How are Engineering Ethics Integrated into High School STEM Education in Colorado? (Fundamental)

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How are Engineering Ethics Integrated into High School STEM Education in Colorado?

Abstract
Engineering education continues to become more prominent in high schools, catalyzed in part by Project Lead the Way and the Next Generation Science Standards (NGSS). An important topic within engineering is ethics, including macroethical issues such as the environmental and societal impacts of engineering and technology. This research therefore examined if and how engineering ethics are being implemented in high school STEM education, seeking to understand teacher practices and perspectives. While exploring these perspectives, an emergent goal of the research became to determine whether teacher’s beliefs about their incorporation of ethics in their STEM-based courses matched the evidence they provided. This qualitative research was conducted by interviewing 14 high school STEM teachers in Colorado. The teachers represented multiple subjects (engineering, computer science, science, and math), school districts, public and private schools, as well as religious and nonsectarian institutions. Five of the teachers had bachelor’s degrees in engineering disciplines, and some also had engineering work experience in industry. The study found that 13 of the 14 teachers integrated engineering ethical issues. However, the majority of the teacher interviewees viewed environmental and societal impacts as being different from ethics, revealing confusion about macroethics. Interestingly, among the 7 teachers whose focus was engineering education, 3 did not believe that they integrated engineering ethics and/or environmental/societal impacts into their teaching, while all of the 7 non-engineering STEM teachers believed that they integrated ethics and/or societal/environmental issues in their teaching. These results on STEM teaching practices in high school provide insights into the variable backgrounds and attitudes that incoming college students might have regarding the importance (or lack of importance) of ethical issues in engineering.

Introduction
There is a need for qualified and capable engineers to serve the needs of society. These engineers are faced with ever-evolving problems which impact people, the environment, and society itself. The ethical education and development of engineers is important so that working engineers will understand the weight of their role and the impacts their practices may have. Under the accreditation requirements for engineering programs under ABET [1], students should have the “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.” The American Society for Engineering Education (ASEE) notes that engineering educators should “work to cultivate students’ abilities to recognize ethical and professional responsibilities in engineering situations” [2]. Embedding the culture of ethical practice in engineering education from the start may be particularly impactful. This led to the question, “What is being done in K-12 engineering programs regarding ethics?”

Engineering ethics encompasses the moral issues around engineering activities and the standards for engineering practice as it relates to the impacts of engineering on society and the environment. In this respect, engineering is similar to other STEM fields because science and technology also have significant impacts on the world. It is important to recognize that these impacts can be both positive and negative, often involving trade-offs and uneven distribution of these benefits and
harms. While sometimes engineers become focused on how to achieve a particular task (problem solving) it is important to first consider how the problem has been defined (by whom, inclusive and excluding which perspectives). It is important that the critical nature of ethical practice is embedded within the culture of how both the public and engineers perceive engineering.

Through a process of consensus the engineering profession has codified its expectations with respect to the ethical behavior of engineers. Initially these codes had a heavy focus on the individual business practices of engineers [3], such as not falsifying data, taking bribes, or competing unfairly with other engineers. This is termed microethics. Engineering has also long recognized the importance of protecting human health and welfare, but this was largely viewed through the lens of individual actions (e.g. working within one’s area of competence). Macroethics attends to the engineering “profession’s collective social responsibility, and the role of engineers in societal decisions about technology” [4, p. 683]. Macroethics are reflected in engineering codes of ethics. For example, the American Society of Civil Engineers (ASCE) code of ethics added environmental protection, sustainability, and treating all persons fairly/equitable participation in 1976, 1996, and 2017 [5], respectively. The update in 2020 moved to a hierarchical stakeholder model that places obligations to society and the environment first [6]. The ASEE code of ethics includes sustainable development and social justice [2]. Engineering educators need to teach students about both macroethical issues and microethics [2], and stay current as the ethical expectations of the profession evolve.

Engineering education continues to become more prominent in K-12 education around the country through dedicated courses and integration into other STEM courses (such as science and mathematics). Particularly important in this movement has been Project Lead the Way [7,8] and the Next Generation Science Standards (NGSS) [9,10]. Project Lead the Way (PLTW), a nonprofit organization focused on integrating STEM-based courses into K-12 education, has been adopted across the U.S. including in both public and nonpublic high schools in Colorado. PLTW has three main pathways at the high school level: computer science, engineering, and biomedical science. Within engineering, PLTW includes problem solving, critical and creative thinking, collaboration, communication, and ethical reasoning [7]. Specifically, the engineering essentials course and the introduction to engineering design course both include ethics [7]. For example, the engineering essentials course outline states, “[ethical reasoning] is particularly important as the course encourages students to consider the impacts of engineering decisions.” Macroethical issues such as sustainability are also evident in many of the PLTW courses. However the level of effectiveness of the ethics content is unclear [11,12].

