Board 30: Incorporating the Impact of Engineering Solutions in Global, Economic, Environmental, and Social Contexts into our Core Curriculum

Taryn Melkus Bayles, University of Pittsburgh
Dr. Joaquin Rodriguez, University of Pittsburgh

oaquin Rodriguez is an Assistant Professor at the Department of Chemical and Petroleum Engineering at the University of Pittsburgh since 2018. He received his bachelor degree in Chemical Engineering from Universidad Simon Bolivar (Caracas, Venezuela), MSc. and PhD in the same discipline from the University of Pittsburgh (1990-92). He developed his expertise in thermal cracking processes and advanced materials (cokes, carbon fibers) from oil residues, and became a business leader for specialty products (lube oils, asphalts, waxes, cokes) at Petroleos de Venezuela, PDVSA (1983-1998). He is a founding member of Universidad Monteavila (Caracas, Venezuela) (1998—2018) and became the Chancellor of this university (2005-2015), and the President of the Center for Higher Studies (2015-2018), including teaching in the Humanities. After rejoining the University of Pittsburgh, he has been teaching Pillar courses on Reactive Process Engineering, Process Control, Process Control Lab, and Process Design. In addition to technical courses, his service extends over curriculum development, outreach programs, alumni network, team and leadership skills development, global awareness, sustainability, and diversity, equity and inclusion.

Robert Enick

How We Incorporate the Impact of Engineering Solutions in Global, Economic, Environmental and Social Contexts

Introduction

The ABET student outcomes (2) “the ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety and welfare, as well as global, cultural, social, environmental and economic factors” and (4) “ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental and social contexts” require faculty to include content and experiences for engineering students to demonstrate their abilities in addressing these broader impacts. Our chemical engineering department has structured the core curriculum for the last 20 years in a series of six sequenced Pillar courses (5-6 credits) [1], [2], [3], [4], five of them with a companion lab course (1 credit unit) [5], and the capstone process design course integrated with a course on Ethics and Safety (2 credits). In order to directly and quantitatively assess the achievement of these student outcomes, competency is measured in a variety of required courses across our curriculum using various assignments as reported below in Table 1. The assignments in the sophomore and junior year are intended to provide students with the foundation they need to complete larger scale projects during their senior year, in three capstone courses (Process Control, Safety & Ethics, and Process Design). Simultaneously, rubrics have been developed, used, and refined to assess the attainment of these outcomes. Some basic rubrics have been established at the departmental level (Tables 2 and 3). However, instructors are encouraged to develop variations of these rubrics to better assess the specific assignments. In addition, during lectures of each of the classes – the students are provided specific examples of considerations in terms of the global, environmental, cultural, and social impact of engineering solutions.

Table 1. Selected courses and type of assignment to implement and document ABET student outcomes 2 and 4. DP: Design Project, E: Exam, HW: Homework assignment, P: Project, Q: Quiz.

Year	Course	Outcome 2	Outcome 4
Sophomore	Foundations of Chemical Engineering	DP	-
	Thermodynamics	-	HW
	Product Design I	DP	-
Junior	Transport Phenomena		Q
	Reactive Process Engineering	-	P
Senior	Systems Engineering I: Dynamics and Modeling	-	HW, E, P
	Ethics and Safety	E, DP	E, HW
	Systems Engineering II: Process Design	DP	DP

Table 2. Department level rubric for ABET student outcome 2.

