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ORIGINAL PAPER

Evolution of Students' Varied Conceptualizations About Socially Responsible Engineering: A Four Year Longitudinal Study

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Abstract Engineers should learn how to act on their responsibility to society during their education. At present, however, it is unknown what students think about the meaning of socially responsible engineering. This paper synthesizes 4 years of longitudinal interviews with engineering students as they progressed through college. The interviews revolved broadly around how students saw the connections between engineering and social responsibility, and what influenced these ideas. Using the Weidman Input–Environment–Output model as a framework, this research found that influences included required classes such as engineering ethics, capstone design, and some technical courses, pre-college volunteering and familial values, co-curricular groups such as Engineers Without Borders and the Society of Women Engineers, as well as professional experiences through internships. Further, some experiences such as technical courses and engineering internships contributed to confine students' understanding of an engineer's social responsibility. Overall, students who stayed in engineering tended to converge on basic responsibilities such as safety and bettering society as a whole, but tended to become less concerned with improving the lives of the marginalized and disadvantaged. Company loyalty also became important for some students. These results have valuable, transferable contributions, providing guidance to foster students' ideas on socially responsible engineering.

Keywords Social responsibility · Qualitative research · Engineering ethics · Longitudinal study

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Introduction and Background

Engineers impact every person in society through designed products, the built environment, and events like war and disasters. While the impacts of engineers may be easy to see, the extent to which engineers feel responsible for these impacts remains largely unknown. There is not a single, widely endorsed view of the social responsibilities of engineers, with significant differences found in the engineering codes of ethics, engineering educational requirements, and body of knowledge elements in different countries and across disciplines (Bielefeldt 2018). There is widespread agreement that an engineer's professional social responsibility must encompass protecting public health and safety, many microethical issues (e.g. loyalty to clients, working within areas of competence), and nearly universal mandates for environmental protection. Sustainability is more widely endorsed internationally, with a number of US ethics codes failing to include it (e.g. aerospace, biomedical, chemical) and others "encouraging" (National Society of Professional Engineers 2007) and "striv[ing]" (ASCE 2017) for sustainability, but not mandating it. One problem with sustainability may be the lack of consensus on the full meaning of the term, although the social context of engineering designs (Herkert 2000), environmental, and economic considerations, as well as considerations for future generations are typically included. An area with fairly broad but not universal endorsement includes diversity, with nearly universal acknowledgement that everyone should be treated with respect, and some in the profession encourage and promote diversity within the engineering profession (Australia, UK, ASCE). Only a few groups have expressly considered engagement in public policy (National Society of Professional Engineers 2007) and pro bono work (Passino 2009; NPSE, ASCE policy stmt). A range of other social responsibilities of engineers have been promoted by various individuals, but seem to lack widespread endorsement, such as empathy and caring (Hess et al. 2012), and striving for social justice and peace (Riley 2008; Baillie and Catalano 2009). Social justice ideas seem particularly controversial (Bielefeldt 2018). Thus, socially responsible engineering (SRE) represents a spectrum of both microethical and macroethical issues; from safety and adherence to laws to deeper considerations of the role of technology in society and the impact of infrastructure on community relations (Barry and Herkert 2014). Further, while the profession may specify minimum requirements and aspirations, individuals may personally subscribe to these elements and others to varying degrees. Understanding how students think about SRE provides insight into what this generation of engineering professionals believe; the profession must embrace a holistic understanding of SRE in order to address major issues such as those outlined in the Grand Challenges of Engineering (National Academy of Engineering 2008) and Sustainable Development Goals (United Nations 2015).

Regardless of a college student's major, university education can and should play a significant role in personal social responsibility development as students transition into adulthood and acquire responsibilities through their careers (O'Neill 2012; Crebert et al. 2013; Association of American Colleges &

Universities 2014). Some engineering students seem to be defining their social responsibility to include assisting those who are less fortunate, as evidenced by the growing number of students choosing to be involved with Learning Through Service (LTS) activities like the Engineering Projects in Community Service (EPICS) service-learning (S-L) program and co-curricular activities such as Engineers Without Borders (EWB) (Zoltowski and Oakes 2014; EWB-USA 2013; Bielefeldt et al. 2010; Litchfield and Javernick-Will 2014; Schneider et al. 2009; Lucena and Schneider 2008).

However, some studies have also shown that many engineering students' attitudes towards the importance of considering social impacts and ethics in engineering decrease as they proceed through college (Cech 2014; Bielefeldt and Canney 2015). This concerning trend could mean that engineering students are learning through their college education that the engineering profession is not driven by caring, and/or that those students who do highly value engineering's positive impact on society are leaving engineering majors prior to graduating from college (Bielefeldt 2017; Rulifson and Bielefeldt 2017). Previous research has found that women are more motivated towards service and helping through their careers than men, which has implications for recruitment, retention and persistence, which all need to be improved for a profession that better represents the society it serves (Schreuders et al. 2009; Eccles 2007; Miller et al. 2000).

This study aims to develop a better understanding of how the college experience influences students' ideas about SRE. Weidman's updated Inputs–Environment–Outputs (I–E–O) model of undergraduate socialization (Fig. 1) (Weidman 2006) was used as a framework. Weidman et al. (2014) performed a meta-analysis of studies that have used the Weidman (1989) model to help shed light on the process of college students' socialization (Weidman et al. 2014). Weidman et al. (2014) states, "Foremost among [these insights] is the recognition of the importance that the normative contexts experienced by college students can exert lasting influences on students' academic, social, and personal development." The Weidman model has proved itself to be effective at tracking and categorizing student experiences in a wide range of contexts.

Weidman describes that "socialization outcomes are the resultant changes (values, beliefs, and knowledge) that occur in students" (Weidman 2006). These *Outcomes* are the result of *Inputs*, which the student brings into college and the *Environments* in which students act. Environments include the higher education loci of socialization such as the classroom and co-curricular activities (clubs, professional societies, sports, and sororities) (National Survey of Student Engagement 2011). *Environments* include intramural spaces where formal learning and peer interaction take place and students' *Personal* and *Professional Communities* where more influences affect student dispositions and identities within and outside of their major. For this study, the "socialization outcome" of interest is the students' conceptualization of SRE; including knowledge of SRE, believing that socially responsible engineering requires skill, and having a disposition that guides a student's ideas about SRE; these are all related, but different *Outcomes*. Specific *Inputs*, *Environments*, and O*utcomes* for each student were identified and tracked each year through methods described in the next section.

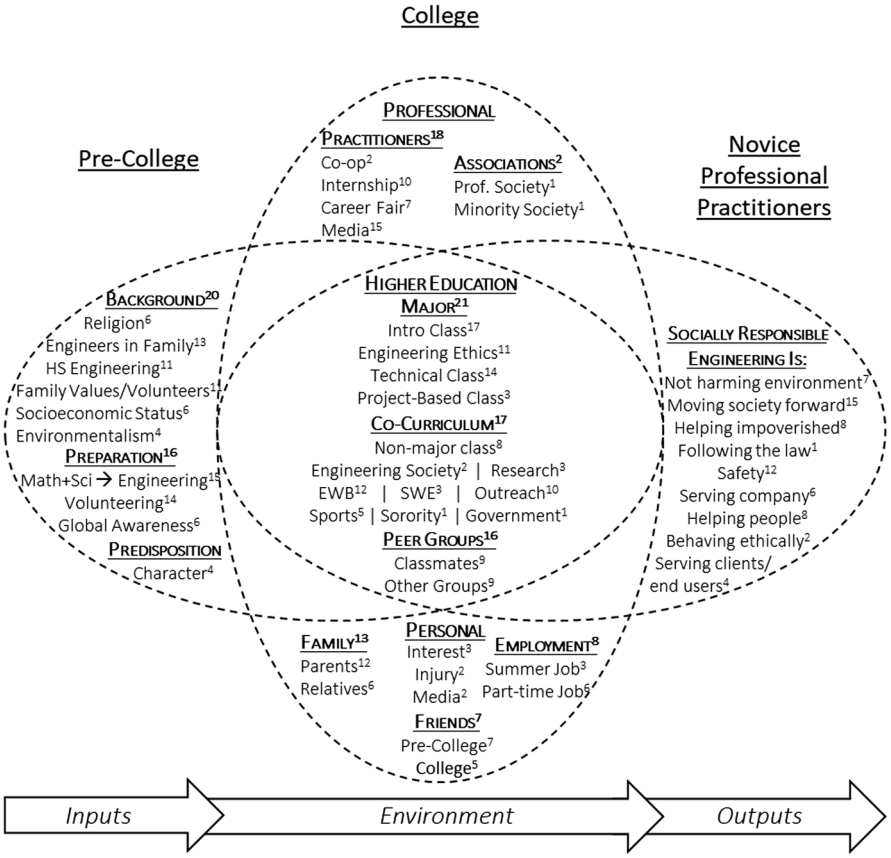

Fig. 1 Synthesized SRE I–E–O model representing 21 students (superscripts are number of students)

Previous research that studied engineering students' social responsibility has found that high school community service activities and religious beliefs are two important *Inputs* (Bielefeldt and Canney 2014; Canney and Bielefeldt 2013); service learning (S-L) is a normative context has been shown to be an important *Environmental* influence (Bielefeldt and Canney 2014). A wealth of research has shown how internships, family, and friend groups affect students' knowledge and dispositions through college (Stevens et al. 2008; Erickson et al. 2009; Tonso 2007), and these *Environmental* influences may also impact students' understanding of social responsibility.