Within the NGSS, “Science and engineering are integrated into science education by raising engineering design to the same level as scientific inquiry in science classroom instruction at all levels and by emphasizing the core ideas of engineering design and technology applications” [8, p. xiii]. Thus engineering topics are integrated with science, while ‘engineering design’ is also a stand-alone core idea at the elementary, middle school, and high school levels [9, p. 1]. The NGSS consider the ‘influence of engineering, technology, and science on society and then natural world’, which reflects macroethical considerations. For example, within life science HS-LS2-7 states “design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.” [9, p. 267]. Within engineering, outcome HS-ETS1-3 states, “when evaluating solutions, it is important… to consider social, cultural, and environmental impacts.” [9
Moore [13] mapped the NGSS to a Framework for Quality in K-12 Engineering Education. Related to issues, solutions, and impacts (ISI) they found 1 to 6 performance expectations and 1 to 4 learning goals per grade band. But related to ethics there were no performance expectations nor learning goals in the Kindergarten through Middle School grade bands; in high school there was a single ethics-related performance expectation and 2 learning goals. The majority of the engineering NGSS elements related to the process of design, applying science, engineering, and mathematics knowledge, and engineering thinking.

Even prior to the NGSS, a number of states integrated engineering elements into their state standards. A review of K-12 STEM state standards that were in force in December 2010 determined that 41 states integrated engineering skills and knowledge [14]. This encompassed a range of themes and elements, which seemed to focus heavily on design. They also identified elements related to the impacts of engineering such as safety and environment. The only mention of ethics in the manuscript was with regard to California standards. Moore’s study [13] exploring state standards in December 2011 found that 12 states explicitly included engineering in their standards and 24 had ‘elements of engineering implicitly stated in their standards’. Their analysis found that the NGSS included less ethics in engineering compared to these pre-NGSS standards, while the focus on ISI was similar. The NGSS have been widely adopted across the U.S., with 20 states fully adopting the standards and 24 states developing their own standards based on the NGSS [10]. Colorado is among the states that adapted the NGSS, because it did not adopt the stand-alone engineering design standard but fully adopted the science-related outcomes.

Critiques related to the framing of engineering in the NGSS have been leveled. Gunckle and Tolbert concluded that the NGSS “promote a technocratic perspective” of engineering, “ignoring the socio-political foundations of many of the world’s most pressing problems” and “ignores issues of justice.” [15, p. 938]. These critiques of engineering in the NGSS align with the broader critiques of the NGSS by Rodriguez [16] which notes the lack of equity and diversity dimensions in the NGSS. It is troubling that as students develop their initial impressions of engineering that considerations of ethics, societal and environmental impacts, and issues of equity and justice may not be adequately encompassed.

Within science education, the issue of integrating ethics and societal impact topics has been explored, often termed socioscientific issues (SSI). Sadler et al. [17] classified 20 middle and high school science teachers into five categories based on their responses to interview questions about the role of ethics in science and science education, and how they handled these topics in their own classes. They found attitudes ranged from “rejecting the idea that science and ethics are interrelated” to the notion that all education should contribute to students’ ethical development. In their study the largest number of teachers (n=7) viewed SSI as important and taught about it in their classes. Specific examples of SSI integration into middle school and high school science courses have been published [18, 19]. Webster [20] argues for an integration of science and ethics in teaching, from the perspective that there is not a divide between science and ethics. More broadly, Falloon et al. [21] includes ‘considers impact of innovation on people, society, environment and resources’ among 9 criteria for STEM literacy, arguing that K-12 education should strive for STEM literacy among all students. This framework is helpful for a holistic integration of ethical issues into both science and engineering education.
While there is limited inclusion of ethical issues within the context of engineering in PLTW and the NGSS, the engineering ethics education in high school has not been widely characterized. This research thus examined if and how engineering ethics are being implemented in high school education, seeking to understand teacher practices and perspectives.

Research Questions

In contrast to higher education in the U.S. where engineering education is dominated by ABET accreditation standards, there is not a single standard for high school education where there may be large differences among states and even within states at a local or district level. Thus, a nationwide exploration of engineering ethics education at the high school level was deemed too large a question. This research chose to focus on Colorado. The research reported in this paper examines two main questions:

RQ1. Do Colorado high school teachers engaged with engineering/STEM incorporate engineering environmental and societal impacts in their teaching, and if so, how?
RQ2. Do Colorado high school teachers engaged with engineering/STEM incorporate ethics in their teaching, and if so, how? Furthermore, how do they define ethics with regards to environmental and societal issues or other factors?

Methods

This preliminary qualitative research study was motivated by the lack of existing information regarding the implementation of engineering ethics in K-12 engineering/STEM programs. A qualitative approach using teacher interviews was deemed appropriate given the how and why questions and exploratory nature of the study. Colorado was selected due to convenience and local contacts of the research team. The STEM subjects of math, science, and computer science were analyzed alongside engineering programs. This allowed the inclusion of engineering topics outside of explicit engineering courses, such as other STEM courses that draw in engineering topics (e.g. problem solving, iterative design) and clubs (e.g. a science teacher mentoring an engineering robotics club). All research was conducted in accordance with IRB Protocol #19-0263 which was approved by the Institutional Review Board for Human Subjects Research as xx University.