Outcome 2 Rubric	10 Exemplary	7 Proficient	4 Apprentice	1 Deficient
Apply engineering design:				
i. The student identified specific project design objectives based on general project requirements	All important project objectives are identified.	Important objectives are identified but one or two minor ones are missing.	Most objectives are identified but at least one or two important ones are missing.	Most or all important objectives are not identified.
ii. The student gathered and used relevant design information	All relevant information is obtained and used to support design recommendations.	Sufficient information is obtained and used to support design recommendations.	Some information is obtained but more is needed to support design recommendations.	No significant background information is gathered.
iii. The student applied Math, Science and Engineering knowledge to reach a design solution.	All relevant Math, Science and Engineering principles were applied to reach a design solution.	Important Math, Science and Engineering principles were applied to reach a design solution.	Some Math, Science, and Engineering principles were applied to reach a design solution.	Math, Science and Engineering principles were not applied, and a design solution was not reached.
The student considered relevant constraints (if applicable):				
Economic	All relevant economic issues included; computations are correct.	Important economic issues correctly included; minor ones may have been ignored.	One or more important considerations ignored; but computations correct.	Most if not all economic considerations ignored; and/or computations flawed.
Health and Safety	Issues including safety of public and work health considered.	Primary issues considered; one or two secondary issues may have been ignored.	Most, but not all, important issues considered.	Most, if not all, important issues ignored.
The student considered multiple factors, at the same time in the engineering design (however, it is not necessary all to be relevant in the design):				
1) Economic 2) Environmental/Sustainability, 3) Public health, Safety and Welfare 4) Global, Cultural, and/or Social	All four factors have been considered (they do not have to be relevant to each other).	Three factors have been considered (they do not have to be relevant to each other).	Two factors have been considered (they do not have to be relevant to each other).	Only one factor has been considered.

Table 3. Department level rubric for ABET student outcome 4.

Outcome 4 Rubric	**1** **Deficient**	**4** **Apprentice**	**7** **Proficient**	**10** **Exemplary**
4.1 Recognize ethical and health issues and put in the context of the overall project objectives	Most, if not all, important issues ignored	Most, but not all, important issues considered	Primary issues considered; one or two secondary issues may have been ignored	Ethical issues of public and work health considered
4.2 Understand the impact of engineering solutions in a global, economic, environmental, and societal context	Most, if not all, primary issues ignored	Most, but not all, primary issues considered	Primary issues considered; some secondary issues may have been neglected	Problem placed in appropriate global, economic, environmental, and social context; all issues considered
4.3 Choose an optimal solution based on technical and economic criteria and considering relevant constraints	Only one solution considered; better solutions were available; most constraints ignored	Satisfactory solution is recommended; better solutions were available and should have been considered	Reasonable solution is recommended; other alternatives should have been developed and analyzed	An optimal solution is recommended that meets all stated criteria and constraints

Foundations of Chemical Engineering

In the **sophomore year**, students apply the engineering design process. The design challenge requires students to design, construct, evaluate, test and report on their product, but also to develop a mathematical model to predict their product's performance. It is important that the students have a fun yet inexpensive project to design and build, but they must also develop a mathematical understanding of the fundamental engineering principles that make their design work. Through this mathematical modeling the student cultivates the connection between mathematics and science, as well as an understating of the fundamental engineering design principles.

In the most recent design challenge, students designed, constructed, and tested hot air balloons [6] – their design met various criteria and constraints, which required them to maximize volume to surface area, payload, and time aloft; minimize cost; and develop an accurate mathematical model. In the design report, students were required to address how they considered safety, public health, and welfare considerations in the context of their design. They also discussed their design process and connection to math/science when determining the force balance, size/shape of balloon, ideal gas relationship for the air on the inside and outside of the balloon, and the rate of heat transfer (and the factors which influenced it). In addition, they discussed the ethical and professional responsibilities which impact the design of their balloon, from an environmental, global, economic, and societal context. Teams provided a real-world context for the use of their hot air balloon design (i.e., deliver medicine to a remote location in a third- world county; spread seeds after an area has been destroyed by a forest fire; deliver painting supplies in an efficient, and environmentally sound approach, etc.). This allowed teams to be able to address the impact of their design in global, economic, environmental, and social contexts.

