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Material and Energy Balances and Character Development: An Investigation of Student Responses to Intentional Virtue Education in a Traditional Chemical Engineering Course

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Abstract

Engineering education has long held that along with cultivating engineers with solid technical skills, programs must also develop students to be safe, ethical, and community engaged professionals. This has been emphasized time and again through professional organizations across all engineering disciplines and within the ABET accreditation structure. Specifically, these goals are spelled out in ABET student outcomes 2, 4, and 5[1]:

> (2) an 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;
>
> (4) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts;
>
> (5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

These emphasize ethics and values of students as crucial to earning an engineering degree. However, at many schools these discussions are saved for specific courses on ethics or design rather than intentional integration across the degree. This paper explores the intentional and explicit inclusion of character and virtue building in the context of a traditional chemical engineering course during the sophomore year.

Student taking their first chemical engineering specific course, Introduction to Chemical Engineering Processes, were asked to reflect throughout the semester on the importance of virtue/character in their development as a chemical engineer. These reflections were graded work within the class and either replaced or augmented traditional engineering problems. The material included:

- A pre-semester survey including questions on what students believe to be important “skills, values, and attributes” of working engineers,
- Homework problems across 3 assignments requiring student reflection on virtue and character development and a self-assessment,
- Short answer exam question probing how they have intentionally worked on a virtue during the semester, and
- A final homework and end of semester survey reflecting on this experience and again answering what they believe are important “skills, values, and attributes” of working engineers.

Additionally, a control group of the same course but a different instructor's section was given both the pre-semester and end of semester survey, but had no value/character instruction during the rest of the class.

Qualitative feedback from these assignments were collected and thematically coded to form an introductory answer to the following research questions:

1. What do incoming sophomore level students view as the most important silks, virtues, and attributes of working engineers? Does this change over the course of the semester?
2. How do students connect the ABET student outcomes to a specific list of virtues?
3. In self-assessment, what values do students identify as strengths and things to work on?
4. Does intentional inclusion of virtue and character development in a class have any effect on student perception of their ability or interest in chemical engineering?

Introduction

> *"[E]ngineers must be active and responsible participants in framing the issues they work on, not only from a technological perspective, but also from a political and value-based perspective" – Darshan M. A. Karwat et al.*[2]

Engineering, by nature of its impact on the way humans live, has a professional responsibility to strive for an ethical and just world. This belief is described time and again in educational research [3-5]; however, engineering does not have an explicit guide to values and morals for how engineers should engage with these topics [6]. In fact, many believe that engineering curriculum shortchanges professional ethical responsibility due to the high technical demands of the major. Mitcham [7] argues that the ultimate grand challenge of engineering is "self-knowledge, that is, of thinking reflectively and critically about the kind of world we wish to design, construct, and inhabit in and through our technologies." If this is true, it is easy to see that ethical behaviors and values should be taught across all engineering courses and in many contexts. Luckily, engineering ethics is being taught in engineering departments. Unfortunately, there are mixed reviews to the appropriateness and student perception of these education experiences [18-20].

Engineering ethics education can be sorted into a number of categories related to their perceived objectives. Newberry[8] posits three categories: particular knowledge, intellectual engagement, and emotional engagement. "Particular knowledge" would indicate an emphasis on ethical codes, common ethical issues, and case studies of ethical precedent. This details guidelines to students of what ethical practice may look like in the engineering careers, and it is accounts for many of the engineering ethics curricula. "Intellectual engagement" deals with student understanding of the principles of moral reasoning and how to engage with ambiguous scenarios. Here, students are asked to practice how to make ethical decisions and what may be guiding these decision frameworks from a provided ethical framework. Finally, "emotional engagement" may be the most important but least explicitly covered ethical instruction. Its objective is to develop the student's intrinsic desire to "recognize, to care about, and to resolve ethical issues."[8] While these categories do not have to stand alone, the inclusion of ethical codes (particular knowledge) without the deeper intellectual and emotional engagement will be fruitless[9].

In light of these needs for greater connections for true engagement, virtue-based (or character-based) ethics education has been suggested [10] with promising initial findings. A recent study at Wake Forest University [11], explored student perspectives and suggested a number of modifications to traditional engineering courses in order to add virtue-based education across curriculum. This paper uses a similar values framework to engage sophomore chemical engineering students in values-based engineering instruction within a traditional engineering course. This exploratory study sought to clarify student perceptions of values with only minimal changes to an Introduction to Chemical Engineering Processes course. Therefore, the research was guided by 4 key questions:

1. What do incoming sophomore level students view as the most important silks, virtues, and attributes of working engineers? Does this change over the course of the semester?
2. How do students connect the ABET student outcomes [1] to a specific list of virtues?
3. In self-assessment, what values do students identify as strengths and things to work on?
4. Does intentional inclusion of virtue and character development in a class have any effect on student perception of their ability or interest in chemical engineering?

Virtue Education Background

Like many engineering instructors, the instructor for CBE 20255: Introduction to Chemical Engineering Processes has little formalized training in the philosophical or theological frameworks of ethics. Multiple papers have outlined faculty members' low familiarity and confidence in these subjects as a key limitation to instruction [12] along with the low weight given to ethics education [13]. Therefore, the virtue educational materials provided to students were developed by several colleagues in the College of Engineering at the University of Notre Dame. This was done to provide continuity of ethics education across the college and to use materials that have been vetted by those with more familiarity in formalized ethical frameworks. This was developed based on the virtue ethics framework created by the Jubilee Center [14] and previous work completed by Dominic Chaloner[21] in the College of Science at the University of Notre Dame. As an example, The Jubilee Centre created a framework for Virtue-Based Profession Ethics. The main graphic is shown below and informed the categorization of the course's virtue primer.