This study explores the following research questions:

RQ1: How did students' pre-college experiences impact their views of socially responsible engineering?
RQ2: What are the main influences that shaped evolving ideas about socially responsible engineering during students' 4 years of college?

RQ3: How do undergraduate engineering students change in the ways that they understand socially responsible engineering during college?

Methods

Qualitative research was conducted in order to capture the complex experiences that are not well understood through quantitative surveys (Chism et al. 2008; Borrego et al. 2009). Interviews were conducted with 34 engineering students at the end of their first year in college. These same students were invited to participate in interviews in each of the following 3 years. By checking in with the students each year, it was possible to understand how the students' attitudes evolved. Further, some influences were persistent, while others changed quickly and drastically through college. Through the longitudinal study, students answered questions about what they believed and were experiencing at the time of the interview, and also reflected on their past.

Using criterion-based selection (Miles et al. 2013), the students in this study initially represented (1) a range of attitudes toward social responsibility (SR), (2) an oversampling of women in engineering, (3) four universities, and (4) primarily three engineering majors. Students' attitudes about social responsibility were initially assessed quantitatively via the Engineering Professional Responsibility Assessment (EPRA) instrument (Canney and Bielefeldt 2016) administered within the first month that the students entered college at five institutions—referred to in this paper as the "initial" survey (Canney 2013). There were 236 first-year student responses to the survey, and 75 of these students indicated a willingness to participate in an interview at a later date. Average SR scores were computed by averaging the responses to fifty 7-point Likert items, and the initial SR scores of the incoming first-year students ranged from 3.51 to 6.98. Females were intentionally over-sampled to participate in interviews due to literature indicating that helping others in their careers is more important to women than men (Wilson et al. 2011; Pierrakos et al. 2009); the initial SR scores for first-year students averaged 5.8 for females versus 5.4 for males (Canney 2013). One original goal of the study was to understand how attitudes about SR fit into decisions to major in engineering and stay in the degree. Students were initially majoring primarily in mechanical engineering (ME), civil engineering (CE), and environmental engineering (EnvE); at two institutions students did not start with declared engineering majors, so students were asked about their likely engineering major. The students selected for interviews were initially enrolled at four institutions: a large public research-intensive university (LPU), a technically-focused medium-sized public university (TechU), a medium-sized public university (MPU), and a medium-sized private research-intensive university (PrU); students at a Military Institution participated in the EPRA survey, but none consented to participate in the interviews. A summary of the demographics of the 21 individuals who both remained in engineering and participated in at least 3 years of interviews are shown in Table 1; they are the focus of this study.

Over time, a number of the students changed majors. For example, Trevor was majoring in environmental engineering on the initial survey and had switched to

Table 1 Demographics of 21 interviewed students

Pseudonym	Gender	Entering major	Institution	Initial SR Avg Score	Yr4 major[a]	Graduation date[b]
Jason	M	Mechanical	TechU	4.7	Civil[4]	May 2017
Madison	F	Mechanical	TechU	4.9	Mechanical	May 2016
Todd	M	Mechanical	TechU	5.1	Mechanical	June 2016
Quinn	M	Civil	LPU	5.3	Elect/Comp[1]	May 2017
Tucker	M	Civil	LPU	5.5	Civil	May 2016
Trevor	M	Environmental	MPU	5.5	Civil[1]	May 2016
Kim	F	Environmental	LPU	5.5	Civil[2]	Dec 2016
Ashley	F	Engineering	PrU	5.6	Chemical	May 2016
Jamie	F	Mechanical	TechU	5.6	Mechanical	May 2016
Brandon	M	Environmental	TechU	5.8	Civil[3]	Dec 2016
Julie	F	Engineering	PrU	5.9	Mechanical	BS/MS M17
Wynne	F	Civil	LPU	5.9	Architectural[2]	May 2016
Denise	F	Engineering	PrU	6.0	Mechanical	May 2016
Tanya	F	Environmental	TechU	6.1	Environmental	May 2017
Nathan	M	Civil	TechU	6.1	Civil	Dec. 2015
Rachael	F	Engineering	PrU	6.1	CompSci	May 2016
Katherine	F	Civil	MPU	6.3	Civil	May 2016
Derek	M	Engineering	PrU	6.3	Mechanical	May 2016
Shawn	M	Environmental	LPU	6.5	Chemical[2]	May 2016
Sarah	F	Civil	TechU	6.6	Civil	[c]
Jolene	F	Civil	TechU[d]	6.6	Civil	May 2016

[a]Superscript indicates the year changed to this major

[b]As described by the student in their year 4 interview, for most an anticipated future date

[c]Did not participate in year 4 interview; unknown

[d]Changed to a medium-sized Public Institution not among initial groups of institutions (MPU2) after first year

civil engineering by the end of his first year (CE^1) when the first interview occurred. By the end of the fourth year, the students spanned seven different majors (nine Civil, six Mechanical, two Chemical, one Environmental, one Architectural, one Electrical & Computer, one Computer Science). Jolene transferred universities after completing 1 year at TechU.

The SR scores of the 21 students in the study were over-represented in the upper quartile (n = 8) and fewer in the lower quartile (n = 3), as compared to the SR scores among all incoming first-year respondents. This appears to indicate a bias in the students who were willing to participate in interviews. Among 12 students who indicated a willingness to be interviewed on the survey but did not respond to the interview requests, the average SR score was 5.3; the students who participated in the study had an average SR score of 5.8.

Additional demographics were gathered on the EPRA survey. Sarah, Tanya, and Denise were first-generation college students; Denise identified as Hispanic, and

Tanya was African-American. Derek was 21–23 years old at the start of college, while all other interviewees were 18–20. Quinn was international. Tanya and Jolene described themselves as "very active" in their religious activities.

All of the research was conducted according to methods approved by the University of Colorado Institutional Review Board for Human Subjects Research, Protocol 11-0414, and included the acquisition of informed consent before each interview and online survey.

Interviews

Interview questions were developed each year to elicit the students' ideas about SRE. In the first year, questions were about students' reasons for entering engineering, their social issue awareness and involvement, and how they connected engineering and social issues (Rulifson et al. 2014). The second year interview questions led students to comment more explicitly on their *Professional Communities*; therefore, the questions were balanced between their experiences over the past year within and outside their major, potential and ideal careers in the future, and connections between these three broad areas in relation to social responsibility (Rulifson and Bielefeldt 2015). The third year interview questions were more directly focused on understanding how students conceptualized SRE. The fourth year questions built on the previous 3 years regarding college courses, significant events, and thoughts on social responsibility. These questions had the general goal of eliciting the students' reflections on their time in college overall and intentions for their future engineering profession. The interview questions from each year are provided in the "Appendices 1, 2, 3 and 4".

Semi-structured, audio recorded interviews of between 30 and 120 min in length were conducted by the same male researcher from February to August 2013, March to April 2014, March to April 2015, and March to April 2016. Students were compensated $100 for each interview. In the first year, three interview formats were tested: in person (n = 6), Skype (n = 2), and phone (others). The phone interviews were the most candid and easiest to conduct, so all other interviews were conducted by phone. Staying rigorously on script through a structured interview may have limited students' deeper expression, so the conversation was allowed to flow naturally and return to the interview questions when appropriate (Saldaña 2003; Eisenhart et al. 1998).

After the first interview, each interviewee was assigned a pseudonym using typical conventions (Ogden 2008). Interviews were transcribed verbatim into Microsoft Word using Dragon voice recognition software. Then, each rough transcript was edited while listening to the interview to produce an accurate transcript. This transcript was then imported into Nvivo 10 for identifying and classifying multiple themes around SRE and related influences.

As the first round of interviews was exploratory, inductive coding methods (Miles et al. 2013) were used. Three researchers (Ph.D. student, faculty advisor, and an engineering undergraduate) co-developed a code book based on a sub-set of 13 interviews (four per person plus one in common), achieving an inter-rater reliability

of 91%. Further details regarding the first year analysis can be found in Rulifson et al. (2014). For the subsequent rounds of interviews, the reliable code book developed in the first year was used while remaining open to emergent codes, with coding by just two researchers (Ph.D. student, faculty advisor). (see Rulifson and Bielefeldt 2015, for more details). After year three and four, student interviews were mapped to the Weidman (2006) I–E–O model. This provided a theoretical framework to better conceptualize the path through which engineering students came to understand connections between engineering and social responsibility.

