in the long run, and help to influence the decisions I make." (5) "Before the project, while I knew that recycling was helpful, I did not know the significance of it." (7)
How was the experience of preparing and presenting technical information to a non-technical audience? (24)	"Being able to present technical information to a non-technical audience is a very applicable skill in the real world." (6) "I found that writing for an audience that wasn't well-versed in technology forced me to have a better understanding of how things affect the real world." (5) "At first, it was challenging to try to simplify such complex processes involved in aluminum production without feeling like you were leaving out necessary information." (6) "We learned to tailor the information to our particular audience's needs." (18) "Our audience didn't seem to quite get what we were talking about." (2)
Did this project affect your thoughts about energy on a daily basis? Do you have a more tangible understanding of energy use? (24)	"It really made me think about other ways I can save energy." (8) "Relating the energy saved to everyday uses made it easier to see how much energy is really saved." (9) "I honestly never really thought of recycling as saving energy." (15) "This project made me realize just how much energy goes into the production of the things I use every day." (3)
How was the experience of learning about an engineering process without it being taught in the classroom? (29)	"Learning the process made me excited for my future as a chemical engineer." (4) "I found it very satisfying to learn how chemical processes work." (6) "Learning outside the classroom about a process was fun." (6) "It opened my perspective to how broad the field is globally." (4) "Learning specifically about a certain process definitely boosts my confidence about being a future engineer." (9)
What did you learn about working in groups? Do you now have an answer for potential interview questions about solving team problems? (27)	"You need to be very specific and intentional when delegating tasks." (7) "Communication is the key factor when working with a group." (8) "I can't always get what I want, and I need to be a leader who doesn't just lead, but also follows." (3) "I learned that working in a group is about give and take." (7) "Working around schedules and activities is difficult, and people get frustrated." (8) "Set the standard early." (3)

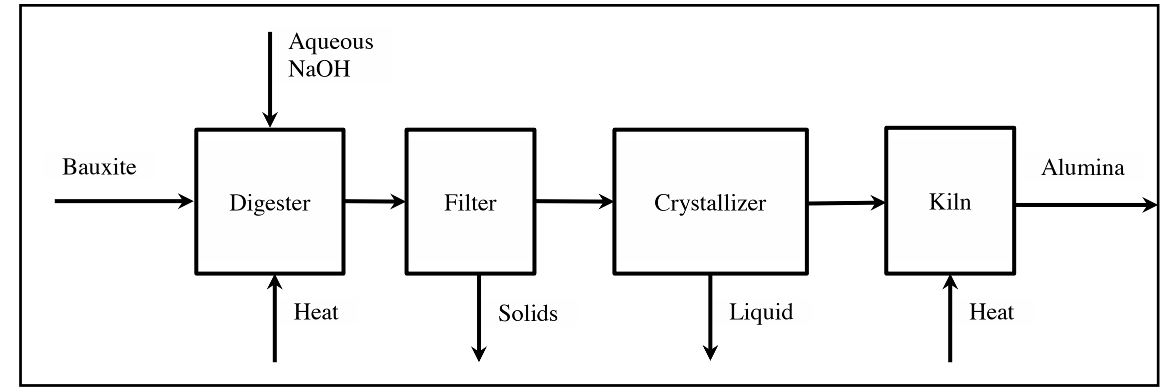


Figure 1. Process flow diagram for the Bayer process converting bauxite ore to alumina.

The responses in the table exhibit general themes that were repeated in the student reflections, and a count of how often those sentiments were conveyed is included. The student responses are summarized in the discussion below.

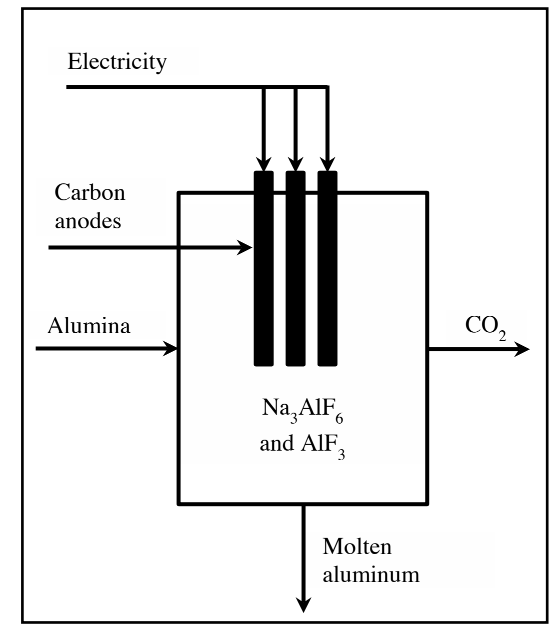


***Figure 2.** The Hall-Héroult electrolysis process reducing alumina to molten aluminum metal.*

TABLE 5
Selected energy expenditures equivalent to energy savings from recycling aluminum cans, as reported by students