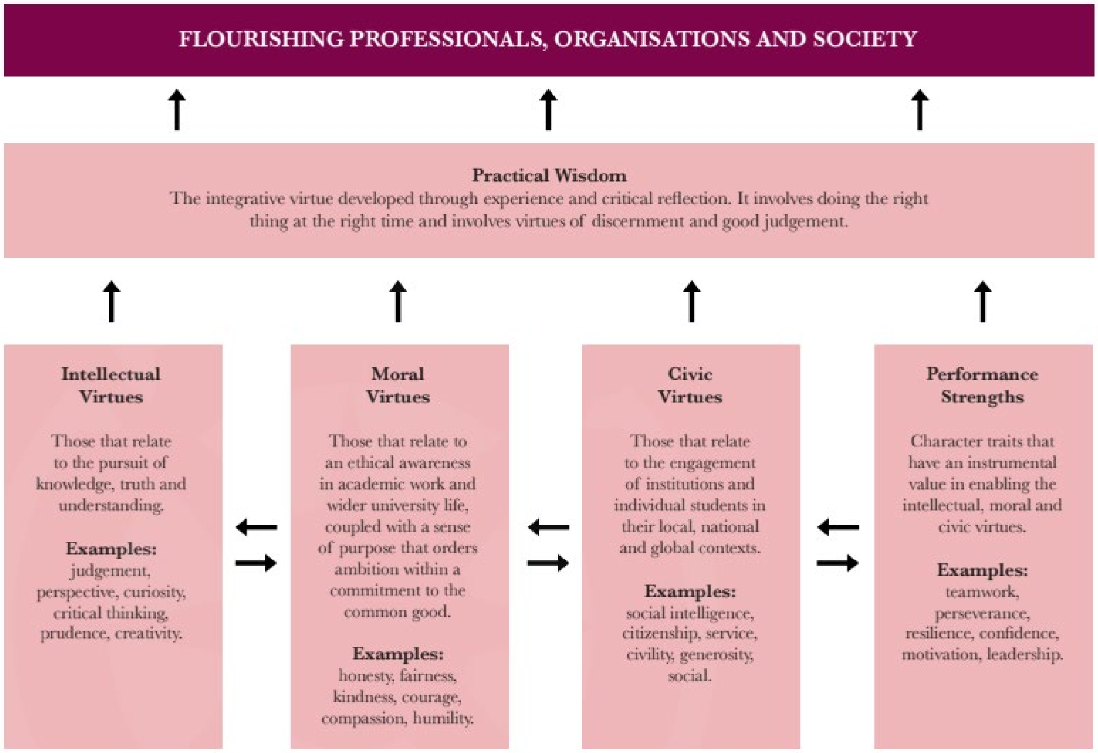

Figure 1: Jubilee Center Framework for Virtue-Based Professional Ethics [14]

Much like the framework above, students were provided with a list of virtues broken down into several categories: Civic Virtues, Performance Virtues, and Intellectual Virtues. Moral virtues were not explicitly included as their own category but were instead folded into the intellectual virtues. While there are many frameworks for virtue instruction that could be used [15, 16], this document was created by an ad-hoc committee in order to create a common language and instruction to be used for the entire College of Engineering across departments and year in program. Therefore, there were only minor changes made by the instructor to the document in order to ensure cohesive instruction.

The full virtue primer given to students is included in Appendix A. No additional lecture style instruction was given on virtue frameworks in class. Instead, virtue development was woven into the course lectures or reflection points when appropriate and easily done. Therefore, this intervention could be considered low effort and requiring minimal theological/philosophical knowledge from an engineering professor.

Study Context

University Structure

This study was conducted at the University of Notre Dame, a medium-sized, private, selective, religious, Midwestern institution within the Department of Chemical and Biomolecular Engineering (CBE). Students in this study were all enrolled in the Introduction to Chemical

Engineering Processes course (CBE 20255) which is the introduction to the chemical engineering degree and curriculum. At Notre Dame, all engineering intended students take a common first year engineering sequence that does not involve any chemical engineering courses. There are no administrative gates from the university for major selection as long as the student is in good academic standing (minimum GPA of 2.0). There is no application, GPA requirement, or cap placed on major selection. Students use two first-year engineering courses to explore and confirm their major choice before officially selecting their major in the spring of their first-year. Notre Dame has a very strong retention rate with more than 90% of the students entering this sophomore course continuing on and graduating with a chemical engineering degree within 4 years.

The Department of Chemical and Biomolecular Engineering fluctuates in size due to the nature of major selection at the university, but regularly has between 50 and 90 students entering the department as sophomores. Along with students that have matriculated from the first-year engineering class, a small number of transfer students are generally enrolled as their first engineering course at the university. The course in this study is traditionally taken during the fall semester of the sophomore year and is a pre-requisite to almost all of the remaining chemical engineering classes. This study took place in the Fall 2023 semester, with a total of 82 students enrolled across two sections of the Introduction to Chemical Engineering Processes course.

Course Structure

This 3-credit course covers the basics of material and energy balances. A total of 82 students were enrolled in Introduction to Chemical Engineering Processes during Fall 2023, split across 2 sections with 2 different professors. Both sections used the same book, covered the same book sections, and had the same number of major deliverables. Both courses meet for class 3 times a week for 50 minutes each. In addition, there is a 50-minute tutorial section used for problem solving in each section. Both professors used lectures with active learning in the form of problem solving as their main teaching technique. Otherwise, the sections were run independently from one another and did not overlap in the homework, lectures, or day to day material.