The first step was to recruit teachers to participate in the study. It was decided to email individual high school STEM teachers. To identify the names and contact information for the teachers, the public web pages of high schools in Colorado were explored. The contact list identified the primary subjects that teachers taught; these have been grouped into ‘engineering’ and ‘non-engineering’ Table 1. Many individuals taught multiple subjects, but if they taught 1 or more engineering courses they were included in the engineering cluster. This list also includes 6 teachers who were identified through snowball sampling.

Table 1. Number of teachers invited and participated in interviews in different groups.

<table>
<thead>
<tr>
<th>Subject Taught</th>
<th>Public N invited / N interviews</th>
<th>Charter N invited / N interviews</th>
<th>Private N invited / N interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering</td>
<td>35/4</td>
<td>7/2</td>
<td>4/1</td>
</tr>
<tr>
<td>Non-engineering</td>
<td>40/4</td>
<td>4/1</td>
<td>4/2</td>
</tr>
</tbody>
</table>
Contact was established for the identified high school teachers through email. Teachers representing 33 schools in 15 districts/geographic areas were invited to participate in the study, with a total of 94 teachers sent invitations. These invitation emails were sent out in three waves in May, August, and September 2019. The email subject line was “high school engineering study” and the email body invited the teachers to participate in “research exploring the extent to which engineering integrated into K-12 settings includes elements of societal impacts or ethics.” Participants were provided $50 Amazon e-gift cards to compensate them for their time. Teachers who did not respond to the initial email invitation were sent one or two reminders. Ultimately, 14 Colorado high school teachers instructing STEM-based courses were interviewed.

The demographic characteristics of the high school teachers who participated in the interviews are summarized in Table 2 (pseudonyms were selected by the teachers). There were 14 STEM teachers interviewed (8 male, 6 female). Seven of these teachers primarily taught engineering courses, 5 science (biology, chemistry, environmental), 1 computer science, and 1 math. The extent of teaching experience ranged from 3 to 25 years. Five of the teachers had bachelor’s degrees in engineering, and five had prior work experience as engineers/computer programmers. There were 13 different schools represented (8 public, 3 public charter, 1 private nonsectarian, and 1 private religious); the schools were randomly assigned an upper case letter. These schools spanned 8 different districts/geographic areas in Colorado; these areas were randomly assigned a lower case letter. As an indicator of the average socioeconomic status of the students attending the schools, the percentage of students eligible to receive free or reduced cost lunches (FRL) ranged from 4% (Joelle’s school) to 86% (Palden’s school). The overall 4-year graduation rates from the high schools ranged from 82% (Allison’s school) to 98.6% (Joelle’s school). Note that the FRL and graduation rate information was obtained from the State education website; private schools are not required to report this information.