Thermodynamics

In the Thermodynamics course, a homework assignment is posed, and students are asked: "In the context of depositing salts on to roads to melt snow and ice in the winter, which compound would be more effective, NaCl vs $CaCO_3$? Briefly explain which should be used by considering your previous answer and any environmental pros and cons as forms of support." Solving this problem correctly first requires a physical understanding of molecular interactions and charges, where higher charges on the calcium and carbonate ion (relative to that for sodium and chloride) will result in a greater degree of freezing point depression per mole. Then it becomes clear that less $CaCO_3$ should be needed to melt an equivalent amount of snow or ice, but the subsequent explanation of student reasoning is intentionally open-ended to allow students to discuss factors such as material costs per unit mass, environmental considerations to mine or produce these salts, and the environmental fate of these salts that inevitably enter water run-offs.

A second homework problem is assigned in the context of waste streams entering natural ecosystems, students should develop a mathematical relationship in the form of a heat exchange system where a stream of hot aqueous liquid with a heat capacity of Cp_1 and at temperature of T_1 having a given mass flow rate, m_1, is introduced into a natural stream of water at a different T_2 with a different flowrate, m_2. Assuming idealized mixing conditions, under what conditions of

Cp_1, m_1 and T_1 are suitable to ensure that the temperature of the stream does not increase by more than five degrees C and create a potential environmental risk?

Product Design

The Product Design class teams were required to design a computations data center (specifically a Bitcoin mining facility) that can efficiently transfer heat out of the building while also considering design elements such as conveniently located bathrooms and parking spaces. For the data center project, students groups are asked to imagine that they are bidding for a design contract with world's top Bitcoin mining company, Bitmain, headquartered in Beijing, China. Although Bitmain designs and constructs many Bitcoin mining data centers on its own in China, they would like to politically de-risk their operations by spreading their data centers in other jurisdictions. In this case, they are issuing a request for proposals (RFPs) for the design of an urban data center that could operate on a small lot (1 acre) in a US city and abide by all local health, safety, and noise level laws. A high priority for Bitmain is profitability, so the data center must have the highest density of computers possible while dissipating heat quickly enough to prevent a disastrous fire. Finally, the data center will need employees and so it must have logical parking, office space, bathrooms, and an accessible fire exit, all of which impact the space and layout of the center. To successfully come up with a competitive design, student groups must (1) develop thermal transport code in Python to simulate the temperature distribution throughout their data center as a function of time, (2) use net-present-value (NPV) calculations to demonstrate profitability of the center given its large upfront capital costs and continuous costs of operation (i.e., significant electricity usage), (3) consider the safety and comfort of the employees that would work there, including the significant noise generated by the Bitcoin mining equipment, and (4) persuasively argue for a location in Pittsburgh relative to other possible locations (in the US and globally), which requires taking into account the environmental impact of the data center (including the carbon-intensity of its power source). Students are aware that they are working in a competitive context, such that it is not enough to merely satisfy all of the criteria, they must come up with the 'best' design, although what is considered 'best' is intentionally unspecified and left up to them for interpretation.

Transport Phenomena

In the **junior year**, students completed an in-class heat exchanger problem where they used river water to cool a reactor, and they calculated the final temperature of that water. In a take home quiz, they are asked if they think this water should be discharged back into the river and to justify their answer. For full credit they are asked to provide a logical justification for their choice based on external resources with references. They are provided a review article titled "The Thermal Regime of Rivers: A Review" [7].