In the control group (n=39), no virtue or character instruction was given in the semester. In the study group (n=43), a small amount of virtue instruction was given through lecture connections and in homework problems along with the virtue primer described above. Otherwise, there are no major changes to course content. Responses rates are shown in the section below and full descriptions of the assignments are included in Appendix A and Appendix B.

Methodology

This study focused on some quantitative measures from student surveys along with qualitative analysis of student responses in surveys and homework. Students in both sections were give the same pre and post course survey to complete. Responses in the pre-survey were completed before and during the first week of classes while post course surveys were given during the final two week of classes.

Neither group received credit for content of the pre- or post-course surveys, which were distributed by the professor of the study group using individualized email links through Qualtrics. The study group was reminded to complete the post-survey in class, which may account for the difference in response rate between groups for the post-survey. In the study group, there were 10 homework assignments with 5 questions on each. In homework assignments 1, 4, and 8, one technical question was replaced with a question that probed virtue and character reflections. These were graded for effort and therefore responses could not negatively affect their grade in the course.

Table 1. Summary of Respondents

	Number Responses Completed (Percentage)	
Feedback Assessment	**Study Group**	**Control Group**
Pre-Survey	43/43 (100%)	37/39 (94.9%)
HW 1 – Introductory	43/43 (100%)	-----------------
HW 4 - Community Awareness	42/43 (97.7%)	-----------------
HW 8 – Curiosity	42/43 (97.7%)	-----------------
Final Survey	43/43 (100%)	22/39 (56.4%)

A number of the survey questions returned quantitative data on a Likert scale. This data is summarized for each section and t-tests were used to identify statistical significance when appropriate. Qualitative responses were thematically coded for key words and patterns using emergent themes. These were all completed by a single researcher for all student responses.

On the whole, both courses have near gender parity. Using the National Science Foundation categorization for underrepresented minorities yields too small of numbers to give a robust picture of URM experiences in this single course. While the researcher does have access to student grades and demographics, neither was considered in this study as they were not included in the IRB request. Future studies will include additional cohorts to create a more robust data set.

Results and Discussion

Each of the research questions is addressed in the sections below using the methods indicated in the methodology section. When possible, statistical comparisons are included.

Question 1: *What do incoming sophomore level students view as the most important silks, virtues, and attributes of working chemical engineers? Does this change over the course of the semester?*

A survey question was posed to students in both sections during the pre-course and post-course surveys. The survey prompt was:

What skills, attributes, or virtues do you think are required to be a good practicing engineer? (Not just an engineering student)

Students were not given any information before providing this response, and it is assumed they are answering based on exposure in previous courses or their own preconceived notions. Upon first reading, approximately 90 skills and virtues were identified based on student responses in both the pre and post survey. These were then combined into 11 themed codes as shown in Table 2, below.

Table 2. Emergent themes from coding of the open ended question *"What skills, attributes, or virtues do you think are required to be a good working engineer?"* **ordered by codes with the largest total mentions across both class and both surveys.**

Code	Example Descriptions in student work	Pre-Course		Post-Course		Total Mentions
		Study	Control	Study	Control	
Critical Thinking	Critical thinking, Analytical thinking, Logical, Deep thinking, Problem Solving	29	28	18	18	***93***
Teaming	Team work, collaboration, communication, Soft skills/people skills, accountable	28	18	18	10	***74***
Resilience	Resilience, Persistence, Tenacity, Adaptability, Perseverance	13	12	25	5	***55***
Hard Work	Hard work, Work ethic, Dedication, Diligence, Discipline, Determination, Concentration, Commitment, Drive	18	16	9	4	***47***
Ingenuity	Creativity, Curiosity, Ingenuity, Innovation, Open-Mindedness	18	10	9	2	***39***
Growth Mindset	Growth Mindset, Accept Ideas, Ability to ask for help, Ability to learn, Likes a Challenge, Adaptability	11	16	8	4	***39***
Technical Knowledge	Math/Science Skills, Technical Skills, Computer Skills	8	5	2	5	***20***
Moral Virtues	Amiable, Kind, Composed under pressure/stress, Honesty, Humility, Patience	6	5	3	5	***19***
Confidence	Confidence, Courage, Bravery	1	0	12	0	***13***
Social Responsibility/ Civic Virtues	Care for community, Understand impact, Accountable, Empathy, Awareness of impact	3	3	5	1	***12***
Ethics	Ethical, Moral, Just, Integrity	0	3	5	0	***8***

While there are many changes in raw values, it is impossible to make a direct connection of increasing and decreasing mentions due to changes in response numbers and additional guidance to students during the semester. The study group had been given virtue education materials that specifically listed vocabulary that could be used which, anecdotally, appeared in more responses of the post course survey.

Although the values cannot be considered on their own, many of the changes seen here match expectations of the course faculty.

(1) Teamwork is a large portion of the first-year engineering sequence with required team projects in both semesters. This is less emphasized in CBE 20255; therefore, it is unsurprising for that to be less emphasized in student response post-course.

(2) Resilience rises in mentions in the study group while falling in the control group. In the study group, resilience and persistence were common themes of class lectures and office hours. This was a deliberate inclusion when students struggled, especially around large assessments. Therefore, class instruction can be linked to this change.
(3) Confidence had a significantly increased inclusion in the study group. Again, this is expected within the course context. This was again emphasized in the class based on student responses in their first homework assignment. The more explicit analysis of this change will be discussed when addressing Question 3.