Online Survey

The students in this study were asked to complete the online EPRA survey each year (Canney 2013). Students received $5 compensation for completing the initial EPRA survey at the start of their first year (September 2012) and $10 compensation for completing the EPRA survey in the spring of 2013, 2014, 2015, and 2016. The survey responses provided another resource to learn about the students. The EPRA survey included 50 Likert-items used to measure social responsibility attitudes and questions to quantify the extent of participation in community service activities. A few open-ended questions asked students to define social responsibility, identify college courses that influenced social responsibility attitudes, and influential events/people regarding their views of community service and/or social responsibility. The survey concluded with demographic questions. Multiple journal papers have already explored the quantitative data from EPRA. For this study, the open-ended responses from the survey were compared to the interviews. This revealed other activities students were involved with and significant influences not mentioned in the interviews.

Results and Discussion

This section has four parts. First, to address RQ1, the pre-college events that appeared to influence students' incoming attitudes on SRE are presented. This is followed by a discussion of activities and events during college that were influential, to address RQ2. To answer RQ3, changes in attitudes toward socially responsible engineering are described. A synthesized I–E–O model of all the students is then presented. Finally, three students are discussed in greater detail to provide a more nuanced understanding of the evolution of students' ideas in their own words.

RQ1: Elements that Shaped Students' Incoming Attitudes

Students' incoming attitudes toward SRE were a combination of their personal views toward social responsibility generally, combined with their knowledge and beliefs about engineering. This mirrors the Professional Social Responsibility Development Model (Canney and Bielefeldt 2014). The online survey asked students to "briefly describe any events that have influenced your views of community service and social responsibility." This would reflect students' personal

social responsibility, but does not directly address engineering elements. Eighteen of the 21 students provided an answer to this question. Ten included personal impacts from volunteering; four mentioned helping disadvantaged groups explicitly (homeless, poverty); three discussed international experiences; two discussed individuals who they looked up to as role models for helping others; two discussed that root problems need to be solved; one mentioned leadership of a co-curricular group in high school; and two mentioned family (with four additional respondents mentioning family members on the spring first year survey in response to "are there any individuals who have been influential to your views of SR or community service"). It is interesting that a wide range of volunteer experiences were indicated on the survey, but frequently these were not cited in the open-ended response as influential to views of community service or SR.

In the first year interviews, most students cited influences that occurred before college (*Inputs*) such as a family value to volunteer or high school engineering experiences. For example, students described *Inputs* such as 'a love for the environment' and 'high school engineering.' Examples of unique, diverse influences on student ideas of SRE include: a father who leads mission trips to Ethiopia; family that lives in Colombia; spent 3 years between high school and college playing hockey in Alaska; sister adopted from Guatemala; first generation college student from Detroit.

Students most often discussed that upon entering college their ideas about engineering were shaped by engineers in their family (n = 13) and high school engineering courses (n = 11). These gave them an idea of 'real world' engineering. They also commonly cited that they knew engineers were good at math and science (n = 15), and possibly little more about engineering. Fourteen students also commented that volunteering before college was important to them and gave them an idea of who could be impacted by engineering. Table 2 provides example quotes from the interviewees that correspond to some of the *Inputs* listed above.

Table 2 Example pre-college influences

Theme	Individual, year, representative quote
Engineers in the family	Jamie, Y1: My uncle is a manufacturing engineer…. Engineering was always sort of in my background. Both my parents were engineers
High school engineering	Shawn, Y1: We had a program called River Watch…. We took accurate samples, we got to go back to our school and did some basic titrations to figure out dissolved oxygen or something like that, and then we actually sent it into the US Fish and Wildlife Service
Volunteering	Rachael, Y1: I volunteered a lot when I was in middle school and high school. I worked at the Children's Museum. I volunteered there weekly and everything and it was really fun and I guess it shaped how I saw, like, social responsibility
Engineering if math and science proficient	Trevor, Y1: I've always preferred math and science as opposed to humanities. I like the job opportunities that come with it, and I feel engineering is a good honest way to make a living
Environmentalism	Brandon, Y1: I wanted to do something related to the environment almost and I always enjoyed nature and stuff and I guess the environmental engineering aspect of it,…it's kind of your job

RQ2: Influences During College

Some influences persist into college, and many new ones take hold during college. These *Environmental* influences included 'familial situations' during college, 'popular media', 'introductory engineering courses', and 'co-curricular organizations' like the Society of Women Engineers (SWE); note that these influences can contribute to an expanded or more narrow view of SR in engineering. One student even discussed a co-curricular college event on the initial survey: "Engineers Without Borders have influenced my views of community service and social responsibility. After attending the informational meeting, it has encouraged me to get more involved because as an engineer I do feel as though it is my duty."

Each year, the online survey asked if there were any college classes that they found influential to their view of SR (Table 3). Eight respondents said no in year four, but six had described courses in earlier years. So perhaps those "impacts" were fairly transient, and not remembered as the student neared graduation. Only 2 of 21 students consistently said no courses in all years; both were students attending TechU. However, other TechU students in the same majors did identify technical courses that presumably all students would take. Thus, the different student definitions of SR may have influenced their perceptions of course impacts, or the students already had developed beliefs on SR and felt those courses did not change their opinions. Eleven students identified non-technical courses (such as humanities/social science electives) as impactful. Five students identified first-year engineering introductory courses (typically associated with ethics), four students' capstone/design courses, four students' professional issues/engineering management/leadership courses, and eleven "other" technical courses (many associated with environmental issues).

Students described courses and other elements as influential to their understanding of socially responsible engineering during the interviews (Table 4). Unique influences that were significant to students' understanding of SRE were found in some of the interviews: Reserve Officers' Training Corps (ROTC); serious concussion in college while playing club sports; severe head trauma during a summer internship on a construction site; 20 h/week at an internship with a full course load; captain of the club soccer team; studied abroad in China; no engineering internship through 3 years.

Beyond the diversity of responses overall, some influences had a persistent impact and others changed significantly over the four interviews. In the first year interview, many students described their college experience in the first year as highly influential on their social responsibility ideas, such as: introductory engineering ethics courses or modules, EWB, or discussion with classmates. Over the following 3 years, engineering internships became a much larger influence in addition to technical courses (some increased, others decreased SR and engineering connections) and further leadership opportunities in their co-curricular activities.

As the students became more ingrained in the engineering profession through societies and internships, these became more influential compared to the curricular influences that weighed heavily in the earlier years. Depending on the students' particular experiences, and the extent to which these were enjoyable, perceptions

Table 3 Survey responses on college courses influential to understanding social responsibility

Pseudonym	Major	Institution	Yr1	Yr2	Yr3	Yr4
Jason	Mechanical → Civil[4]	TechU	Intro Eng 1&2; Ethics	Eng1, Ethics	Technical	None
Madison	Mechanical	TechU	None	Intro Eng1&2, Ethics	None	None
Todd	Mechanical	TechU	None	None	None	None
Quinn	Civil → ElectComp	LPU	{No survey}	{No survey}	Non-technical	Non-technical
Tucker	Civil	LPU	Non-technical	None	None	None
Trevor	Civil	MPU	Non-technical	Env Sys	Tech	Senior design
Kim[a]	Environmental → Civil[2]	LPU	None	Tech—FundEnvE	Non-tech	Senior design
Ashley	Chemical	PrU	[Blank]	{No survey}	Non-tech & Tech	None
Jamie	Mechanical	TechU	Non-tech	Non-techical	Technical, AirForce	None
Brandon	Environmental → Civil[3]	TechU	[Blank]	[Blank]	Technical	Non-technical
Julie[a]	Mechanical	PrU	Non-technical	None	None	None
Wynne	Civil → Architectural[2]	LPU	Intro CivilE; eng projects	Non-technical	Intro CivilE, ethics	Global eng entrep
Denise	Mechanical	PrU	Ethics	Almost all, tech	All engrg	Technical
Tanya	Environmental	TechU	Intro EnvEng	Tech—IntroEnvE	EngFund, non-tech	{No survey}
Nathan[a]	Civil	TechU	None	None	Prof practice	Prof practice
Rachael	Computer Science	PrU	None	None	Eng leadership, ethics	Eng leadership
Katherine	Civil	MPU	[Blank]	{Incomplete survey}	Technical (environmental)	Capstone design
Derek	Mechanical	PrU	None; opposite of SR	Eng leadership/ mgmt—ethics, liability	Engineering management	Design classes, technical
Shawn	Environmental → Chemical[3]	LPU	Intro EnvEng—ethics; non-tech	Non-technical	None	Non-technical
Sarah	Civil	TechU	None	None	None	None
Jolene	Civil	TechU[b]/MPU2	None	None	None	Prof practice, ethics

[a]Student described in detail later in the manuscript

[b]Student transferred to MPU2, which was not part of the original four institutions

Superscript number indicates the year in which the student changed their major

Table 4 Example higher education influences

Theme	Individual, year, representative quote
Intro class/engineering ethics	Denise, Y1: The closest thing I got to social responsibility was learning about ethics in engineering. We had a class and we spent a whole day talking about ethics
Technical class	Katherine, Y2: I think especially my environmental systems class has really opened my eyes to the kind of work that I can do as far as water pollution and air pollution
Non-technical class	Jamie, Y1: World cultures—opening my eyes to a wider array of things to think about
Outreach	Ashley, Y3: I think the pro bono work would mostly be probably with tutoring or, yeah mainly with tutoring that is connected with engineering
Classmates	Shawn, Y1: I mean, it's hard to set a straight set of guidelines for what your own social responsibilities are but I think that's something that you figure out through your life and definitely through college, because right now, being an intellectual habitat, that's where these conversations are to be had

of future professional realities began to crystalize. Examples are shown below in Table 5.