The semi-structured interviews were conducted via phone or Skype, lasted 30-60 minutes, and were audio recorded. The semi-structured nature of the interview asked each teacher interviewee the same base questions with varying follow-up questions regarding their responses. Early questions in the interview prompted teachers to describe the courses they taught, how they integrated engineering (topics) into their teaching, and if/how they included societal, environmental, and ethical issues into their classes. In the middle of the interview, Question 5, teachers were asked, “Do you include the societal and environmental impacts of technology in your instruction?” A later question, Question 8, asked, “Do you explicitly integrate ethical issues into the classes you teach (and/or programs you mentor)?” In defining engineering ethics, both these questions were expected to yield responses regarding insight into ethics implementation. The elements were separated due to previous distinction under ABET [22].
<table>
<thead>
<tr>
<th>Pseudonym</th>
<th>Subject primarily taught</th>
<th>Degrees</th>
<th>Years work as engr/CS</th>
<th>Years teaching</th>
<th>School</th>
<th>District or Organization</th>
<th>School type</th>
<th>Free/reduced lunch (2018-2019)</th>
<th>Graduation Rate (2017-2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allison</td>
<td>Science – Environmental</td>
<td>BS, MS Sport Sci</td>
<td>0</td>
<td>20</td>
<td>E</td>
<td>g</td>
<td>Public</td>
<td>66.8%</td>
<td>82.0%</td>
</tr>
<tr>
<td>David</td>
<td>Engineering</td>
<td>BS Physics Edu, MS Technol Edu</td>
<td>0</td>
<td>15</td>
<td>D</td>
<td>c</td>
<td>Public</td>
<td>28.7%</td>
<td>91.6%</td>
</tr>
<tr>
<td>Jeff</td>
<td>Engineering</td>
<td>BS Civil Engineering</td>
<td>10</td>
<td>6</td>
<td>K</td>
<td>b</td>
<td>Charter</td>
<td>47.9%</td>
<td>84.4%</td>
</tr>
<tr>
<td>Jimmy</td>
<td>Engineering</td>
<td>BS Engrg, MA Science Education</td>
<td>5</td>
<td>23</td>
<td>L</td>
<td></td>
<td>Private</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Joelle</td>
<td>Science – Biology</td>
<td>BS Biology, M.Ed. Leadership</td>
<td>0</td>
<td>20</td>
<td>F</td>
<td>e</td>
<td>Public</td>
<td>3.6%</td>
<td>98.6%</td>
</tr>
<tr>
<td>Larry</td>
<td>Math</td>
<td>BS Math Education</td>
<td>0</td>
<td>25</td>
<td>C</td>
<td>a</td>
<td>Public</td>
<td>17.2%</td>
<td>94.5%</td>
</tr>
<tr>
<td>Lori</td>
<td>Science – Chemistry</td>
<td>BS, PhD Chemical Engineering</td>
<td>5</td>
<td>3</td>
<td>M</td>
<td></td>
<td>Private Relig. affil.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Michael</td>
<td>Computer Science</td>
<td>MS Computer Science</td>
<td>18</td>
<td>15</td>
<td>A</td>
<td>d</td>
<td>Public</td>
<td>34.8%</td>
<td>89.5%</td>
</tr>
<tr>
<td>Olivia</td>
<td>Engineering</td>
<td>BS Biomed Eng, MS Biology</td>
<td>0</td>
<td>15</td>
<td>G</td>
<td>d</td>
<td>Public</td>
<td>45.0%</td>
<td>87.3%</td>
</tr>
<tr>
<td>Palden</td>
<td>Science – Environmental</td>
<td>BS Physics, MS Atmospheric Sci</td>
<td>0</td>
<td>10</td>
<td>I</td>
<td>b</td>
<td>Charter</td>
<td>86.4%</td>
<td>No graduated class yet</td>
</tr>
<tr>
<td>Paul</td>
<td>Engineering</td>
<td>BS Civil Eng, ME Energy Eng, MEd Math Ed</td>
<td>10</td>
<td>15</td>
<td>B</td>
<td>e</td>
<td>Public</td>
<td>13.0%</td>
<td>92.8%</td>
</tr>
<tr>
<td>Renae</td>
<td>Science – Biology</td>
<td>(unknown)</td>
<td>0</td>
<td>5</td>
<td>M</td>
<td></td>
<td>Private Relig affil.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Ron</td>
<td>Engineering</td>
<td>BA Physics, MS Math Edu</td>
<td>0</td>
<td>8</td>
<td>J</td>
<td>b</td>
<td>Charter</td>
<td>47.9%</td>
<td>No graduated class yet</td>
</tr>
<tr>
<td>Simon</td>
<td>Engineering</td>
<td>PhD Physics</td>
<td>0</td>
<td>6</td>
<td>H</td>
<td>f</td>
<td>Public</td>
<td>13.0%</td>
<td>94.1%</td>
</tr>
</tbody>
</table>

Uppercase letters pertain to de-identified schools, lowercase letters pertain to de-identified public school districts.
Following the interviews, the audio files were uploaded to the transcription website Trint, creating rough text documents with some incorrectly recorded information. These transcriptions were then manually edited to more accurately reflect the interviewee’s responses (although at some points the audio was still unclear).

Qualitative analysis of the transcripts occurred in three phases. The two authors negotiated the analysis and codes at each step in the process. First, all of the transcripts were read and a coding approach was used to analyze the text. It was determined that a codebook lacked the ability to analyze the transcripts with the desired level of detail. The second iteration was designed to define three categories pertaining to ethics and/or environmental and societal integration, placing each teacher interviewee into one of these categories best representing their perspective. A scale was designed alongside the categories to detail their placement differences within the category clusters. It was discovered that this approach, while more appropriate than the codebook, lacked adequate definitions detailing the differences between environmental /societal impacts and ethics, and how the teacher interviewees perceived their inclusion of these topics.

The final iteration was a qualitative analysis flowchart that led to four defined categories (see Figure 1). This flowchart was used for each teacher interviewee and the final category assigned depended on how they answered the primary questions regarding environmental and societal impacts and ethics, detailing their personal understanding of ethics and/or environmental and/or societal impacts. Flow charts are among the more sophisticated qualitative analysis methods that go beyond identifying themes [23, 24]. Note that in this study the researchers defined ethics to include both microethics and macroethics. Thus engineering ethics, environmental, and societal impacts (EESI) is a key construct. However, previous research with engineering faculty in higher education determined that many were unfamiliar with the term macroethics, and some distinguished between ethics and environmental/societal impacts (EESI) is a key construct. However, previous research with engineering faculty in higher education determined that many were unfamiliar with the term macroethics, and some distinguished between ethics and environmental/societal impacts [25] (reflecting the previous distinction within ABET between ethics outcome f and impacts outcome h [13]). Teachers may or may not have included environmental and societal impacts as ethical issues. In addition, a teacher may have answered “no” to incorporating ethics, however provided follow-up examples that were believed to be valid examples of integrating ethical topics. This iteration drew heavily from the grouping method, as it also incorporated a plot similar to the scale in assessing placement of teachers with regards to the four codes.