Finally, there was one very surprising finding in that both groups had decreased mentions of Critical Thinking. This is especially surprising for the study group where the response rate was equivalent in both surveys. There is currently no clear explanation for why this decrease occurred, and it runs counter to other data that will be presented in subsequent results. This will be an active area of study for a more in-depth review moving forward.

In all, the skill, attributes, and virtues identified by students were in line with expectations both before and after the courses. On the whole, students did not appear to have largely changed their perception of the skills and attributes needed to be working engineers. Next steps would include completing a pair-wise comparison for individual students to determine individual migration of responses.

Question 2: *How do students connect the ABET student outcomes to a specific list of virtues?*

In the first homework of the semester for the study group, students were asked to read the virtue primer (Appendix A) then complete the following table with the virtues that they believed were necessary for meeting each of the 7 student outcomes from ABET.

Table 3. Homework Response sheet for ABET Student Outcomes 1-7

	ABET Outcome	**Virtues Needed**
1	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and math	
2	An 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	
3	An ability to communicate effectively with a range of audiences	
4	An 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 societal contexts	
5	An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	
6	An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions	
7	An ability to acquire and apply new knowledge as needed, using appropriate learning strategies	

Figure 2, below, shows the top 5-7 virtues selected by students. Many more virtues were listed by students for each student outcome (found in Appendix C, Table C.1).

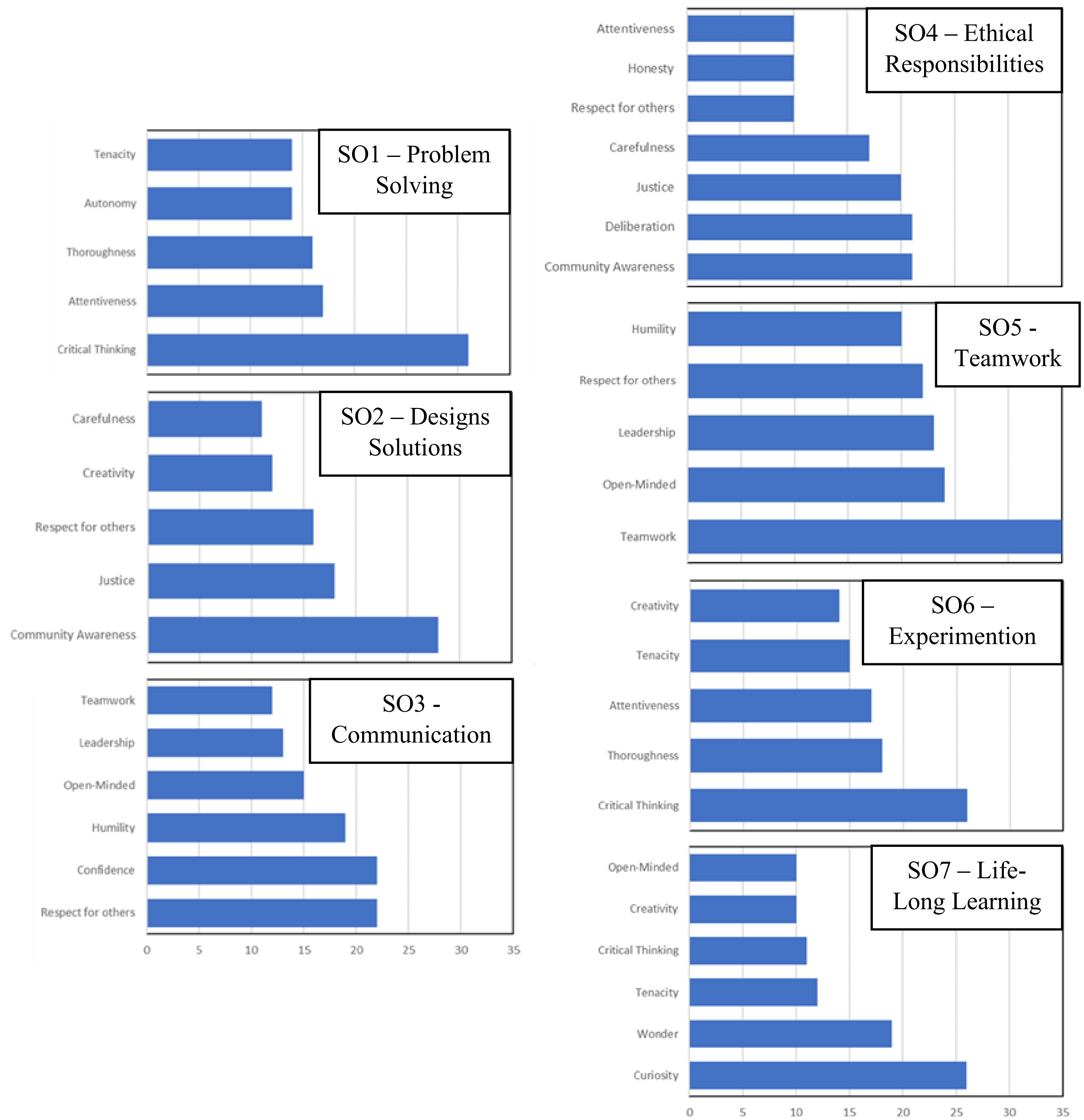

Figure 2: Student responses to virtues needed for each student outcome. Many other virtues were listed but only the top 5-7 virtues are included here. Each x-axis is shown at the same scale.

These findings are not particularly surprising. In fact, when compared to the Kohler et al. study[11], many of these student responses match instructor-determined virtue mapping of ABET outcomes.