Many persistent and some new influences in students' personal realm were very important (Table 6). The implications of these findings will be considered further in the "Discussion" section, as this aspect of students' lives has been understudied and perhaps undervalued in engineering education research.

RQ3: Changes in How Students Interpret Socially Responsible Engineering

During the interviews, students spoke about SRE in many ways. This was expected based on the intentional sampling of students with a range of social responsibility scores from the EPRA instrument. Table 7 summarizes the most common themes in

Table 5 Example professional influences

Theme	Individual, year, representative quote
Internship	Sarah, Y3: …getting more exposure through my co-op…it hits home a little bit, seeing the impact that engineers have on the rest of the world kind of shows how much social responsibility I think engineers should have…
Media	Julie, Y3: I read a lot about the case where Chrysler, like, their ignition switches were not working, were faulty or something. So thousands of people ended up getting in car accidents and just reading about the engineer who literally just signed off on things that came across his desk…
Minority society	Tanya, Y2: …with the Society of Black Engineers and what the organization does, what we do is go to schools locally and go to different high schools in Detroit and teach about what it is and do activities that involve engineering, and talk about what engineering is all about, and find what interests them

Table 6 Example personal influences

Theme	Individual, year, representative quote
Parents	Jolene, Y2: …my dad's company now where we're working, he just went over all the values in our Monday morning meeting and so there are a list of values there and core goals of the company that I really can appreciate and relate to
Friends—college/religion	Jamie, Y1: She was, just out of the blue, at the computer, and she asked me 'hey, do you ever consider the fact that you kill people?' 'Well, I don't yet, but yeah, I will.' 'Oh, how does that fit with your Christianity?' 'I hope that if I'm good to people that I'm going to be okay'
Summer job	Denise, Y3: I feel like we also, there is some responsibility of teaching…getting more people who are interested in engineering because even if they don't end up being an engineer, I think a lot of the engineer design process can be applied to many different things

each of the 4 years that interviews were conducted. The 'Total' in the table includes a student who at any point over the 4 years discussed the theme. Dominant themes for SRE included *move society forward* (15) and *help community/people* (8); all but three (Quinn, Rachael, and Shawn) of 21 had one or both of these themes. Seven included environmental elements in SRE, including sustainable buildings and alternative energy. Eight discussed *helping impoverished*, such as EWB-type projects or programs to assist those in poverty. Twelve discussed *safety*. Derek and Todd included pro bono as SRE (one student, Jason, specifically indicated that SRE does not require pro bono work). Other themes that were less frequent related to: problem solving, involvement with policy, communicating with public, energy, medicine, assistive technology, and creating jobs.

Interestingly, as seen in the table above, priorities for what constitutes 'Socially Responsible Engineering' changed over the students' time in college. Notably, *moving society forward* and *helping the impoverished* decreased in the number of mentions over the 4 years. Conversely, many others increased significantly such as *safety*, *serving the company*, and *serving clients/end users*. It seems clear that the professional influences of internships, co-ops, career fairs, and courses changed the idea most students had of the engineering profession and the connected responsibilities. Further analysis of these changes will continue in the "Discussion" section.

Synthesized I–E–O Model

A visual representation of most of the commonly discussed influences that shaped students' ideas about SRE were synthesized into an I–E–O model that combines all 82 interviews and surveys (Fig. 1). The superscripts represent how many of the 21 students mentioned a particular theme in one or more of their interviews or online surveys. Cross-over between categories was common; categorization was based on how the student discussed their influence. For example, the Society of Women Engineers (SWE) functions as a co-curricular community within the university structure, a professional society that provided increased exposure to engineering practice, and an outreach organization. Finally, all of these influences over 4 years of college

Table 7 Socially responsible engineering themes in interviews

SRE theme	Individual, year, representative quote	Number of students with this theme				
		Yr1	Yr2[a]	Yr3	Yr4[a]	Total
Safety	Madison Y3: …I guess a big responsibility is safety for the users…whatever you are doing should be safe for people…	1	3	4	10	12
Not harming environment	Julie Y3: …making sure that whatever they are working on is not, like, detrimental to any, like, group or, like, the environment or something like that	3	2	1	5	7
Serving company	Rachael Y4: Making sure that you are serving the company in good faith	0	0	1	5	6
Moving society forward	Nathan Y1: the goal [of engineering] is to make society better	9	9	8	4	15
Serving clients/end users	Trevor Y4: …to make sure I perform all of my work to the best of my ability and make the client happy	0	0	0	4	4
Helping people	Ashley Y3: [Engineers] should be trying to find solutions to help people	4	2	2	2	8
Behaving ethically	Tucker Y4: Following the code of ethics and really doing the right thing with all of your decisions…	0	0	0	2	2
Helping impoverished	Jolene Y3: …using the skills that I acquire here to be a part of that company down there to improve their wastewater system…	6	3	3	0	8
Following the law	Derek Y2: …I don't think that the institution has to give back kind of past certain rules and certain requirements…	0	1	0	0	1

[a]Only 20 of the 21 students participated in interviews this year

added up to students' evolving understanding of 'Socially Responsible Engineering'. Most students were not consistent with how they described SRE or their influences. Therefore, the following figure shows the total number of students that included these influences, experiences, and definitions at some point over the 4 years of interviews and surveys.

It became clear through the interviews that it was not only important to track which influences were helping to grow a students' understanding of SRE, but also which influences may have limited their understanding. Examples of this phenomenon are a brother in a corporate mechanical engineering firm who did not talk about his societal impact, and entering college with the idea that math and science proficiency are enough to become good engineers. At the end of year 1, when asked if any classes influenced his views of social responsibility, Derek wrote: "Not really. Most classes were intro classes. I feel like they might have done the opposite, causing me to focus a lot on my problems and studying."

In addition to the synthesized model, individual I–E–O models were created for each student (Rulifson 2015). This model represents the influences that contributed to their understanding of SRE and year they discussed the influence, represented by a superscript—'0' for the initial survey, and '1, 2, 3, 4' for the year of the three following surveys and interviews. The '/' indicates the student specifically mentioned they no longer were involved with this activity during that year's interview. Influences written in the survey, but never mentioned in interviews, are italicized. Those commonly found in this study, but not a factor for the individual, are shown in gray text. In the following section, three students who represent a diversity of institutions, majors, and experiences are described in detail in order to provide readers with a richer understanding of students' descriptions of SRE and their influences.

Student 1: Julie

Julie was an engineering student at PrU where first-year students choose their particular major at the start of their second year—she chose mechanical engineering. Julie's I–E–O model (Fig. 2) summarizes the influences that she discussed in her interviews and wrote in her surveys over the 4 years, as well as her ideas about SRE. In her first year, Julie thought of SRE as solving problems through new technology, alternative energy, and K-12 outreach to bring more students into engineering. Three major, persistent influences and ideas led Julie to her understanding of SRE as she neared graduation: (1) her passion for engineering without much familiarity of what engineers actually do, (2) her multiple engineering courses that were socially relevant and interesting, (3) her involvement with engineering outreach activities through her university and her summer job along with occasional volunteering. To Julie, SRE included safe technology advancements that hopefully improve society at large (i.e. alternative energy), or particular people (i.e. assistive technology or prosthetics); part of SRE could also include outreach and volunteering outside of or through their company. Importantly, Julie's ideas about SRE narrowed from year 1 to 4 as can be seen in the figure below. Originally, she discussed multiple elements, and in her fourth year she only discussed *safety* as important to SRE.