Number of cans	Equivalent
1	Pop 4 bags of microwave popcorn
1	Burn a 100 W light bulb for 2 hours
6	Cook 25 cups of Ramen noodles
6	Run a laptop computer for 53 hours
12	Ride an electric bike 630 miles
24	Power an apartment for 1 day

STUDENT OUTCOMES AND PERCEPTIONS

Learning course content

In terms of reinforcing the technical content of the course, the intent of the project was simply to show students a real-world application of some of the basic calculations and concepts they had learned. However, the outcome was considerably more significant. While the instructions to students were just to learn the basic differences between aluminum recycling and refining, they instead reported in detail on the Bayer process for extracting alumina from bauxite[17] and the Hall-Héroult electrolysis process for reduction to aluminum metal,[18] which are depicted in Figures 1 and 2, respectively. Studying these processes and representing them in process flow diagrams turned out to be an additional reinforcement of the material balance concepts as well as the energy calculations. The depth in which the students learned about these processes was far more than expected, and provided an excellent exposure to chemical processes in general. One student stated that it made all of the "boxes and arrows" in other problems less confusing. Several students reported that their ability to learn about and understand the refining process boosted their confidence in learning the rest of the course material.

A selection of the energy equivalents students calculated is shown in Table 5. Students said that devising the energy equivalents enhanced their grasp on quantifying energy expenditures. One student reported that he had never even considered that one could equate gasoline usage and electricity usage. Nearly all of them stated that the project raised awareness of their own energy usage and ways they could reduce it.

Teamwork skills

This project afforded students the opportunity to function as a team to accomplish a task that included learning, but went beyond learning to application. Having a deliverable to an audience other than the instructor resulted in a heightened level of professionalism and teamwork than what is often demonstrated at the sophomore level. Through the course of the project, students came to realize that they had a message to share and an audience with whom to share it—it became more than just a grade to them. As a result, they divided tasks and organized their work more effectively, giving greater attention to the respective strengths and interests of the group members. In this respect, this assignment varied significantly from a group homework assignment, where ultimately every member is responsible for knowing how to do all of it.

Instead, they gave consideration to which members were best suited to the required tasks, generally dividing the workload fairly.

In their reflections, students made insightful comments about what they learned about working in groups. A common theme in their discussions is that successful teamwork requires compromise and flexibility. Another recurring comment was that they learned the importance of frequent communication with other team members. They also noted the importance of timely intervention if a team member was not performing as expected. A few students discussed the leadership skills they had discovered as they stepped up to make sure the project was performed to their standards, while making sure that the tasks were delegated to match individual strengths.

In both their memos and in the survey response, the students discussed some of the challenges they faced working out schedules and managing poor performers. These included team members missing meetings, not responding to communication, or not meeting agreed-upon deadlines. The reflections were mostly focused on what solutions they employed and what they learned from the experience. The class was frequently admonished through the semester that these problems would arise, and that if they were able to solve them without the instructor's intervention, they would be developing insightful answers to common job interview questions. All-in-all, the project was an excellent opportunity to develop teamwork skills early in the curriculum and should enhance their approach for the projects they will encounter in the junior- and senior-level courses.

In addition to the written comments about team performance, the students submitted a brief evaluation of their peers after the project was completed. An example evaluation form is shown in Table 6.

TABLE 6
Form for peer assessment of group member participation and contribution

Student:	Overall rating (circle, 10 is best) 1 2 3 4 5 6 7 8 9 10				
Was professional and courteous	Never	Seldom	Sometimes	Usually	Always
Performed assigned tasks well	Never	Seldom	Sometimes	Usually	Always
Performed assigned tasks on time	Never	Seldom	Sometimes	Usually	Always
Actively participated with group	Never	Seldom	Sometimes	Usually	Always
Made valuable contributions	Never	Seldom	Sometimes	Usually	Always

Communication skills

The external audiences chosen by the student groups included university organizations, high school assemblies, and an environmental foundation, as well as the Mobile City Council and representatives from the mayor's office. While the instructor had offered to assist in selection if needed, the students engaged and scheduled their audiences independently. In each case, they had to consider the background and interests of their audience, and to tailor their presentation to match its needs. This preparation was quite different from preparing a presentation to be given to an instructor for a grade. Most significantly, it helped students to focus on the information they were communicating and what the ultimate message to their audience should be. This lessened the intimidation factor that is often inherent when students present to an instructor, which is likely founded in their fear of saying something incorrect to a more knowledgeable audience. In essence, the speaker's approach became "I have a message to communicate" rather than the more common "I have to communicate" often associated with oral assignments. Students reported that this made the presentation fun and gratifying, rather than something to be dreaded.

The first drafts of the slides that were turned in contained process information that was far too complex, technical, and detailed for the audiences. Following the instructor's suggestions, the students distilled this information, mostly into graphics, and highlighted the energy-intensive parts of the processes. Students learned that in most professional presentation situations, the speaker should know far more depth than is actually presented, but condenses the information, reserving detail for later discussion if needed. They also found that knowing so much more than they were actually presenting gave them confidence in their expertise to present the material. They reported that trimming down the material to present required a deeper understanding, as they had to analyze what was important to communicate.