Interestingly, the highest selected virtues for each student outcome (critical thinking, community awareness, respect for others, deliberation, teamwork and curiosity) do not uniformly appear as the most important virtues working engineers needed as seen in the post-course survey (Table 2). While some overlap, critical thinking actually decreased in responses for the study group. It could be that students did not recall the ABET student outcomes and their own responses and therefore answered with some other thought process on the post-course survey.

To dig deeper, students in both sections were also asked the following rating question in their post-course survey:

> *By graduation with an engineering degree, you should show attainment of these outcomes. Provide feedback on how much you think the CBE 20255 course focused on each of these. 0 indicates that it was not a part of the class at all and 100 would indicate it was something that was integral to the course and covered nearly every day.*

The responses for these scaled responses are given in the box and whisker plot below with solid blue boxes used for the study group and the dotted boxes used for the control group.

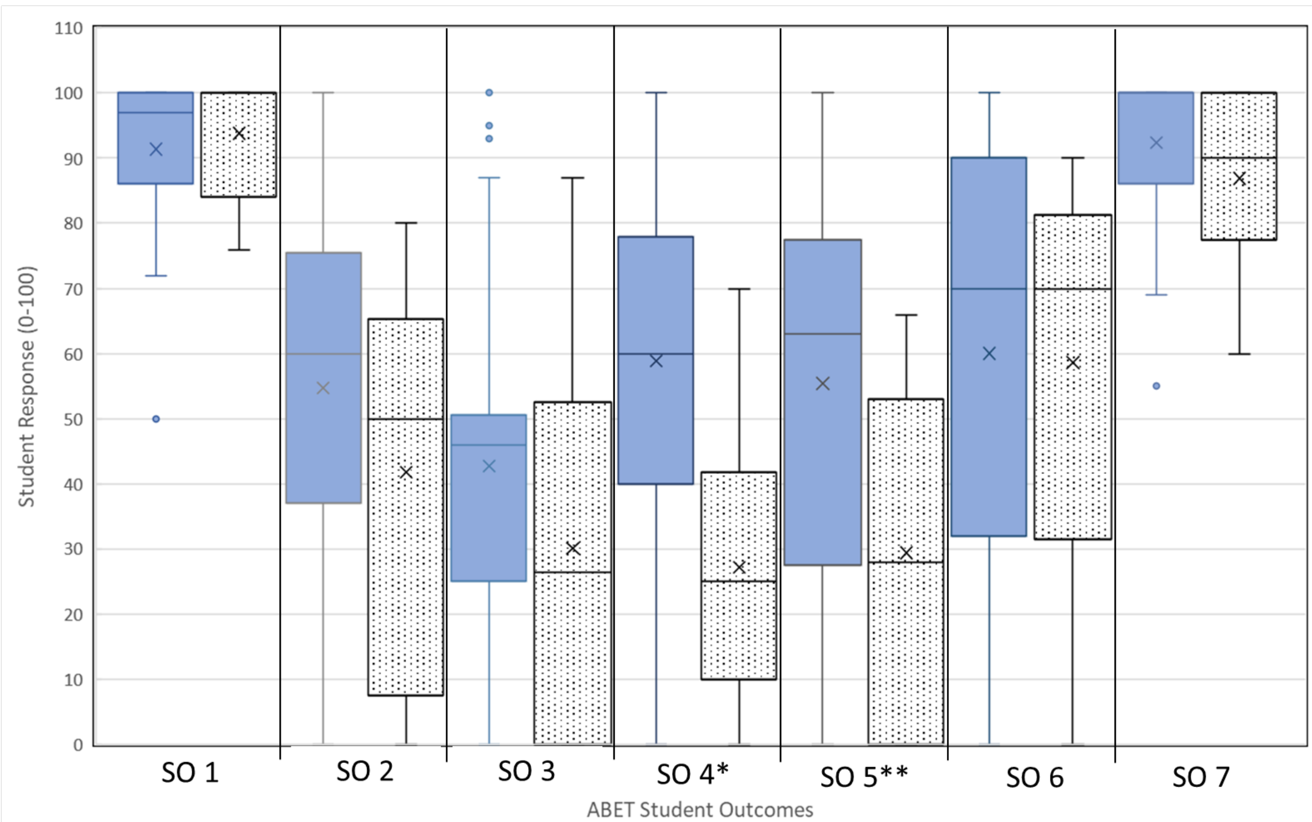

Figure 3: Student evaluation of ABET Student Outcomes (SO) 1-7 from the study group (blue solid) and the control group (black dotted). *p-value of 3.7×10^{-6}, **p-value of 0.0038

In both the study and control sections SO 1 (Problem Solving) and SO 7 (Lifelong learning) are rated as integral to the CBE 20255 courses. This makes the results of decreasing critical thinking responses in Table 2 even more surprising. It is clear that this phenomenon needs additional study to understand how students are interpreting the questions and considering their answers.

Additional interesting takeaways from this work are the statistically significant differences found in SO 4 and SO 5. Student Outcome 4, describing ethical and profession responsibilities, shows a higher course focus in the study group. This is assumed to be a result of the intentional inclusion of virtue discussions in class. It may also link explicitly to the homework 4 problem that asked students to research and respond to a time when community awareness and respect for others may not have occurred. Interestingly, this was a single point intervention, but a marked change in student perception – a promising result in support of small ethical discussions throughout the curriculum.

Finally, Student Outcome 5, ability to function on a team, also showed statistically significant differences between the two classes. This is believed to be due more explicitly to the ABET statement of "create a collaborative and inclusive environment" which was emphasized regularly in the study class. The instructor begins the course with an inclusion statement and forms student informed course expectations around creating an inclusive course environment.