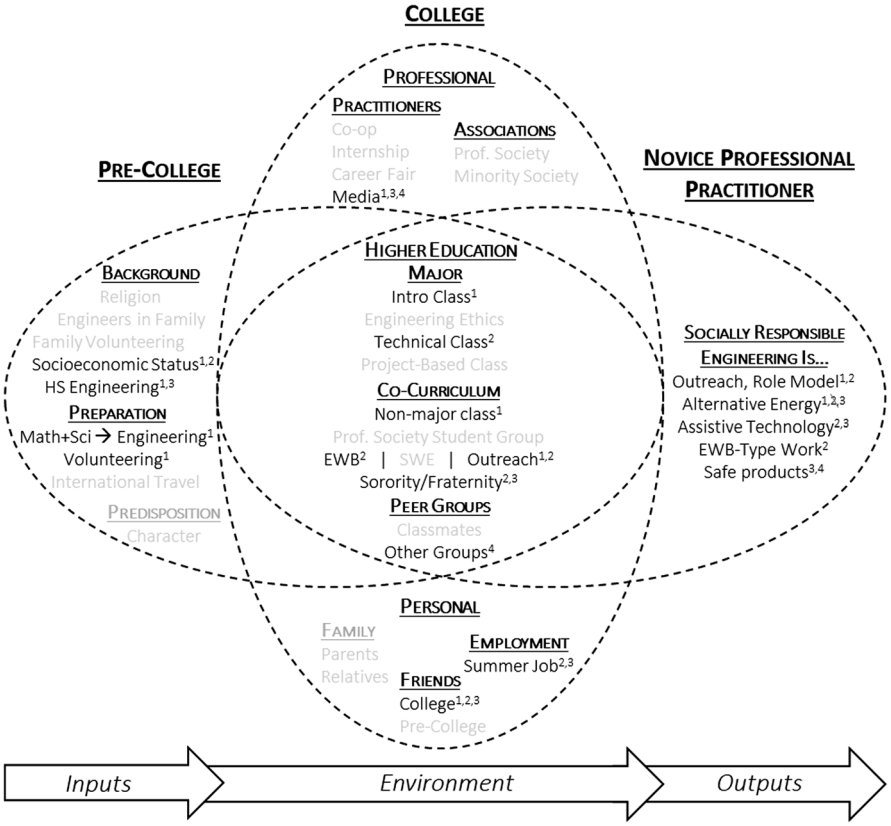

Fig. 2 Julie (ME, PrU) SRE I–E–O model

Julie: Inputs

Julie described that even before entering college, she developed a love for engineering. She participated in a pre-engineering summer session before starting college, and her mentors were mechanical engineers. This *Preparation* led her to choose ME and associate it with fun; she learned that, while she had "always been best at science and math type things," engineering would allow her to embrace her creative side by innovating and having some autonomy in how to achieve her professional goals. Somewhat different from many engineering students, however, Julie "hadn't known too many engineers personally, so [she] didn't have a really good view of what they did as a job…." She thought an engineer "use[d] math and science knowledge to, like, solve problems and create new technologies that, like, improve people's lives." Additionally, she described her impactful involvement with volunteering during high school, as she wrote in her initial survey (Table 8). This participation set the stage for her to include engineering with her desire to help others.

Table 8 Julie—inputs coding examples

Theme	Year, representative quote
High school engineering	Y1: I had a really limited view of engineering sort of as antisocial engineering science nerd people. Then after attending the program, I realized that engineers are just pretty much normal people who liked math and science
High school volunteering Global awareness	Y0: *Partaking in Amnesty International illustrated to me very clearly that there are people who are not as fortunate as I am and that it is inexcusable to just ignore their lack of basic needs and human rights. However, volunteering in a homeless shelter in my town showed me that there are people in need of basic resources living within miles of me who should not be overlooked*

These combined experiences seemed to give Julie a rather high social awareness that had the potential to combine with her college engineering courses and co-curricular activities to develop into an advanced understanding of SRE.

Julie: Environment

Julie's enthusiasm around engineering was obvious from the first interview's commencement. When asked how the first year had gone, she replied, "It was great, I loved it. [PrU] is a great school, especially for me. It's like, a perfect fit. And I love engineering so far, and I'm having a great time." Some of her courses in the first and second years were particularly impactful for understanding what engineers, and mechanical engineers in particular, could design. Her Structural Art class exposed her to iconic buildings and some of the engineering behind them. She reflected on one of the impacts of the class, "…I just sort of decided it was too much responsibility, like, if my bridge collapsed. That's a much bigger problem than if my robot short-circuits." She set up a hierarchy of SRE by discipline from what she understood after her first year; civil engineers were responsible for people's lives, and mechanical engineers just designed products. In the second year, she learned more about ME's potential to benefit society through her Human Factors Engineering course, which discussed assistive technologies and devices.

Due to Julie's own positive experiences on the receiving end of outreach before college, and a first-year non-engineering seminar that informed her about the broader issue of "science literacy," she wanted to give back in a similar way. She explained, "I feel really blessed to have always been a really great math and science

student and to have had the great teachers in my life. So I wanted to sort of give back in that regard of like, well now I could be an inspiration or a teacher to another child who like, could someday become interested in engineering." Thus, she worked with an on-campus engineering outreach program all 4 years. Her job was to (Year 1) "go into the elementary school and teach them engineering concepts," (Year 2) "teach robotics to students in Chinatown," and "go into a fifth-grade classroom every week and teach robotics." Also, her summer job following her first and second years was in a similar field—working at a pre-engineering summer session leading middle and high school students through projects that represented different disciplines. In the summer after her second year, she was the program director, and had more responsibility, but less interaction with the students. Further, Julie continued to volunteer with friends and her sorority, through which she gained more responsibility by being elected chief education officer in her third year. In the summer before her fourth year, she worked to develop better educational materials for Lego and researched acoustic properties on her campus. Therefore, she did not have many professional influences that contributed to her understanding of SRE. In fact, her senior design class was to redesign a spice jar, so this perhaps pushed her further from considering the impacts of her engineering work.

Because Julie did not yet have an engineering internship by the fourth year when she was interviewed, she still did not have an intimate understanding of the engineering profession. In the third year interview at the end of the Spring semester, Julie was "hop[ing] to be [at PrU] doing research with a professor, but other than that, just kind of chilling." She did this research, but did not gain an understanding of the engineering profession more broadly. She was accepted into the mechanical engineering master's program, so she would be at PrU for one extra year. Thus, Julie would go through her education without working in a non-academic engineering setting. Her fourth year classes had an impact; she said "…what I'm doing now is actually real," then continued to describe how she enjoyed her classes more than before.

Julie: Outcomes

Julie's understanding of SRE evolved from her first year in which she believed engineering inherently benefited society and included an outreach component. In her second year, these were still true with the specific example of human factors engineering. Julie developed an interesting understanding of SRE by her third year, which she discussed at length. When asked about an engineer's responsibilities, she replied, "…maintaining safety standards…and making sure that whatever they are working on is not, like, detrimental to any, like, group or, like, the environment or something like that." When she was asked about engineering's impact on society, she had difficulty answering. In contrast, when asked about how engineers *should* impact society, Julie responded remarkably:

> I think that people who realize that they have these skills, and also can be creative and make something to really help people, are the people who should be engineers and end up doing the most good, as opposed to people who are just

like in, in the machine, who just want to make money and are not particularly innovative or necessarily doing their work to benefit anyone.

Her description of a hypothetical engineering profession above could be interpreted as far more advanced than her understanding of her current understanding of SRE noted above. She reiterates later in the interview that "intentionally not being innovative is part of a major problem," to which she seems to have been exposed through her friend, who she believed was being irresponsible with his professional decisions to work in the petroleum or finance industries. This tension between a high salary and positive social impact that frustrated Julie seemed to come from her background of volunteering and passion about engineering's potential to make major changes to society and individual's lives through creative technological advances. Finally, though, in her fourth year, Julie described only the safe product nature of SRE. She did not discuss any of the elements about bettering society that she described in her third year.

In summary, while Julie had more experience with volunteering and was in a university environment that was very active and supportive of service activities, she still did not connect these directly with engineering. She ultimately decided that pro bono work for marginalized communities was not required for SRE, "but if you have time and are willing to do that, then more power to you." The resistance to require volunteering likely comes from her influential sorority and high school volunteering experiences; she described they felt forced to participate without intrinsic motivation. It seemed that overall Julie believed that the mechanical engineering profession, with its advancement of technology, would benefit society at large. Engineers needed to make the products safe to be responsible.

Student 2: Kim

Kim started college as an environmental engineering major at LPU and switched to civil engineering after her second year. Kim's I–E–O model (Fig. 3) summarizes the influences and outcomes regarding SRE that she discussed. At the beginning, Kim's idea of SRE was mainly confined to protection of the environment and technological advancement. Kim had three persistent lines of influence on her understanding of SRE: (1) she was not as academically prepared for engineering as many of her peers; (2) she entered engineering largely due to her love for the environment; and, (3) her courses, both within and without engineering, were impactful. These led to her understanding that SRE preserves and protects the environment, if done properly and safely, and prioritizes the environment and society over profits.

Kim: Inputs

Kim grew up in a small town near LPU where she enjoyed the outdoors, and developed an appreciation for the environment. She decided to pursue engineering while touring engineering schools, combining her love for the environment and the fact that she "always liked math and science more than writing papers…." She described that her high school, however, offered few advanced math and science classes that