A1: The teacher interviewee believes they integrate ethics and/or environmental and societal impacts in their instruction. This personal understanding of EESI is aligned with the targeted understanding.

A2: The teacher interviewee believes they integrate ethics and/or environmental and societal impacts in their instruction. This personal EESI understanding is not aligned with the targeted understanding (for example, that societal impacts are part of engineering ethics).

B1: The teacher interviewee does not believe they integrate ethics or environmental and societal impacts in their instruction. This personal understanding of EESI is aligned with the targeted understanding.

B2: The teacher interviewee does not believe they integrate ethics or environmental and societal impacts in their instruction. This personal understanding of EESI is not aligned with the targeted understanding.
Figure 1. Interview analysis flow chart characterizing each teacher’s EESI instruction
Results and Discussion

Research question 1: Environmental and societal impacts

After the teachers were comfortable in the interview and had discussed their general teaching practices related to engineering or STEM, they were asked: “Do you include the societal and environmental impacts of technology in your instruction?” This was question #5 in the interview script, and was posed anywhere from 15 minutes to 30 minutes into the interviews. Responses ranged from an affirmative response, “yes,” from 10 teachers, to a negative response, “no,” from 4 teachers. Note that 3 teachers had already described their EESI integration in their earlier description of teaching engineering and/or other STEM courses. In addition, 3 teachers who said “no” went on to describe ways that they did in fact integrate EESI, possibly unknowingly. In addition, some noted that only environmental or societal (or social issues) were included. For example, Michael stated that he included societal impacts but not environmental. Other teachers stated that they did not incorporate EESI in all courses they teach, such as Palden who incorporates ethics in her environmental courses, but not necessarily in her engineering courses.

Ron was an engineering teacher who strongly integrated environmental/societal impacts.

I would definitely say [environmental and societal impacts] is on the forefront of my mind, and in the past when I have developed projects for students that has been a key motivator. We had one group that tried to make a solar powered car, so I think the societal/environmental impacts have always been a driving but underlying force in pretty much all of the big projects that I’ve done. It’s hard to find hope these days in the world at large, but I definitely have hope in my students. I truly believe that this is the generation that is going to make the world a better place because they believe it. They want to learn more about how their actions affect the world around them. They care about the environment even if they’ve never been out there because they have an underlying sense of duty and responsibility to the world. I definitely think that for our students, the kinds of projects that have societal and environmental considerations at their center really resonates with them.

Ron discussed not only how he integrated EESI into his instruction, but also how it aligns with his goal as a teacher. Furthermore, his perspective regarding his students is an example of how students are impacted by this instruction.

Renae, a science teacher who integrated environmental/societal impacts, described:

That’s something I think goes back to our [religious] background, that’s a huge piece of everything we do. We have really tried, especially in the past five years as a science department, to make sure that everything we’re teaching is rooted in something that makes it more meaningful and it gives it more real-life context, and it gives the student more opportunity to feel connected to material. Yeah, we’ve done all sorts of projects regarding social and environmental impact. And yeah that’s something that’s really important to us as a department. And it does come back to some of the NGSS, and I think it’s also tied in because of our [religious] identity too.

Renae, who teaches at a religiously-affiliated institution, detailed how this identity is tied to the EESI implemented within the science department, alongside the Next Generation Science Standards. Moreover, Renae speaks about her department as a whole, indicating that this EESI is
not treated as an individual responsibility of the teachers, rather is implemented on a departmental level.

David, an engineering teacher, discussed limited integration of environmental/societal impacts. There is one particular area that’s in the design and manufacture class [I teach] where we looked at what I would say societal impacts of technology and of automation. And it’s one thing that we take a little bit of time with them, and I give the students a chance to have some peer-on-peer discussions on the societal impact of automation. But that particular topic in that class is sort of limited to that one unit. I think in the biotech engineering class we focus on societal aspects of bioethics and we talk about that throughout the course, actually throughout the year. The ethics piece is actually kind of front and center because it’s played such a big role in biotechnical, biological, medical engineering, those kinds of things.

It was noted that David started talking about ethics prior to the specific question on that in the interview. This may indicate that engineering’s environmental/societal impacts and ethics are congruent for David. However, David also knew that this study was about engineering ethics based on the invitation email and consent process prior to the start of the interview.

Lori, a science (chemistry) teacher, had limited integration of environmental/societal impacts in her teaching.

I guess I don’t explicitly talk about that. But I do talk in my chemistry class about the untapped power of the nucleus and the opportunity for impacting how humans generate energy for our lives. Every first day of school I tell [my students] of the enormous opportunity they have if they can understand chemistry and apply it in the world. … They are going to have an enormous opportunity to affect positive change on a lot of fronts, but obviously the energy and climate connection is where chemistry can have a huge impact. And so, I always try and inspire them about a little bit about how the problems we have today are going to be solved by their generation. That is the Jesuit mentality, where education is not good on its own to be left alone. It’s intended purpose is to serve others. So, when we are solving problems we are contributing to the greater good.