In another section of the Transport Phenomena class, the instructor shared multiple videos to engage the class with a discussion of safety and ethical concerns associated with the design of various equipment ranging from a heat exchanger, a hemodialyzer, a parachute, a blood pressure monitoring device, to a scuba diving computer. These videos were discussed in class, and students were evaluated based on their class participation and their ability to screen the literature or relevant resources. One subject that was of particular interest was the heat exchanger. The instructor presented an educational video generated by the U.S. Chemical Safety and Hazard Investigation Board, which highlighted an accident in a chemical plant due to the failure of a heat exchanger. The case study focused on the explosion in the T2 Laboratories in Jacksonville, Florida, which killed four people and injured 32 others. The incident, which occurred on December 19, 2007, was linked to the failure of the cooling system in the runaway chemical reaction during the production of a gasoline additive. Following the discussion of this video, the students were assigned a take-home quiz to report on some of the common errors in the chemical plant which can impact public health and safety. Students reviewed the literature and generated a written report highlighting the engineer's responsibility to make informed decisions while designing solutions. The students were explicitly advised to discuss an engineer's socioeconomic, environmental, and cultural responsibilities. The students were evaluated on their ability to identify health, safety, and welfare concerns in the design of the heat exchanger equipment through the essay. Thus, the written quiz assessed the student's ability to learn and develop a rationale for safe engineering solutions.

Reactive Process Engineering

In the Reaction Kinetics course, students develop an open-ended semester-long project researching a high-volume product of their choice and one major company producing it. The report and three sequenced presentations (12% of the final grade) should address relevant information about the product on chemical characterization, historical development, production processes, uses, markets, technology, and specifically a selected simplified kinetic model with a code to test the impact of main variables. The report should also include an overall description of a major producing company, production capacity and facilities, business performance, market position, employment, and innovation leadership. In a special report (4% of the final grade), students analyze the social impacts from the product (production chain) and the company (from public records of performance). Table 4 provides examples of the topics covered in one report regarding the producing company.

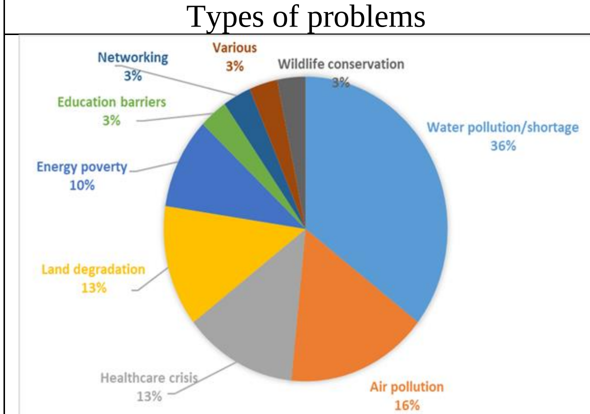
Table 4. Examples of impacts for a fertilizer producing company as evaluated by a student team in the Reactive Process Engineering Course [8]

Global
The company has a worldwide presence across six continents, with more than 20,000 employees worldwide, producing ammonia and other nitrogen containing products, mainly for farming uses
The company network expands over 30 production facilities and 1,700 retail stores only in North America
Environmental
The company has several programs for the reduction of carbon dioxide emissions at their manufacturing plants
The company has invested in the revival of the river around one of its major production facilities
The company commitment to environmental protection resulted a 7% reduction in scope 2 emission intensity for the last 3-year period, and the restoration or creation of two acres per every wetland acre impacted on their operations in the country for headquarters
The company established a $ 600 M capital investment project to reduce 30% emissions by 2030
The company sustains a program for field experts provide advice to farmers to reduce the environmental impact at the point of use of fertilizers
The company has committed to develop manufacturing plants away from population centers and meeting self-containing water-life requirements
The company has implemented programs for the supervision of waste management and announced a new waste minimization strategy including reuse of recycling of materials.
Social
The company's Corporate Social Responsibilities (CSRs) unit covers every aspect of the social impacts guided by five principles: trust, accountability, honesty, respect, and integrity
The company has several programs to educate farmers on safe and efficient uses of their products
The company has recently announced a commitment to diversity, equity, and inclusion by establishing programs for career development of women, Indigenous people, military veterans, and other historically under-represented minorities
The company is advancing a program for diversifying partnership with entrepreneurs who are women, Black or indigenous
The company has committed to institutionalize the promotion of diversity with specific guidelines in the Code of Conduct and two flagship training programs for employees "Inclusive Workplace Commitment" and "Respect in the Workplace Policy"
The company has established a program for offering equitable access to employment to Indigenous population
The company has established an educational program for employees on the history of the Indigenous communities from the land of their operations
The company has invested in recent years over $19 M USD in support of 2,700 communities around the production facilities, and participating in community events
The company sponsors a worldwide program to educate young people on agricultural sustainability, reaching out more than one million people in the history of the program
The company encourages and rewards employees with volunteer participation in community service programs
The company provides nutritional and medicinal help to people in need in nearby communities, with special emphasis on infants and children care
The company has faced ethical controversies in regard to resource extraction at a zone in conflict, posing concerns about worker rights and unethical business practices
Ethical responsibilities
The company code of conduct outlines adherence to fair competition, zero-tolerance policy for bribery, anti-corruption policies, human rights, and integrity
The company has enacted the Audit Committee of the Board of Directors and a network of Integrity Officer-led committees
The company has been backlisted from investing funds for its continued extraction of raw materials from a disputed region under occupation criticized by police brutality, suppression of speech, and violation of other human rights. The company has announced the suspension of operations in that region
Economic
The company has reached a net worth of over $44 billion in 2021, with a revenue of $ 28 billion
The company provides for over 23,000 employees worldwide with a high direct economic impact
The company, as other producer of fertilizers, play an important role in food prices derived from farming (i.e., corn, wheat) as fertilizers accounts for 35% of farmer's operating costs