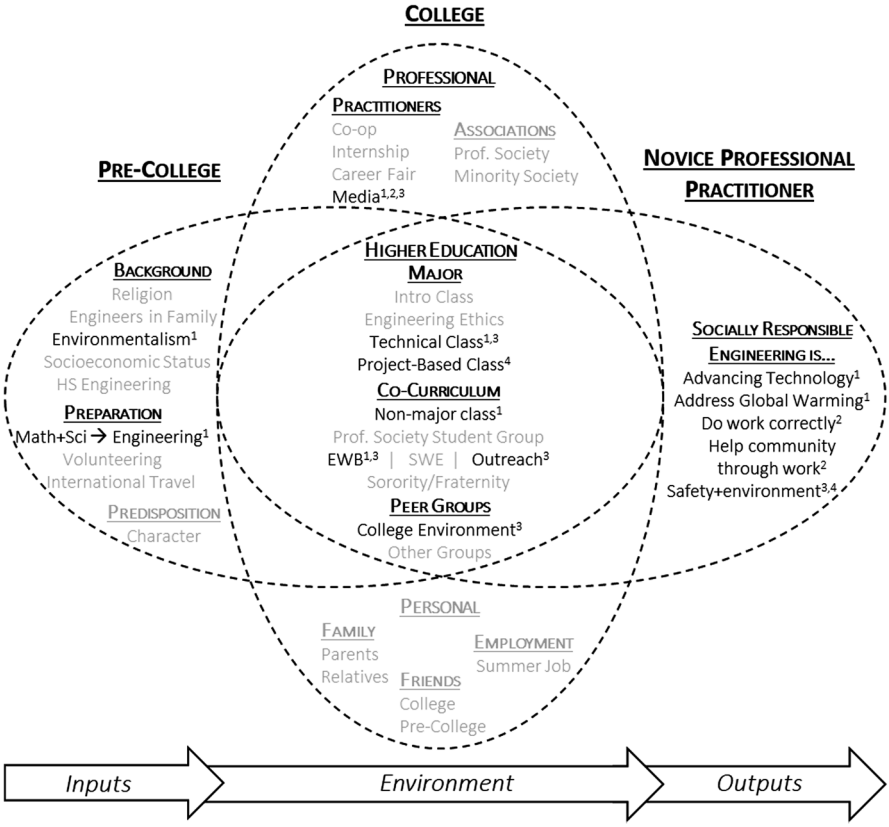

Fig. 3 Kim (EnvE → CE, LPU) SRE I–E–O model

helped prepare her future engineering classmates. Additionally, it seemed that helping people and volunteering was an important part of Kim's life (See Table 9). On the initial survey her high school community service activity frequency was the second highest of the 21 students in this study. This community service activity decreased significantly once she started college.

Kim: Environment

As Kim began college without a strong idea of engineering, her time in college was very influential on her understanding of SRE. Through 4 years, her confidence that engineering was the right choice grew, and aligned well with her *Inputs*.

In the first interview, when Kim was asked how engineering was going, she replied, "It's hard, but it's good." She said about her first year courses, "I feel like a lot of people have taken them in high school and I haven't." When asked what she believed engineers do, she said they "create stuff to better society." She learned this

Table 9 Kim—inputs coding examples

Influence	Year, representative quote
Non-engineering upbringing	Y1: I can't really think of anyone, really the only engineers I know, I guess, are my teachers and stuff, honestly
Volunteering	Y0 (survey): Volunteering experiences included weekly "Nursing Home" and "events around the community," as well as bi-weekly tutoring and monthly food bank participation
Environment	Y1: Interviewer: So do you think the environment part is particularly important to you? Kim: Yeah. I don't know, just like growing up in the mountains, it's kind of my background I guess

from her introduction to environmental engineering course, which included guest lectures from practicing engineers.

In the first and second years of college, Kim's volunteering dropped to nearly none. Also, Kim did not have an internship or research experience that contributed to understanding of environmental or civil engineering practice (her internship was in aerospace), so her idea of SRE emerged almost entirely from engineering courses (which emphasized microethics such as safety) and professors' values, combined with her personal background.

Kim's third year of college was significant—she switched to civil engineering and enjoyed the courses, especially geotechnical engineering. She began volunteering with the Society of Women Engineers at a STEM-focused elementary school, through which she found a community to help students who were possibly like her as a child. In the fourth interview, she described not having a major-relevant engineering internship and she became interested in water resources. She also had a senior design project with Habitat for Humanity in which she saw pro bono applications of engineering.

Kim: Outcomes

In each of Kim's interviews she discussed a lack of time, due to a part-time job and a consistently heavy course load in order to finish in 4 years. This may have prevented her from learning more about how engineering could be socially responsible. Her first year understanding of SRE focused largely on the environment since that was her main motivation for entering the engineering major. In her second year, her ideas did not advance beyond including 'proper' engineering work, "so it's not like, a waste of time and money." In her third year, she often referred to her perception that companies prioritized profit over the environment and society. It was unclear where this idea originated. For example:

> Interviewer: So do you think that the environment is kind of the number one, I guess, responsibility? Like something you have to be considering and prioritizing?
> Kim: Like, over society or?

I: Just sort of like, all the things that would come into a decision.
K: I feel like it should be, but it never is.
I: So what's above it?
K: Probably like, making money.

Kim's story shows how much influence professors and courses have on many students who have no family members or personal acquaintances who are engineers and do not participate in engineering internships in college. In her third year, Kim had the potential to learn more about SRE as she persevered and enjoyed engineering more, but she seemed not to have expanded her ideas about SRE. The fourth year's senior design had some impact leading her to believe that engineering served society as a general entity. On the whole, Kim's ideas around SRE still were vague at the end of her fourth year of college and related to her initial perceptions of engineering.

Student 3: Nathan

Nathan was majoring in civil engineering at TechU; his SRE I-O-E model is shown in Fig. 4. In the first year, Nathan believed that SRE was solving the world's problems including major ones such as poverty in developing communities. Nathan's main influences were (1) his family, both in developing his character and motivating him to pursue engineering, (2) involvement with EWB, and (3) engineering courses that reinforced what he learned in his local internships. These influences led to his fourth year understanding that SRE encompasses most of the engineering profession as it is today, which provides the best service possible for all impacted stakeholders by considering all feasible and safe solutions.

Nathan: Inputs

In his first interview, Nathan described that his family supported volunteering, he participated in church service activities in high school, and that his family adopted his younger sister from Central America. He traveled there and witnessed a vastly different world than his own (see Table 10). Nathan reflected on poverty he had seen in cities near and far. He seemed to think deeply about the plight of people who "spend their whole lives trying to get out of the hole that they're in and they don't get a lot of the chances that we get."

Nathan: Environment

Nathan learned through his first-year introductory engineering course's ethics module that "the goal [of engineering] is to make society better. So, social responsibility is kind of big." In contrast, he said that discussions of SR were not part of his second year classes. Outside of his courses, Nathan joined EWB upon entering college, which worked in the same Central American country where his sister was born. EWB seemed to be highly influential on his ideas about the potential of engineering to affect issues such as health and sanitation, which he described in his first

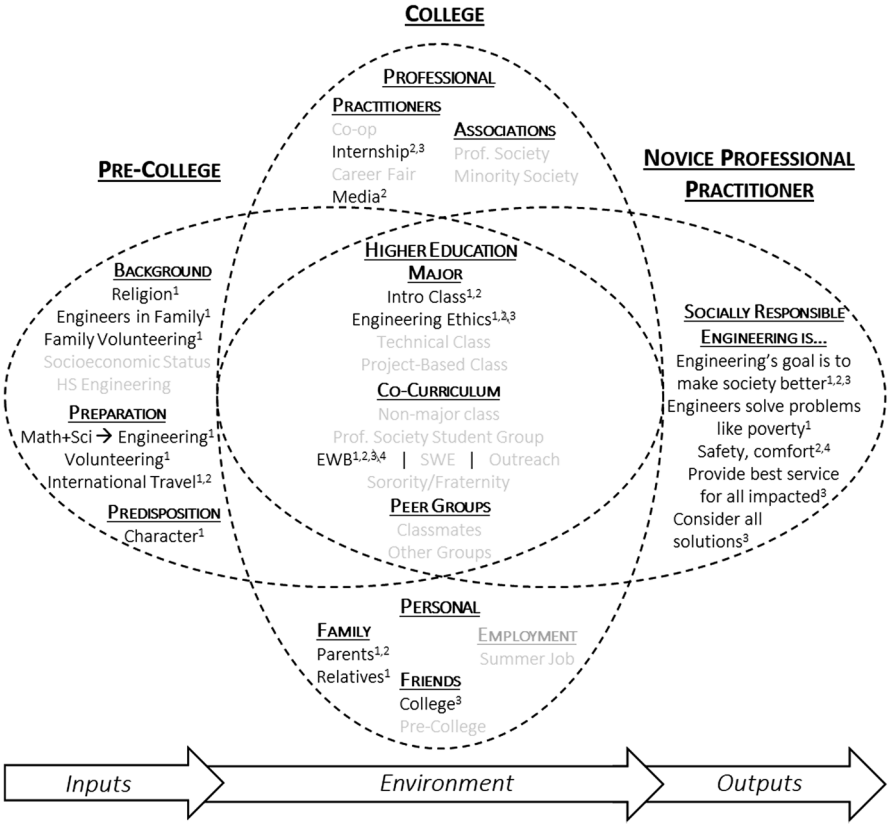

Fig. 4 Nathan (CE, TechU) SRE I–E–O model

Table 10 Nathan—inputs coding examples

Influence	Year, representative quote
Family International travel	Y1: …[my sister's] orphanage, going and seeing all of these kids. I never really knew what an orphanage was and when you see it firsthand…it kind of shifts you. And you see all these kids who don't have, well they have a home, but they don't have a family. And that's kind of hard to deal with sometimes
Volunteering	Y1: We did this thing called "Jesus on the Streets" in [ ] where we just go on a Saturday or Sunday at 7 a.m. in the morning and hand out food to the homeless people in [ ]

interview. When asked if he felt engineering played a role in addressing poverty, he said, "[EWB is] trying to give them their basic needs of nourishment by giving them water they can use for drinking or whatever they need it for." In his second year survey, Nathan wrote succinctly about influences on SR, "My involvement in Engineers Without Borders has increased my desire to help people with engineering. Mainly the adoption of my little sister has influenced my desire to help people in need." He also described that his main reason for pursuing engineering was to give back to his current family and provide for his future family. In Nathan's third year interview, he explained that he stopped participating in EWB because the team "stopped doing work because they were in between projects… and it just got a little bit frustrating."