Question 3: *In self-assessment, what values do students identify as strengths and things they want to work on?*

Again, in homework 1, the study group was asked to reflect on the virtue information they had read and the ABET student outcome responses they had determined before answering the final two prompts.

Select 1-3 virtues that you feel that you have already built up well (something you'd consider a strength for yourself).

Select 1-3 virtues that you would most like to work on improving this semester.

Here, students were selecting from the lists provided by the instructor and were therefore a much narrower list of responses compared to the pre and post course surveys. Again, only the first ~8 responses are shown here, but full responses can be found in Appendix C.

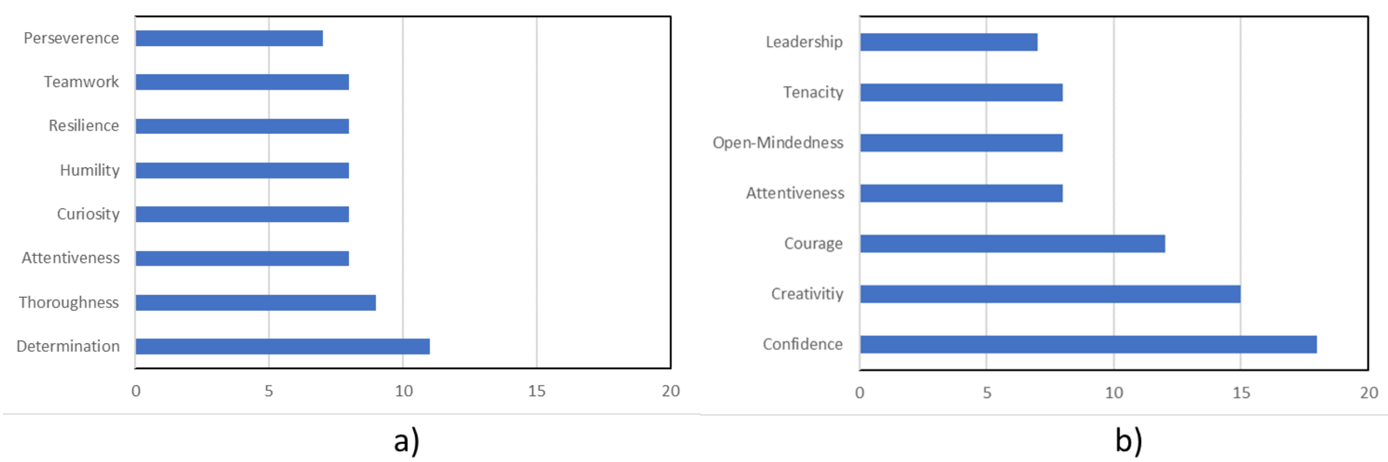

Figure 4. Student self-identified strengths (a) and virtues to work on (b). Only the most popular answers are provided.

Looking at strengths, many students list virtues that could be considered performance virtues, representative of the hard work and high performing background of our students. However, in the virtues to work on, over half of the students listed either confidence or courage. The course level responses were shared with the students to help them understand how many of their peers were struggling with the same virtue development. In class, students brainstormed several ways that they could actively work on their confidence and courage. A few responses that were shared (and practiced) include:

1. Answering a question posed in class when the whole class is listening to the response.
2. Asking a question in class when confused.
3. Attending office hours or student study hours to get additional help.
4. Meeting new people both in and out of the class but specifically to help form study groups.

Later in the semester, students were asked to reflect on their progress for one of the virtues listed in Figure 4b, with many students explicitly relating these activities as concrete evidence of their growth. In future studies, these student responses could be coded for more depth.

Question 4: *Does intentional inclusion of virtue and character development in a class have any effect on student perception of their ability or interest in chemical engineering?*

Finally, this study briefly explored if the virtue instruction played any role in student perception of their ability or interests in major. Data used to respond to this question were limited to two questions that were asked of all students in the both the pre and post course survey. These questions asked the students to rank from 1 (strongly disagree) to 5 (strongly agree) how much they WANT to complete a chemical engineering degree and their ABILITY to complete the degree (Table 4).

Table 4. Average pre and post responses to interest and ability related to chemical engineering degree completion.

To what degree do you agree with this statement:	Group	Pre Class		Post Class	
		Avg	Std Dev	Avg	Std Dev
I WANT to complete a degree in chemical engineering.	Control Group	4.76	0.55	4.55	1.1
	Study Group	4.71	0.74	4.63	0.85
I have the ABILITY to complete a degree in chemical engineering.	Control Group	4.35	0.73	4.2	1.06
	Study Group	4.45	0.63	4.19	1.1

In the end, there are no statistically significant changes in the responses of students due in large part to the high initial responses of students to these prompts. While it appears that there is a slight decrease in student interest and ability for both classes, these are indistinguishable within the data collected and do not indicate a true change in student perception. However, a phenomenon of decreasing interest and ability responses (as students are under high stress due to course final exams) is not surprising and matches anecdotal experiences. This could be an artifact of the larger university context for students at this point in time.

Additionally, this comparison was only looking at overall course information. Instead, a paired t-test to look at individual changes over the semester would be an interesting inclusion. In addition, demographic data may elucidate if there are any significant shifts for specific groups, as has been found in other studies [17].

Limitations

The data and findings presented here represent only student perceived virtue development. At no time did a faculty member assess students on their virtue knowledge and expression. There could be growth in virtues that students have not yet recognized.