Process Control

For the **senior year**, in the Process Control course, students complete a Global Project in collaboration with a foreign partner or organization to become acquainted with a problem in that foreign country and propose engineering solutions [9]. Process Control theory and concepts provide the frame mindset for the analysis. “Problems” are to be considered as “deviations” of certain “output variables” in relation with certain “standards of living” (set-points). Some comparative metrics (i.e., conditions in developed countries) can help in a semi-quantitative assessment. Selection of a variable of impact (manipulated variable) and some approaches to actuate on it (control device) should provide for an attempted solution in a certain “feedback control” strategy. Other variables (disturbance variables) are to be considered in limiting or affecting the selected proposal. Communication with the foreign partner is essential to assess a realistic approach in the analysis and in the proposal for solution. This project earns 10% of the final grade and includes a proposal 3-min presentation (2nd week), a progress report 3-min presentation, a project management follow-up, a final 5-min presentation, a poster, and a self-assessment. The final presentation and poster are delivered in a public event where we invite representatives from industries with global operations, and from academic offices and centers dealing with global or regional affairs (i.e., Center for Asian studies, Latin American Studies, African Studies) to serve as judges and to engage in conversations with the students about their topics and proposals. This project has been running in collaboration with the University Center for International Studies. Figure 1 exemplifies that environmental problems are the main concern, and students advocate for educational proposals (like websites to develop awareness of the problem) as much as technical proposals. Most described as a unique experience, very different from the common classroom setup, to engage in proposal to impact positively people around the world. Students have the capabilities, experience, training, and interests to identify a problem, analyze it, and develop a proposal. On the other side, a common criticism is the lack of more specific guidelines, the uncertainties at the start of the project, the time investment, and the many deliverables hard to fit in the schedule of graduating seniors.

Types of problems



Types of solutions

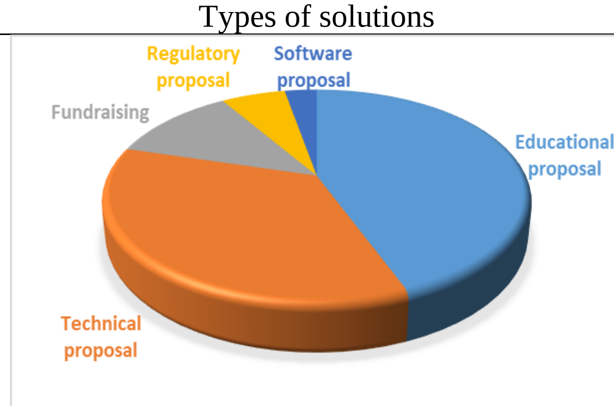


Figure 1. Types of problems and solutions addressed in recent years in the Global Projects