Discussions with professionals at career fairs and his own research were possibly the most significant influences in his second year. His SRE ideas started leaning toward the U.S. and local context and included safety, energy efficiency, and quality roads. He made an important comment about engineering: "I make something that's not going to fall down and kill a bunch of people and that is just, that just seems like human decency, but it's something that I would like to make and to not only be safe, but also to be helpful to the community." At this time, SRE still went beyond safety and legality. Connecting with his desire to continue EWB as a professional, he also glimpsed what poverty alleviation could be as a practicing engineer through a discussion with his future boss about participation in an Indian water treatment organization. Nathan's third year interview largely revolved around his internship that impacted his ideas about how engineers impact local communities. In the fourth interview, Nathan described that he graduated a semester early and had the same consulting firm internship which led to a full-time job. He was focused on getting into a graduate school in Germany to be with his girlfriend.

Nathan: Outcomes

In the first year, Nathan had a strong understanding that SRE made society better overall, and should help others in poverty domestically and abroad. In his second year, his understanding additionally included an engineer's promotion of safety and comfort through their work. Nathan's third interview revealed that his ideas of SRE continued to become more local and aligned with on-the-job microethical dilemmas. His internship did provide a better understanding of how engineers directly impact communities as he traveled to the company's project sites, but also seemed to push him to believe that his main responsibility as an engineer is to satisfy the client. One influential class in his junior year was about being a practicing engineering professional where he learned about "situations where you have a boss telling you that you have to do this one way and you know that's wrong…, but at the same time, they were getting around the law somewhere." He also described how an engineer needs to consider all who would be impacted by a decision, research multiple options, and ensure the negative effects are mitigated.

Towards the end of the third interview, when asked about his previously mentioned international development goals, he replied, "I don't know if I see it happening with my career as much now as I did before, but I definitely would still want

to take the time to go on some sort of trip or plan something and try to help these communities." Nathan still saw engineers as having great social responsibility, but rather than to bring people out of poverty, engineers can fulfill this responsibility by researching all solutions to any given problem defined by the company and client. His ideas really did not change from the third to the fourth year, except being more focused on microethical adherence than broader community benefits.

Comparison of Julie, Kim, and Nathan

In summary, while each of these three students conceptualized SRE in different ways, some common threads emerge. Julie and Nathan believed that status quo engineering practice is socially responsible; they believed that, by its nature, engineering makes society better for everyone. Further, Julie believed that technology, which engineers advance, improves society at large. Julie and Kim both had ideas that beyond technical work, underrepresented groups needed to be included in engineering through outreach and accessibility. Julie and Kim also included environmental protection, though in different ways. Table 11 provides condensed statements of these students' fourth year ideas about SRE.

Discussion

Socially responsible engineering is a complicated idea without consensus among disciplines and across countries; students reach personal conceptualizations of SRE from diverse influences within and outside of the higher education environment. These 21 students give insight to the differential weighting of any particular experience's impact on students across majors and universities. Some influences change over time, and others persist. The highlighted students illustrate how certain influences were more powerful.

While the *Inputs* are not in the university's control except through outreach programs, many efforts could be made across the permeable boundary before the students enter college to prepare the students to have an advanced and accurate idea of the social impacts of engineering. Twelve of the 21 students were impacted by EWB; while none of them continued involvement beyond their second year due to

Table 11 Highlighted students' understandings of SRE in year 4

Student	Socially responsible engineering…
Julie	advances technology that is safe and hopefully, but not necessarily, gives back to society at large (i.e. alternative energy) and could include outreach and volunteering outside of or through a company with the time and resources they have available in order to increase opportunities for others
Kim	Preserves and protects the environment; is done properly, safely and according to company guidelines; prioritizes the environment and society over profits
Nathan	Is most of the engineering industry that provides the best service possible for all impacted stakeholders by considering all available, reasonable, and safe solutions

a lack of time or organization within the group, this awareness expanded engineering's connection to helping humanity in these students' minds. On the other hand, 16 of the 21 students discussed the message they received from high school teachers, parents, and their own research, that 'if one was good at math and science in high school, then engineering would be a good fit.' Entering college with this mindset might already close students off to the other crucial traits that they should develop such as care, empathy, and passion (Moriarty 1995; Capobianco et al. 2011; Capobianco and Yu 2014), which will all be needed to address the most complex issues in society today and in the future.

Additionally, if the faculty can be more aware of engineering students' pre-college experiences and interests in volunteering, travel and high school engineering, the faculty can make their courses more directed. Students spoke of the high impact of courses connected with the 'real-world,' but this was usually only in the first-year introduction to engineering course or not until their final year.

As other studies have discovered, a major component of the dearth of diversity in engineering is that the profession became inaccessible or uninteresting to potential future professionals (National Academy of Engineering 2005; Eisenhart et al. 2015; Capobianco et al. 2011). If engineering was perceived as more helpful or caring, perhaps students with more focus on SR (which tends to be women) would enter engineering, graduate with degrees, and persist into the profession and stay there. Anderson et al. found that "most engineers' identities were…linked to their work meaning something," although that meaning varied (2010, p. 168). Thus, the *Inputs* dimension deserves a more focused study in collaboration with early education researchers and sociologists to help improve perceptions of the engineering profession that align with a broader diversity of SRE understandings.

Impacts through the Higher Education *Environment* include engineering ethics courses, though many teach microethical responsibilities of engineers (Herkert 2005): avoiding lawsuits and loss of life rather than the larger societal and environmental impacts of engineering work (Winner 1990). Engineering ethics courses are an important opportunity for professors to increase students' awareness of the "social context of engineering" (Herkert 2000). Evidence has also been found that engineering faculty actually perceive this contextual understanding is a gap in students' knowledge and professional preparation while they admitted to not teach macroethics of engineering in their classes (Bielefeldt et al. 2017). Further, integration of ethics and social issues into core engineering and design-focused courses, rather than isolating these topics in dedicated courses, may send a better message that both technical and non-technical issues should always be considered through problem solving and design processes (Lucena and Leydens 2015). Notably, the quantitative part of this research found that students who started with lower SR scores showed significant increases over 3 years (Bielefeldt and Canney 2015), showing that expanding students' understanding of SRE is possible and is happening for some.

Eleven students said in the fourth year that an engineer's responsibility is to the company and help the company make a profit. They said this first—before safety or impacting society in a positive way. While the question, "To whom will you be responsible as engineer?" was not asked explicitly in the first year interviews, students expressed more interest in bettering society through engineering than

gaining profit for a company (Rulifson et al. 2014). This is a troubling change of priorities between the first and fourth years. This "culture of disengagement" over time was found in previous quantitative studies (Cech 2014), and through the quantitative side of this research (Canney and Bielefeldt 2015; Bielefeldt and Canney 2015). Based on these interviews, this seemed to result from a combination of (1) a lack of macroethical instruction within the engineering curriculum, such as the broader context and impact of engineering works alongside the real potential for addressing deep societal issues, and (2) witnessing what responsibilities were prioritized during their engineering internships.

At the porous boundary of the Professional and Higher Education *Environments* lies the powerful engineering internship. From these longitudinal interviews, it was seen that students' initial humanitarian priorities may fall below the company's profit-driven priorities. If students are fully immersed in a company culture that only promulgates microethical responsibilities such as cost-efficiency, correct calculations, and occasional donations, students like Nathan and Julie will come to believe that these are the only social responsibilities of a practicing engineer. Students also talked about messages through the media and career fairs. If advertising is mainly about 'cool technology' rather than the potential positive impact of engineering, students who do have an advanced understanding of SRE may begin to dissociate themselves from the profession, and those who have a limited understanding will have their ideas reinforced.

At the same time, students did engage in activities that exposed them to how engineering can act with a high level of social responsibility. Co-curricular activities such as K-12 outreach, research, and engineering societies play a large role in shaping students' ideas. If the activities and messaging in the co-curriculum were more connected with macroethical instruction, students may begin to see the skills and values of volunteering or outreach as aligned with engineering practice rather than on the margins of 'real' engineering.

Overall, these conversations show many opportunities in the different spaces through which students travel that could improve students' understanding of the potential impacts of the engineering profession. With this awareness, they could push the profession to be more socially responsible over time, as these students become "Novice Professional Practitioners" and eventually leaders themselves. The balance of where engineering efforts are spent needs to be addressed by the next generation of engineers; for inspiration and guidance, those faculty role models currently striving for a more just world through a commitment to an ambitious understanding of SRE can interact with students in classrooms, networking events, and career fairs. Engineering students should be encouraged by trusted influences to take opportunities to make any number of changes within the spaces they operate, or will operate—peer groups, internships, and future jobs. The students in this study have shown unsurprisingly that engineering students are caring in their own ways, but it is also clear that they need more opportunities to talk about, engage with, and serve society in meaningful ways. Then, they can begin the process of fulfilling the engineering profession's well-recognized potential to be wholly socially responsible.