Additionally, this study is in an exploratory phase and has not yet been broken down to follow changes at the individual student level. This could provide more detail on how students are responding to this instruction.

Finally, student grades and demographics play a large role in how students interpret courses and their place in the university environment. Those factors have been ignored in this study, but are acknowledged as important facets of fully understanding these results. Future work could focus on possible differences seen in women, underrepresented minorities, transfer students, international students, previous virtue instruction, and religious affiliation.

Conclusions

In this study, students were asked to take part in small reflections and interventions around the development of virtue. The students were largely positive about these problems and engaged with the material as fully as other more traditional technical problems they were assigned. Based on responses, it’s clear that students can successfully link a number of virtues to ABET student outcomes, showing the importance of virtue development as part of engineering education.

There is still a significant amount of work needed to understand the correlations between the course changes and student responses, but this work is promising. A limited number of small and introductory virtue lessons did have small effects on various student responses. From faculty observations, this also improved the faculty’s ability to learn about the students and respond as unique needs came up during the semester. Overall, it is a promising method for an efficient and effective way to introduce virtue throughout the curriculum without a burdensome redesign or expertise needed by the engineering faculty.

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Appendix A: Virtues in Engineering, A Primer Provided to Study Group*

*Partially redacted for peer review

Virtues and Engineering, a Primer

Engineering requires intellectual, civic, and performance virtues in order to be successful and to meet the University's mission as "a force for good in the world". Good engineering education requires that we build both technical skills and character as it pertains to your professional identity. Some of this information may be information you've learned in theology classes, philosophy classes, or other points of your education. However, character and virtue development are not exclusive to religious thinking. The notion of needed virtues and how to behave virtuously may even change dependent on circumstances you are in. Therefore, this practice will be about deliberative and reflective building of virtues as it pertains to your future career.

The following list of virtues was created by building off of the Jubilee Center's Framework and the work of Dom Chaloner. You will find many examples of virtue education, Catholic virtues, and engineering ethics that will all define these needs differently. That's ok – we are not treating this exercise as a philosophical or theological purist might!

Engineering as a Virtuous Practice

Engineers play a large role in shaping society. Therefore, virtuous and ethical engineers need to develop virtues around civic, intellectual, and performance areas.

Civic virtues allow engineers to define and understand their ties and responsibilities to society. The unique influence of engineers makes civic virtues integral engineering character development. These are necessary for engaged, responsible citizens contributing to the common good of society.

- **Deliberation** is using reasonableness and good judgment through the use of logic
- **Community awareness** is the purposeful inclusion of community partners in dialogue
- **Justice** is valuing and working for fairness and equality
- **Respect for others** is the capacity to engage others and not overstate one's own status in the community.

Performance virtues help us respond well to various situations. These are often tested at job interviews with questions like "How do you handle conflicts?". These are often defined as virtues that enable people to manage their lives effectively. Without performance virtues, you are unlikely to be able to live the intellectual, civic, and moral virtues in everyday life.

- **Confidence** is the belief of yourself arising from appreciating your own abilities and qualities.
- **Determination** is having purpose and resoluteness towards a goal.

- **Leadership** is a set of behaviors that can be used to align people, groups, or organizations in a collective direction.
- **Teamwork** is the combined action of a group towards a goal, especially when effective.
- **Perseverance** is doing something despite difficulty or delay in achieving success.
- **Resilience** is the ability to withstand or recover quickly from difficulties.

Additionally, some **main intellectual virtues** can be defined as follows:

1. **Wonder** is the disposition to be inquisitive and to ask why, and as a consequence the desire to explore in search of understanding. Characterized by asking deep and meaningful questions.
2. **Humility** is the willingness to admit one's own limitations and mistakes. Characterized by being unconcerned about ones intellectual status and willing to admit what is not known as much as what is known.
3. **Autonomy** is the capacity for self-directed thinking. Characterized by being able to think and reason independently.
4. **Attentiveness** is the ability to remain focused on the task at hand while noticing important details. Characterized by being able to avoid becoming distracted when a task is especially difficult or easily completed.
5. **Carefulness** is an awareness of the needs for sound thinking while noticing and avoiding intellectual pitfalls and mistakes. Characterized by looking for ways to better understand information rather than simply rote memorization.
6. **Thoroughness** is a willingness to probe for deeper meaning and understanding. Characterized by not being satisfied with easy and superficial answers.
7. **Open-mindedness** is being receptive to new ideas, especially those that go against conventional wisdom. Characterized by considering other viewpoints and perspectives.
8. **Courage** is a readiness to continue thinking despite the possibility of embarrassment or failure. Characterized by being willing to take intellectual risks.
9. **Tenacity** is the willingness to embrace intellectual challenges. Characterized by being able to focus on long-term objectives and not giving up when confronted with challenges.
10. **Honesty** is an awareness of the need to be fair and straightforward in ones conduct. Characterized by always adhering to the facts and being transparent about what has been done.
11. **Creativity** is thinking of new ways to solve problems and create new opportunities or products.
12. **Curiosity** is being interested in new ideas, experiences, and people.
13. **Critical Thinking** is being analytical and approaching challenges from multiple perspectives.

Appendix B: Virtue Assignments for Study Group

PROBLEM 1 (HOMEWORK 1)

1. As engineering students, you are going to be continually assessed and graded on technical pursuits. However, to be a good working engineer you also need to build character traits as well. These are the most important aspects of actually working in engineering fields!
   a. Read "Virtues and Engineering, a Primer" for background on virtues as they relate to working as an engineer.
   b. Below are the student outcomes that the department MUST show evidence of your completion. Fill in the table with which virtues that you think would be most needed to meet each outcome.