Lori also references the broader teaching goals of the school in her response, and how EESI integration is aligned with these goals. Furthermore, like Renae, she links the inclusion of ethics to that of the school’s mission statement.

Allison, a science (environmental) teacher, contrasted the extent of environmental/societal impacts integrated among the various courses that she taught.

I do. I do more in environmental [class] than in geology, but Earth Science has been kind of hit-or-miss just because the kids that we teach are freshmen. Yeah, there is definitely a huge issue of how that is impacting them on a daily basis. In AP Environmental Science, we cover the whole Industrial Revolution. How it changed the earth, and ultimately we hope that what saves us is our technology. Even though it has put us in this pickle, including overuse of resources and unsustainable population growth. In my AP class, they absolutely understand [the societal and environmental impacts]. My environmental class is more ubiquitous. When they are learning how to problem solve, I don’t know that they are extending their thinking past what they are doing at that moment. I don’t think they are sending their vision past that.
Allison provided an example of incorporating EESI into her environmental science classes, however comments on the distinction between her AP and non-AP variants. So, while she does integrate ethics in her courses, her level of integration is dependent on the type of course and may be further dependent on rigor.

Michael, a computer science teacher, said regarding the integration of environmental/societal impacts in his instruction.

Our feeder schools and their teachers have done a fantastic job of helping kids recognize digital citizenship and the ideas behind technology as far as the responsibility behind it and the ethical aspects of it. I spend time reinforcing and reminding them of this. And if you are in my AP Computer Science class, that’s part of my curriculum, where we very specifically talk about the ethical aspects of technology. … A lot of it is just recognizing how the technology we are talking about affects society. Now when you say environmental, that’s a little bit trickier. I don’t see much of my curriculum addressing the ecological aspect of things.

Michael details both the understanding his students have regarding societal impacts before taking his class, and how he organizes his curriculum to accommodate this and build upon what they are expected to know. However, he does not have any notable examples of the “environmental” part of EESI.

Jimmy, an engineering teacher, answered that he did not integrate environmental/societal impacts in his classes.

You know, not a lot. There is something in everything you touch on as the course gets going. For example, I have an article on the most recent issue of [construction] magazine, which is really interesting as it talks about the concrete and steel industry and how mass timber is a kind of a saving grace for both the environment and the construction industry. So that’ll be part of a discussion on the depth of knowledge required to make family conscious economically viable or sustainable decisions. But I think those sorts of things are part of a conversation, or ongoing conversation, around each individual project choice.

Jimmy initially responds “no” to incorporating environmental/societal impacts in his courses. However, he then provides an example of what integration he does incorporate. What can be identified is that Jimmy considers these topics to be best incorporated regarding projects, rather than being an established part of the course curriculum.

Simon, an engineering teacher, did not believe he integrated environmental/societal impacts.

No, I don’t really. That’s something I have considered. So right now, for example, I don’t cover much discussion on renewable energy sources as you say the societal impact of engineering. And this is partly because it still remains to a large degree a fairly theoretical physics class with labs that apply that theory... We don’t stray too far from that kind of core curriculum at this point.

Despite not currently implementing environmental/societal impacts, Simon has considered doing such. It is important to note that Simon teaches engineering physics, which was generalized into engineering in this study. His detail of how the theoretical nature is part of the reason for this non-inclusion indicates a possible obstacle for EESI.
These examples detail the range of responses to the question about the implementation of environmental and societal impacts in their teaching. Overall, the teachers were not opposed to including or addressing these concepts, however some may not view what they teach to involve or relate to EESI. There is also variability in how environmental/societal impacts is related to ethics. Before the specific interview question about ethics, it is evident that the teacher interviewees varied on whether they viewed environmental/societal impacts as being linked to ethics. Some teachers explicitly mentioned ethics or ethical topics without prompting while others did not include any mention of ethics.

Research question 2: Teaching ethics

Some teachers clearly viewed environmental/societal impacts as congruent with ethical issues, as noted above and observed in their responses to RQ1. This aligns with the macroethics side of engineering ethics. However, some teachers seemed to view ethics as distinct from environmental/societal impacts. The explicit question that was asked in each semi-structured interview was: “Do you explicitly integrate ethical issues into the classes you teach?” (If appropriate, the question also included the phrase “and/or the programs you mentor”). This question was asked after allowing the teacher interviewee to elaborate on their environmental/societal impacts integration answer and possibly detail its importance, typically about 25 to 40 minutes into the interview. Within the interview protocol the primary question regarding environmental/societal impacts integration was question #5 and the question regarding explicit ethics integration was question #8.