Limitations and Validity

As it is not possible to understand the students' complete ideas on any issues, interpretation of the students' words by the researchers was necessary. Both authors have backgrounds in civil and environmental engineering. It became clear through the interviews, but also through discussions about this study, that the authors have a particular lens through which they see student experiences, and the role of engineers and engineering educators. The authors reached out to a professor in mechanical engineering, an undergraduate student, and a professor in the School of Education who has a wealth of experience with qualitative studies in science and engineering education. Each of these reviewers brought their own perspectives and expertise to help ensure a balanced understanding and presentation of the students' ideas. While any person's words in an interview may not completely communicate their complex beliefs, the authors strongly believe they represented the students' thoughts as well as possible, and did not bias the interviewees' responses by stating a definition of SRE at any time throughout the interviews.

Another limitation is that of the 236 first year students with validated responses to the EPRA Survey, 75 checked a box that they might be willing to be interviewed; the $100 interview incentive was not mentioned on the survey. Perhaps the students who agreed to participate in the interviews were more interested in speaking about social responsibility than typical engineering students. This may account for why more students in the lowest quartile of SR scores did not consent to participate in the interviews. This may have limited the ability of the study to observe expanded definitions of SRE in students over time; the quantitative survey results in the larger study found that 20% of the students increased in SR scores after 1.5 years, and these students initially had lower SR scores (Bielefeldt and Canney 2015). Besides these issues, there is little reason to believe that the students are drastically different from engineering students overall.

Conclusions and Future Work

Socially responsible engineering does not have a single, agreed-upon definition by engineers, engineering educators, nor the engineering students in this study. These 21 students, and particularly Julie, Kim, and Nathan, illustrate different visions of SRE. Engineering students enter college with complex backgrounds. Some give students a predisposition for wanting to help society through engineering—experiences such as volunteering (domestically and internationally), which lead to a larger awareness of situations in society. Some students developed their ideas of SRE in engineering classes and co-curricular activities such as EWB and outreach. These seem like powerful avenues through which engineering can be seen to help. Other students, however, did not experience a college environment that fostered an idea that engineering could or should be connected strongly with

their own perceptions of social responsibility. Instead, they interpreted from engineering professors, professionals, and sometimes family members that engineering is a "good job" that is inherently socially responsible if the codes of ethics are followed and the public is kept safe. These influential members of a student's environment could instead, for example, expand a burgeoning engineer's sense of responsibility to consider the marginalized global society that has not historically been as positively impacted by engineering advances (Lucena et al. 2010).

Trying to understand over multiple years the strongest influences for any particular student shows the diversity of thought and experiences in an engineering student's college career. Overall, it seems like more communication and discussion about what engineering practice could entail with regards to social responsibility would allow students to make more informed decisions about their future.

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Appendix 1: First Round Interview Questions

1. Just to confirm, what are your major and year in school? And how is engineering going? What are some things you have liked or enjoyed? Found difficult or frustrating?
2. What interests you the most about engineering? What led you to choose engineering as a major? Did you seriously consider other majors?
3. What is your current vision for an ideal engineering career?
4. Describe experiences in your life prior to college or during college that influenced your view of the engineering profession.
5. Describe experiences in your life prior to college or during college that influenced how you understand social responsibility. (What is your definition for SR?)
6. In what ways do you feel you help others?
   - At any scale: globally, locally, within your family/friends
   - How and why are you involved? What are the benefits you see for them and yourself?
   - If not: what are some reasons for not helping?
7. What are some important social issues to you?
   - What were some of your influences that made these important issues to you?
   - How do you see yourself involved in addressing these issues?
   - Do you see engineering playing a role in addressing these issues?

8. Does your sense of social responsibility move you towards, away, or neither from an engineering career?
9. Is there one issue that you feel particularly passionate about trying to address? Why?
   - Can your engineering abilities help with this goal?
   - Can other majors in engineering better help you to reach this goal?
10. How confident are you that you will get an engineering degree and practice engineering after graduation? What are your main concerns?
11. Is there anything else you would like to share, or questions you have?

Appendix 2: Second Round Interview Questions

1. Going way back, what did you do over the summer?
   OR: How was [reference previous interview] over the summer? Give me some highlights.
   a. Follow-up if an engineering internship or activities related to social responsibility
2. Are you still a _____ major? And how is the second year going? What are some things you have enjoyed? Found difficult or frustrating?
3. Do you have any new particular interests within _____ engineering?
4. Ideal career
   a. Is your ideal career still [reference previous interview]?
   b. OR: Have you discovered an ideal career?
5. What are some specific qualities of a job that you are looking for? What influences made these qualities important?
   a. Which of these qualities are deal breakers/makers, most important?
6. Describe experiences in this past year of college that influenced your view of the engineering profession.
   a. What do you think engineering employers are looking for in an interview? Do you think this would be different for an employee, after you are hired?
7. What is your definition of social responsibility?
   a. Describe experiences in this past year that have influenced this understanding of social responsibility.
   b. If very different from previous definition: what do you think influenced these changes?

8. Helping others

    a. Are you still involved in [reference previous interview]?

        i. YES: Describe some of your experiences with that in the past year.
        ii. NO: Why not? Are there other activities you are involved with instead?

    b. What are some new ways you have been involved with helping others in the past year?

i. If none or few or difficult question to answer: what are some reasons you did not help others (much) in the last year?

9. Important Social issues

    a. Are there any social issues you are addressing currently? In what ways?
    b. In our last interview, you mentioned [reference previous interview] as an important issue. Have you become/stayed involved with addressing this issue?
    c. What were some of your influences that made these important issues to you?
    d. Do you see engineering playing a role in addressing these issues?

10. Is there one issue that you feel particularly passionate about trying to address? Why?

    a. Can your engineering abilities help with this goal?
    b. Can other majors in engineering better help you to reach this goal?

11. Do you expect social responsibility will be part of your future engineering career? How strongly? In what ways?
12. Does your sense of social responsibility move you towards, away, or neither from an engineering career? In what ways? Has this changed significantly since last year?
13. Is there anything else you would like to share, or do you have any questions?

Appendix 3: Third Round Interview Questions

1. Are you still a _____ engineering major? (*If not*: why did you switch? [*Move to LEAVER set of questions if major is now outside of engineering*])
2. Tell me about the last year, some highlights and events or activities that were especially important to you.
3. Read the eighteen characteristics I emailed you (see below).

a. Select the five characteristics that you think are most representative of engineers.
b. Are there additional characteristics that you typically associate with engineers?
c. Select the five characteristics that you think are most representative of you.
d. Are there additional characteristics that you typically associate with yourself?

care	fairness	positivity
commitment	flexible	respect
confidence	high expectations	sensitivity
consideration of others	integrity	thoughtfulness
curiosity	judgment	thoroughness
empathy	persistence	tolerance

4. What are the responsibilities of an engineer? Why do you think so?
   a. Who are engineers responsible for?
5. What is the engineer's role in impacting people in society? **reword (how does, *could,* or *should* an engineer impact society?)
6. What are some ways that you think about social responsibility?
   - Has your understanding changed much in the last year? Why do you think that is?
   - How has it changed during college? Why do you think that is?
   - How could any person act on this understanding of SR? [*non-engineering*]
7. How do you think your ideas around personal social responsibility influence your ideas about professional responsibility and vice versa?
   - *If different from responsibilities of an engineer, ask how they deal with the difference.*
8. How does engineering play a role in social issues?
9. Think aloud through the drawbacks and benefits of incorporating social responsibility into your engineering career.
   - How about pro bono work?
10. As a practicing engineer in the future, how do you expect to incorporate your personal sense of social responsibility with your professional practice, if at all?
11. Is there anything else you would like to share, or do you have any questions?

Appendix 4: Fourth Round Interview Questions

1. Are you still a _____ engineering major?

2. Tell me about the last year: some highlights and events or activities that were especially important to you.
3. What are your plans for the coming year following graduation?
4. What is your current vision for an ideal engineering career?
   - What factors would make a job personally rewarding to you?
5. What will be your responsibilities as an engineer? Think narrowly and broadly about the term 'responsibilities.'
   - Who will you be responsible for as an engineer?
6. What are some ways that you think about social responsibility?
   - Has your understanding changed much in the last year? Why do you think that is?
   - How have your ideas about social responsibility generally changed during college? Why do you think that is?
7. How do you think your ideas around personal social responsibility influence your ideas about professional responsibility and vice versa?
   - *If different from responsibilities of an engineer, ask how they deal with the difference.*
8. In what ways do you believe that you might be serving or helping people and/or society in some way during your career?
   - To what extent is this helping aspect of the job important to you?
   - How does the importance of helping compare with other factors such as salary, location, who you work with, etc.?
9. In what ways do you believe that your vision of how you might help society and/or people through your career as an engineer has changed since you began college? What experiences have contributed to these changes?
10. After you graduate, in what ways might you like to help people and/or society outside your work?
11. Is there anything else you would like to share, or do you have any questions?

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