	ABET Outcome	**Virtues Needed**
1	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and math	
2	An 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	
3	An ability to communicate effectively with a range of audiences	
4	An 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 societal contexts	
5	An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	
6	An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions	
7	An ability to acquire and apply new knowledge as needed, using appropriate learning strategies	

   c. Reflecting on parts a and b, select 1-3 virtues (from this list or others) that you feel that you have already built up well (something you'd consider a strength for yourself).
   d. Reflecting on parts a and b, select 1-3 virtues (from this list or others) that you would most like to work on improving this semester.

PROBLEM 2 (HW 4)

2. Chemical Engineers are often involved in many decisions that affect the community around them and could impact others who use their technologies.

   a. How do you believe the virtues of community awareness and respect for others fit into being a chemical engineering professional?

Research how a chemical engineering technology (see next page as needed) has either respected or disrespected a community when being implemented and then complete the following.

b. Write a brief summary (~1 paragraph) of the technology implemented and how it affected the community. If the technology negatively affected the community, was anything done to mitigate the issues? Were they done voluntarily be the organization or required by law (to the best you can tell)?

Examples of situations you could consider:

- There are many examples that stem from environmental racism. One that is especially close to chemical engineering is the ~100 mile stretch of Louisiana known as cancer alley due to the incredibly high number of petrochemical plants. https://www.propublica.org/article/welcome-to-cancer-alley-where-toxic-air-is-about-to-get-worse
- For many years, women were not included in the testing of pharmaceuticals due to hormone shifts. https://www.healthline.com/health-news/we-dont-have-enough-women-in-clinical-trials-why-thats-a-problem
- All fish in Lake Michigan show evidence of PFAS - https://iiseagrant.org/study-finds-pfas-in-all-tested-lake-michigan-sportfish-and-their-prey/

Many other examples were given in the class assignment

PROBLEM 3 (HW 7)

Focusing on the virtue of **curiosity** – In my experience, many students are so worn out from the work and stress of classes at this point in the semester, that it's easy to lose curiosity about chemical engineering. There is a reason you are (or have been) excited about chemical engineering! For this homework problem, pick a product or technology that you are interested in that is connected to chemical engineering. Research a bit about the most important technological questions related to this product or technology. How does this connect to the topics we have covered in class? *Reach out to Dr. Goodrich or the TAs if you have questions about ideas or understanding the technologies needed*

PROBLEM 4 (HW 10)

In your first homework of the semester, you identified 1 – 3 virtues you wanted to work on during the semester.

a. Reflect on each of those virtues. What is one way you've grown in these virtues this semester? Is this still something you want to work on? If so, how will you continue to grow in this virtue – remember that to grow in a virtue you need to both practice and reflect on the experience.
b. What does it mean to you to be a "force for good" in engineering at Notre Dame? How do these virtues fit into your understanding?

c. After finishing this semester, do you have new virtues you plan to work on as you move forward in your career?
d. Is there a way that faculty and courses can explicitly help you in building virtues? What would you like to see as you continue through your engineering degree?

Appendix C: Additional Data

Table C.1: Full Student Responses to ABET Student Outcomes

Virtue	SO 1	SO 2	SO 3	SO 4	SO 5	SO 6	SO 7
All civic virtues	0	0	0	1	0	0	0
All performance virtues	0	0	0	0	1	0	0
Attentiveness	17	5	2	10	8	17	8
Autonomy	14	2	0	4	4	12	7
Carefulness	10	11	2	17	1	11	0
Community Awareness	0	28	8	21	4	0	1
Compassion	0	0	1	0	0	0	0
Confidence	7	2	22	2	5	7	5
Courage	1	1	6	4	5	1	4
Creativity	13	12	0	1	1	14	10
Critical Thinking	31	9	0	7	5	26	11
Curiosity	2	3	4	3	7	9	26
Deliberation	9	8	3	21	3	7	3
Determination	10	6	0	3	1	6	7
Honesty	0	6	10	10	6	2	1
Humility	1	3	19	6	20	2	5
Justice	0	18	4	20	4	0	0
Leadership	0	5	13	4	23	0	0
Open-Minded	5	9	15	8	24	3	10
Patience	0	0	1	0	1	0	0
Perseverance	11	1	0	1		7	5
Resilience	3	3	1	3	3	2	5
Respect for others	0	16	22	10	22	0	1
Teamwork	4	3	12	3	35	0	1
Tenacity	14	6	0	5	4	15	12
Thoroughness	16	8	0	8	2	18	8
Wonder	5	2	1	4	1	12	19

Table C.2: Student self-identified virtues that are strengths and what they want to work on

Strengths		Working on	
Virtue	**Count**	**Virtue**	**Count**
Determination	11	Confidence	18
Thoroughness	9	Creativitiy	15
Attentiveness	8	Courage	12
Curiosity	8	Attentiveness	8
Humility	8	Open-Mindedness	8
Resilience	8	Tenacity	8
Teamwork	8	Leadership	7
Perseverence	7	Wonder	6
Critical Thinking	6	Autonomy	5
Deliberation	6	Community Awareness	5
Leadership	6	Critical Thinking	5
Respect for others	6	Thoroughness	5
Tenacity	6	Humility	4
Honesty	5	Carefulness	3
Open-Mindedness	5	Curiosity	3
Wonder	5	Justice	2
Autonomy	3	Resilience	2
Community Awareness	3	Teamwork	2
Courage	2	Determination	1
Creativity	2	Patience	1
Carefulness	1		