Before presenting to their audiences, the students delivered their presentations to their classmates, who then offered constructive criticism. This practice was especially effective in enhancing their critical thinking with regard to oral presentations, and the critiques were strikingly insightful. Comments included suggestions on the material included with respect to the various audiences, recommendations for improvements to visual aids, and observations about delivery. The comments were sometimes just complimentary remarks, but more often constructive feedback. The peer evaluation of the presentations was so effective that the instructor usually only needed to reinforce it rather than to add more commentary.

It should be noted that the in-class presentations and peer review required a total of about two class periods to accomplish for all 12 groups. They were not all presented in two days, though, but rather spread out over a couple of weeks. The lost time was recovered by the removal of one in-class assignment and one review day from the normal curriculum.

Understanding societal impact

Open responses in the student survey show that the project impressed upon the students their responsibility as engineers to educate the public on relevant technological issues, and opened their eyes to the impact that engineering decisions can have on energy consumption. Several students also reported that the project had also changed the way they thought about their future careers as chemical engineers. Interestingly, this change in perspective was approached from two different directions. In general, the students had chosen to study chemical engineering due to an interest in math and chemistry and for its potential as a lucrative profession. A surprising number of them stated that before this course they had thought of chemical engineering and manufacturing as a means to provide consumer products, without even realizing the potential energy and environmental impacts. Coming from the opposite direction, other students expressed past reservations about working in the chemical industry because of environmental impacts, perhaps as a result of common public perception and media coverage. Both groups stated that working on the project had given them a new perspective on the opportunities that industrial chemical engineers have to reduce the environmental impact of manufacturing the products that society demands. In effect, the first group was enlightened on an important aspect of their future careers, and the latter group was armed with a response to anyone who would challenge their career choice on the grounds of environmental responsibility. The most frequent responses to the reflection questions on societal impact and on energy indicated a new awareness of the importance of energy and environmental issues to the global chemical industry.

Awareness of contemporary issues

While this project focused on a single material and the energy associated with its processing, in a broader sense it raised students' awareness of at least two contemporary issues in green engineering. They had to consider the sources of raw materials that are used in manufacturing consumer products. While aluminum is not as limited a natural resource as many other metals that are employed in technological applications, the study exposed them to the ecological effects of mining and made them more cognizant of how we obtain and use mineral resources. Perhaps more importantly, they learned to investigate the energy differences between alternatives. The project focused on recycling, a familiar lifestyle choice, which made understanding the energy implications more accessible for the sophomore-level students. They were then able to extend that understanding to realize that the decisions they would make as chemical engineers would affect the energy requirements for whatever processes they designed, and that as a result those decisions could have profound economic and environmental consequences.

Lifelong learning

Through their own self-study, students became proficient in discussing the Bayer process for extracting alumina from bauxite, the Hall-Héroult electrolysis process, and processes entailed in recycling aluminum. Some reported that the experience had already inspired them to independently investigate other recycling processes. More generally, they stated that they had gained confidence in their abilities to understand chemical processes and to take initiative to learn new concepts without a professor's assistance. One said that the idea of being hired as an engineer to perform a particular role in a company seemed less daunting now that the ability to self-teach about a specific chemical process had been demonstrated.

Service learning and student attitudes

The service learning aspects of the project included both the presentations to public audiences and participation in aluminum recycling at football game tailgate events. The recycling activity was an essential part of the project because it ensured that the students had first-hand experience with the local recycling infrastructure, providing authenticity in their presentations to other audiences. It also infused the students' attitudes during preparation for their presentations with meaning, as they were able to observe the low level of public awareness of the value of aluminum recycling—when the class's recycling bin was placed immediately beside a trash can, most of the cans were still tossed in the trash can.

After learning about the processes and their energy differences, the students' motivation to complete the project by delivering an informative presentation was increased. A recurring theme in the responses to the survey question regarding social responsibilities was that through performing the project they had realized there were things that engineers might know and understand from a technical perspective that other people would not. In that, students saw a responsibility to inform people in ways they could understand about how everyday choices can affect energy usage and the environment.

CONCLUSIONS

The original objectives of this project were primarily to develop communication and teamwork skills in the sophomore material and energy balances course, while creating an awareness of the societal impacts of engineers. In the end, it accomplished that and more. Through struggles and successes, the students learned team and project-management skills, and each group produced a presentation that effectively communicated its message to its chosen audience. Beyond that, the fundamental material taught in the course was reinforced as the class sought to understand a real chemical process in significantly more detail than is addressed in typical problems. They also gained a more concrete awareness of the importance of energy usage in chemical processes that should bolster their understanding as it is addressed in future coursework. Finally, the students have a new perception of the role that chemical engineers can play in addressing modern energy and environmental issues, both by increasing the public knowledge and by incorporating sustainable practices in manufacturing.

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