In response to the question of ethics integration, there were 9 teachers that said either “yes” and 5 teachers that said “no”. There were 2 examples of teachers responding “no” after responding “yes” to integrating environmental/societal issues. Furthermore, there was one example where a teacher responded “yes” to integrating ethics after answering “no” to integrating environmental/societal impacts integration.

David responded regarding his explicit integration of ethical issues:

Well I would say yes I do with the biotech class. Yes, there is an ethics component into every engineering class that I teach. It’s spread throughout the entire year in biotech engineering, it’s in every single unit. In biotech, we talk about health. We get into genetics, how we are getting to the point where we can test whether someone has a particular disease... But there are ethics involved in everything. When you are talking about cleaning up environmental disasters there is some impact as a result of using microbes in the procedure, and you can have ethical discussions centered around that.

David provides ethical examples pertaining to each of the engineering courses he teaches, showing that his implementation of ethical topics is adapted between classes to be best represented within the context of the course. He also displays an understanding of EESI when he states that ethics has a part in everything he teaches.

Larry, mathematics teacher, on his implementation of ethics.

Yeah, in my [course], myself and my partner on the senior team try to find interesting STEM-based articles that have the potential for a controversial topic. We print those articles for students to annotate through additional research. And at some point, maybe a
week later, we have a seminar together as a class and say, “All right, what are the issues in the article? What do we want this seminar to focus on? What is the Side A and Side B of these articles?” Once we have clearly defined what those are, students are assigned to A and B. Now that they are on teams, they have a couple of days to design what their argumentative approach. We have also had some genetic engineering concepts discussed. We did one [discussion] that really got students fired up a couple years ago about NASA funding, whether it should be funded publicly or privately. So, anything that gets kids to consider real world science, and think about what the implications are, [is covered]. Larry discusses how his focus on integrating ethical issues comes through discussions among students. And while he determines the groups in each discussion, a large part of the ethical development experienced by the students is initiated by themselves through their research of the issue. Most of all, Larry focuses on his students to have an authentic experience regarding science, in which ethics plays an important part.

Jeff, an engineering teacher, at first stated that he did not explicitly integrate ethical issues into his instruction, however then provided possible examples of integration.

Explicitly, no. [In discussing] the Kansas City Hyatt Disaster, we talked about ethics in the way that we tried to analyze the root cause of what happened and how there is serious ethical failures there. [After thinking] We discussed the ethics, I guess so, but it wasn’t my main objective, sort of a byproduct of what I was doing. We also talked yesterday about building codes and what each code is and why it’s important. So, we talk about things like that. It’s not my primary driver.

While the initial response was “no” to integrating ethics, Jeff elaborated about a disaster that has ethical implications. This integrates ethics but his statement indicates ethics isn’t his primary focus, possibly indicating a disconnection regarding what EESI encompasses.

Simon did not believe that he explicitly integrated ethics.

I do not. I try to make sure that everything [students] come across on a regular basis in the materials is ethical, but I don’t actually address issues of ethics explicitly. The focus is on the academic work. And we have a pretty full curriculum and it’s often quite difficult to get through what we have. And so, I feel that’s really the most important thing to address in the course. I think there are definitely situations in engineering where you do have to consider the ethics or the impact of your engineering project. We really don’t get to that point very often in the engineering physics class.

Simon explains why he did not incorporate ethics. As detailed in another part of the interview, curriculum time is one of the identified obstacles to ethics integration [26]. Simon’s engineering physics course does not currently include ethical topics due to his concern that other topics would have to be removed.

The teacher interviewees not only had varying answers to the question regarding ethical implementation, but also varied in how they viewed the concepts of ethics. Some additional examples of different perspectives on “ethics” among the interviews (but not shown by example quotes above) include academic integrity of students, role and responsibility of engineers/STEM workers, ethics considered integral to curriculum but not necessarily expressed outside of it, and seminars or discussions regarding case studies or current events.
Synthesis of RQ1 and RQ2

The environmental and societal impacts of engineering are key elements of engineering ethics in alignment with ABET Criterion 3 Student Outcome 4 [1] and through their inclusion within engineering codes of ethics [2, 6, 27]. Therefore, environmental/societal impacts are defined as being congruent with engineering ethics. The flowchart in Figure 1 was used to assign one of four codes groups to each teacher depending on how they answered the two primary interview questions regarding integrating environmental/societal issues (Question 5) and/or ethics in their teaching (Question 8), and how their personal understanding matches to the understanding that these concepts are congruent. The personal understanding illustrates how the teacher interviewee views their inclusion of these topics, such as giving a negative response to either primary question. However, some teachers seemingly contradicted their initial answer, indicating that their understanding of environmental/societal impacts and/or engineering ethics differs somewhat from the research paradigm. An example is an interviewee answering “no” to implementing ethics before detailing an example activity that the research identifies as being based on ethics. The categorization methodology using the flowchart explicitly acknowledges these discrepancies, providing a more accurate reflection of the teacher perspectives.