Safety and Ethics

The Deepwater Horizon/Macondo Well disaster of 2010 is probably the most thoroughly documented engineering catastrophe that had devastating global, cultural, social, environmental, economic impacts due to lapses in ethical decision-making and a lax safety culture. Therefore, students in the Safety & Ethics course attend two two-hour lectures on the Deepwater Horizon incident given by the course instructor, who served on the DOE NETL flow rate estimation team during this incident. Further, the student teams are pointed to a multitude of excellent reports detailing the impacts of this incident, such as the Chief Counsel's Report [9], the Executive Summary and 4-volume U.S. Chemical Safety and Hazard Investigation Board report [10], the Research Planning, Inc. report [11], the National Commission's Report to the President [12], and the National Academies Press 2012 free e-book on this blowout [13]. Student teams must report on the technical and ethical causes of the disaster, and then expound on the global, cultural, economic, and environmental impacts of the event. Further, they examine the regulatory aspects of deepwater drilling that were in place before this event, and changes introduced by the Obama and Trump administrations. Student teams then apply this learning to analyze the case of an oilfield storage tank explosion. The groups then provide guidelines for preventing similar incidents based on specific design changes in storage tanks, improved signage and security measures, improved training, and community outreaches to prevent such incidents in rural areas. Finally, they discuss the global, cultural, social, environmental, economic impacts associated with their proposed design changes, and make suggested changes to the relevant state regulations for oil storage at a well head.

Process Design

And finally, in the Process Design class, students are required to complete a design project over the course of the semester, which includes process synthesis, equipment design, process optimization & control, and economic analysis of their chemical plant. Students propose a US location for their plant and are also assigned a second location on a different continent and compare the impacts of their design in a global, economic, environmental, and social context for both locations. Student teams produce a section of the final design report, to assess these societal impacts, and in one design section, they produce a poster (3% of the final grade) intended to introduce the construction and operation of the plant to representatives of the surrounding community, where these impacts emerge as decisive criteria for the public acceptance of the project [14]. Table 5 shows an example of the main topics considered by one team for a plant to produce styrene at a US location, while Table 6 presents a succinct list of advantages and disadvantages considered for an alternative location in Europe.

Table 5. Example of main topics considered in assessing the social impacts of the project for the plant location at Louisiana, US [15]

Public Health
Toxicity and carcinogenic classification of hazardous raw materials and products. Risk of gases release and liquid spills. Mitigation safety procedures can prevent accidents that have been taken place in the past.
Safety
Adequate ventilation and PPE are required for handling ethylbenzene. Fire mitigation strategies (water sprays, dry chemicals, and foams). Preventive system to avoid contamination of aquatic habitats. Protective layer to avoid explosion of highly flammable styrene in addition to avoid ingesting and inhaling styrene (PPE). Prevention of the risk of polymerization by the adequate use of inhibitors at operation equipment and storage tanks. Protective layer to avoid explosion of highly flammable benzene (by-product). Prevention of disposal to aquatic habitats. Some similar safety measures for toluene. Close monitoring of temperature and level sensors at storage tanks to prevent risk of explosions
Welfare
Immense store of high-paying jobs for local communities though controversial allocation for selected specialized workforce
Global
Well established global market for styrene limits new entry companies but increasing demand open opportunities. Management challenges for multi-countries operation of styrene producing companies. Potential to develop new markets in countries with increasing industrialization. Technology transfer from highly developed countries to less developed countries but rich inn raw materials Increasing competition in technology and marketing Critical impact of supply chain disruptions by pandemics (i.e., COVID) or war conflicts (i.e., Russia-Ukraine)
Cultural
Demands for transparency on informing about potential risks, waste disposal, accidents prevention, and open communication. Provision for fair wages, ability for time off, and equal hiring opportunities to safeguard cultural values like independence, personal freedom, and equality
Social
Plant location in economically disadvantaged areas ends up with poor and marginalized population bearing the burden of pollution associated with chemical facilities (i.e., “Cancer Alley,” Louisiana) Communication with community leaders and representatives to address risks and benefits of plant operation
Environmental
Increasingly stricter regulations for pollutants generation. References to main legislation applicable to raw materials and products from the plant.
Ethics
Behavior in potentially abnormal situations. The risk of compromising safety with productivity. Importance of an explicit code of ethics. Requirements of training and reinforcements on developing a culture of “safety first.” Illustration by previous accidents. Relevance of updated documentation on procedures and proper training.
Professional Responsibilities
Extension of responsibilities beyond stakeholders and employees (i.e., community, suppliers, customers, public, global) Caring for profitable operations, fair wages, professional development, community services and support (outreach programs) Monitoring and improving social impacts

Table 6. Selection of potential advantages and disadvantages when considering an alternative location at a foreign country [15]

Location	Bucharest, Romania (Nearby rural location)
Potential advantages	Potential disadvantages
Proximity to large styrene demand (France, The Netherlands). Advantageous tax rates (as member of the European Union). Low-cost labor force availability. Increasing educational level. Above European average growth rate for the chemical industry. Much less unhealthy competition in the work environment. Less resistance is expected from the surrounding community as population is familiar with the risks (from coal mines, steel mills, etc.) and they are not at the top of their concerns (crime, social tensions, turmoil, shortages)	Lack of current chemical infrastructure. Limited agency in global affairs. High standards of environmental protection from European Union legislation. Contemporary political instability. Dramatic impact of the nearby Russia-Ukraine war and the flooding of Ukrainian immigrants into Romania

Implementation of ABET student outcomes 2 and 4 in the curriculum.

A full narrative of the sequential introduction of assignments to demonstrate the achievement of these student outcomes in our curriculum, and their corresponding scores is beyond the scope of this paper. However, it can be summarized that the process started in 2017 when the Vice Chair for undergraduate education promoted the implementation of student outcomes 1-7 in the curriculum to update our ABET accreditation standards. It started with a few professors exploring initiatives to introduce in their courses. The implementation gained momentum with our practice of providing direct assessments for every course and every year. This continuous improvement strategy allowed for disseminating successful experiences and prompting faculty teaching other courses to develop their own. Faculty voted to distribute the seven outcomes in the core courses of the curriculum, guaranteeing that every outcome was included at least once in the sophomore, junior, and senior years. Every course ended up with 3-5 outcomes requiring specific assessments to demonstrate the competency of students. Student outcomes 2 and 4 required extensive discussions in order to clarify the scope of the broad concepts included in their description. This was followed by definitions, rubrics, and examples to help in developing the content of assignments. Progress on the implementation was reported once or twice a year in the faculty meeting, disseminating good practices. Certainly, there is room for improvement and faculty is committed to build upon the experience and to innovate in adding value to students' education.

Students have been very receptive to the assignments related to student outcomes 2 and 4. They perceived them as more "real life" content than theory or equations. In addition, they value the opportunity for creativity and engaging conversations in team meetings. A common criticism is the breath of the fields to address, particularly for the projects (providing them with examples, have helped in approaching this problem). Senior students often mention that the constraints of time and multiple activities in the graduation year, packed with job interviews or applications to graduate or professional schools, make them feel that these assignments overload them with additional requirements. However, our experience shows that students generally address all the questions posted in these outcomes though with variable degree of depth.

Conclusions

Our department has integrated a variety of homework, projects, and quizzes into the curriculum across the sophomore, junior and senior years, which allows students to consider the impact of their design, or engineering solutions in a global, economic, environmental, and social context. Their assignments begin as homework and quizzes with reflections so that they can consider the impact of the solutions. By the senior year, the projects are more complex and there are typically many contexts which warrant consideration and analysis.