Categorization of A versus B reflects the researcher’s perspective that they do or do not integrate some aspect EESI, respectively. The categorization of 1 or 2 reflects whether the teacher’s understanding of EESI aligns with the paradigm that environmental/societal impacts are a form of engineering ethics (1= alignment, 2 = difference). Following on the scale categorization from the second analysis iteration, Figure 2 shows a plot with an approximate placement of each teacher interviewee, recognizing that within the same code category two teachers may differ in magnitude with regards to the extent of EESI integration in their teaching (A versus B) or EESI definition alignment (1 versus 2). A negotiated process between the two authors was used to verify the teacher categorizations. The initial independently assigned categorizations agreed for 11 teachers. The three cases with disagreement were discussed and ultimately resolved.

As shown in Figure 2, A1 was the most common category with 8 teachers assigned to this group. A1 represents teachers who believe they integrate EESI in their instruction and their personal understanding is aligned with the congruence of environmental/societal impacts and engineering ethics. All but 1 of the non-engineering STEM teachers fell into this group. Only 1 of the 6 teachers with an engineering degree fell into the A1 group. B1 was the least common with only 1 teacher in this group, which represents the situation where the teacher does not believe they integrate EESI and they provided no information about their teaching practices that contradicted this characterization. All three teachers in the B categories were teaching engineering courses and held degrees in engineering; no non-engineering teachers were placed in the B groups. Furthermore, 2 out of the 3 teachers assigned the A2 code were engineering teachers. The results indicate that engineering courses and teachers with formal education in engineering should not be presumed to have a stronger focus on engineering ethical issues than non-engineering STEM courses.
Despite there being a greater number of male teachers interviewed (8 male teachers, 6 female teachers), all three of the teachers coded with the B code, indicating that they did not believe they necessarily integrated EESI, were male. Alongside this, five out of the six female teachers interviewed were assigned the A1 code, which indicated that the teacher interviewee implemented EESI in their teaching with an understanding that aligned with environmental/societal impacts being among the ethical issues relevant to engineers. These results echo the previous research finding that female college instructors are more likely to implement ethics in engineering courses [28]. It is also interesting to note that two of the three teachers applied a B code detailed how they were comparatively new to teaching, having come from an engineering profession. This indicates that EESI integration is also influenced by experience prior to engaging in teaching and/or the relative inexperience as a teacher. Many older engineers may have received little formal ethics education and/or have a perspective that social and technical issues are distinct based on the pervasive culture in engineering education [29, 30]; they are perhaps perpetuating this socio-technical divide in their teaching practices.
Limitations and Future Work

This preliminary study explored ethics implementation in Colorado high school STEM education. Due to the small number of high school teachers interviewed, the data reported here may be very different from a study with a greater number of teacher interviewees. Additionally, conducting interviews only among Colorado teachers is a limitation, given differences in state education standards. These interviews were conducted in 2019, and since then these teachers, schools, and districts may have adopted new policies or standards regarding K-12 STEM education. In future work, examining a state with explicit integration of NGSS engineering standards is of interest. Differences in implementing engineering, and by extension ethics in engineering, may be different simply by Colorado not adopting the engineering standard in the NGSS. Additional work of note would be to interview more engineering teachers, explicitly comparing teachers with/without engineering degrees, practicing in different times (as engineering ethics education and industry practices have changed over time), and representing different professions (e.g., some disciplines still do not include sustainability in their code of ethics [31]). Following on this, it would be of note to learn more about engineering teachers without explicit engineering backgrounds, and how they learned to teach engineering in K-12 education.

Summary and Conclusions

This qualitative research study found that Colorado high school STEM teachers have different definitions of ethics and different teaching practices with respect to EESI. Due to the nature of there being two primary interview questions corresponding to EESI integration (Questions 5 and 8), teacher interviewees answered these questions without being explicitly informed of their connection. This led to a wide range of explanations and examples regarding the perceived integration of ethics and environmental/societal impacts. The majority of the teachers integrated EESI into their teaching, and recognized that societal and environmental issues have ethical dimensions. These teaching practices took a variety of forms. A small number of teachers did not recognize the ethical dimensions related to their teaching practices that incorporated societal / environmental issues. Only 1 teacher did not integrate EESI into his teaching. Formal education as an engineer did not give those teachers an integrated perspective on macroethics, perhaps reflective of changes within engineering education itself in recent years (i.e., changes in ABET standards). Thus, it appears important that professional development and teacher training explicitly discuss the inter-relationship between ethical issues and engineering. The framework presented in Moore et al. [13] provides a good model. In addition, because similar macroethical issues are inherent in science, an integrated model for STEM education similar to the STEM literacy framework in Falloon et al. [21] could be effective. This would allow science teachers to more fully understand engineering and how it can integrate into their courses, while also illustrating the common ethical issues that permeate STEM. Tangible examples of engineering ethics integration are also likely to be helpful for teachers. Integration of EESI into students’ earliest exposure to engineering will help provide a solid foundation for engineering education in college.
Acknowledgements

This study was funded by the National Science Foundation under Grant No. 1540348. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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