References

[1] J.J. McCarty and R.S. Parker. “The pillars of chemical engineering: A block scheduled curriculum.” *Chemical Engineering Education*, 38(4):291-301, 2004.

[2] J.J. McCarthy, R.S. Parker, and M. Besterfield-Sacre. “The pillars of CHE: An integrated curriculum at Pittsburgh,” in *Proceedings of the AIChE Annual Meeting, November 16-21, 2008*, Philadelphia, PA.

[3] J.J. McCarthy, R.S. Parker, A.A. Abatan, and M. Besterfield-Sacre. “Building an Evaluation Strategy for an Integrated Curriculum in Chemical Engineering.” *Advances in Engineering Education*, 2(4):1-22, Summer, 2011.

[4] J.J. McCarthy, and R.S. Parker. “Evaluation and Results for an Integrated Curriculum in Chemical Engineering,” in *Proceedings of 2011 ASEE Annual conference and Exposition, Vancouver, BC*. 10.18260/1-2-17931.

[5] M. J. Baird, and S. L. Shannon. “Unit Operations Lab Bazaar: incorporation of Laboratory Experiences in Six Integrated Pillar Courses,” in *Proceedings of the 2011 ASEE Annual Conference and Exposition, Vancouver, BC*, 10.18260/1-2-18374.

[6] Bayles, T.M., “Hands-on Project Based Learning Design Project to Accommodate Social Distancing and On-line Learners,” in *Proceedings of the 2022 American Society for Engineering Education Annual Conference & Exposition, Chemical Engineering Division, Minneapolis, MN*, June 27, 2022.

[7] Caissie, D., “The Thermal Regime of Rivers: A Review”, *Freshwater Biology*, 2006, pp. 1389-1406. [Online]. Available: https://doi.org/10.1111/j.1365-2427.2006.01597.x

[8] V. Thiyagarajan, H. Prein, S. Cotton, M. Goga, D. Jung, and A. Kinsey. “Technical Project – Social Impacts Report.” *Assignment submitted for the course CHE 0400 Reactive Process Engineering Course. Department of Chemical and Petroleum Engineering. University of Pittsburgh.* August 5, 2022. Unpublished material.

[9] J. Rodriguez, and D. Sanchez. “Global Projects: An Initiative to Train Chemical Engineering Students in Global Awareness” in *Proceedings of the 2022 ASEE Annual Conference and Exposition, Minneapolis, MN*, 37839.

[9] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Chief Counsel’s Report, Macondo – The Gulf Oil Disaster, 2011.

[10] U.S. Chemical Safety and Hazard Investigation Board, “Investigation Report Executive Summary, Drilling Rig Explosion and Fire at the Macondo Well, 4-12-2016”, and Vols. 1-4, 6-5-2014, Report Numbers 2010-10-I-OS.

[11] Research Planning, Inc., “Gulf of Mexico All-Hazards Coastal Risk Assessment Final Report”, *prepared for Disaster Response Center, National Ocean Service, and National Oceanic and Atmospheric Administration*, 9-30-2015.

[12] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Deep Water – The Gulf Oil Disaster and the Future of Offshore Drilling. *Report to the president*. January 2011.

[13] National Academy of Engineering and national Research Council of the National Academies, *Macondo Well Deepwater Horizon Blowout*. National Academies Press, Washington D.C., 1012.

[14] J. Rodriguez, and R. M. Enick. “Chemical Engineering Capstone Course Improved for Broader Impacts,” in *Proceedings of the 2023 ASEE North Central Section Annual Meeting, Morgantown, WV*. March 2023.

[15] B. Ahlmark, T. Hetz, B. Hudock, D.O. O’Neill, D. Policicchio, and N. Steibel. “Social Impacts Report.” *Assignment submitted for the course CHE 0613 Systems Engineering II: Process Design. Department of Chemical and Petroleum Engineering. University of Pittsburgh*. April 20, 202. Unpublished material.