



Measuring Change over Time in Sociotechnical Thinking: A Survey/validation Model for Sociotechnical Habits of Mind

Dr. Jon A. Leydens, Colorado School of Mines

Jon A. Leydens is an associate professor in the Division of Liberal Arts and International Studies at Colorado School of Mines, USA, where he has been since 1997. Research and teaching interests include communication, social justice, and engineering education. Dr. Leydens is co-author of *Engineering and Sustainable Community Development* (Morgan and Claypool, 2010) and editor of *Sociotechnical Communication in Engineering* (Routledge, 2014). Dr. Leydens won the James F. Lufkin Award for the best conference paper—on the intersections between professional communication research and social justice—at the 2012 International Professional Communication Conference. In 2015, he won the Ronald S. Blicq Award for Distinction in Technical Communication Education from the Professional Communication Society of the Institute for Electrical and Electronic Engineers (IEEE). His current research focuses on rendering visible and integrating the social justice dimensions inherent in three components of the engineering curriculum—in engineering sciences, engineering design, and humanities and social science courses. That research, conducted with co-author Juan C. Lucena, culminated in *Engineering Justice: Transforming Engineering Education and Practice* (Wiley-IEEE Press, 2017).

Dr. Kathryn Johnson, Colorado School of Mines

Kathryn Johnson is an Associate Professor at the Colorado School of Mines in the Department of Electrical Engineering and is Jointly Appointed at the National Renewable Energy Laboratory's National Wind Technology Center. In 2011, she was a visiting researcher at Aalborg University in Denmark, where she collaborated on wind turbine control research and experienced Aalborg's Problem-Based Learning method. She has researched wind turbine control systems since 2002, with numerous projects related to reducing turbine loads and increasing energy capture. She has applied experiential learning techniques in several wind energy and control systems classes and began engineering education research related to social justice in control systems engineering in 2014.

Dr. Stephanie Claussen, Colorado School of Mines

Stephanie Claussen's experience spans both engineering and education research. She obtained her B.S. in Electrical Engineering from the Massachusetts Institute of Technology in 2005. Her Ph.D. work at Stanford University focused on optoelectronics, and she continues that work in her position at the Colorado School of Mines, primarily with the involvement of undergraduate researchers. In her role as an Associate Teaching Professor, she is primarily tasked with the education of undergraduate engineers. In her courses, she employs active learning techniques and project-based learning. Her previous education research, also at Stanford, focused on the role of cultural capital in science education. Her current interests include engineering students' development of social responsibility and the impact of students' backgrounds in their formation as engineers.

Prof. Jenifer Blacklock, University of Colorado, Boulder

Dr. Jenifer Blacklock focuses on project-based learning and developing hands-on curriculum to create strong science and engineering foundations.

Dr. Barbara M. Moskal, Texas Tech University

Barbara Moskal is a research professor in the College of Education at Texas Tech University. She is also a Senior Associate Editor for the *Journal of Engineering Education*.

Olivia Cordova, Colorado School of Mines

Olivia Cordova is a graduating senior in Electrical Engineering at the Colorado School of Mines. As a member of the Institute of Electronics and Electrical Engineers and Society of Women Engineers, she is



passionate about organizing and participating in outreach for the youth in STEM, especially young girls. Technically, she studies power systems analysis and renewable energy integration. This technical background has allowed her to realize the disconnection between social and technical aspects of engineering. Through this realization, she has been able to participate in research regarding sociotechnical integration in engineering education.

Measuring changes over time in sociotechnical thinking: A survey validation model for sociotechnical habits of mind

Abstract

Practicing engineers need to be able to balance the complex interplays that exist between the social and technical dimensions of contextualized, open-ended problems. Engineers often engage in problem definition while interacting with non-engineering stakeholders. Yet in undergraduate engineering education, engineering course work often emphasizes the technical at the expense of the social, and rarely provides students the opportunity to solve open-ended problems. This paper describes the rationale and process for developing an instrument to measuring students' perspective changes in sociotechnical thinking. That instrument is motivated by research that examines the importance of embedding sociotechnical thinking, or the interplay between relevant social and technical factors in the problem to be solved, into the engineering curriculum.

Introduction

Practicing engineers often learn to recognize the complex interplays between the social and the technical dimensions of the typically open-ended problems that they solve [1]–[3]. Professional engineers also engage in elaborate problem definition phases, which feature negotiations of the problem definition with non-engineering stakeholders, and engage in iterative problem solving when approaching ill-structured problems [4], [5]. Yet, in undergraduate engineering education, engineering degree programs usually emphasize the technical at the expense of the social, and primarily provide closed-ended rather than open-ended problems [6]–[8].

Pre-defined, closed-ended, decontextualized problems deprive students of opportunities to experience and practice the crucial problem definition phase [6], [7]. In a review of literature on engineers as problem solvers, and after contrasting the nature of common engineering workplace and classroom problems, Jonassen concludes, “learning to solve classroom problems does not effectively prepare engineering graduates to solve workplace problems” [5], pp. 103-104. The engineering curriculum may fail to engage the social context in which problems occur, fostering the habit of solving problems that come fully formed and that require no problem-definition negotiations with community, municipal, and other stakeholders [7], [8]. This mismatch between how future engineers are taught and the decisions they will make as professionals can lead to negative consequences in society and can damage the reputation of the engineering profession. This paper first describes the theoretical background motivating a new research project in sociotechnical thinking within engineering education, then describes the development of an instrument for measuring students' sociotechnical change over the course of a semester.

Theoretical Background on Sociotechnical Integration

Practicing engineers encounter technical problems situated in social contexts with real clients, stakeholders, and diverse perspectives. The importance of social context is acknowledged by NSF's *Professional Formation of Engineers* initiative, which emphasizes the “formal and

informal processes and value systems by which people become engineers” and “the ethical responsibility of practicing engineers to sustain and grow the profession in order to improve quality of life for all peoples” [9]. Social contexts can shape (and be shaped by) technical problems. Engineering practice involves contextualized engineering problem solving in which the social and technical interrelate [1]–[3], [10], [11]. The sociotechnical nature of problem solving suggests that a sociotechnical method of thinking is a critical component of engineering practice.

Professional engineers sometimes fail to recognize the interrelated nature of sociotechnical systems, instead falsely dividing them into a techno-social dualism [11], [12]. Even the National Academy of Engineering’s 2008 Grand Challenges Report [13], commonly perceived as a key vision of the engineering profession’s view of itself in the 21st century, has recently been critiqued for inadequately incorporating social elements and failing to consider relevant community viewpoints [14]–[18]. In a study that interviewed more than 300 engineers over the course of a decade and survey data collected from almost 400, researchers identified common misconceptions among engineering students and novice engineers about the realities of engineering practice [2]. Specifically, practicing engineers describe engineering practice as much more sociotechnical in nature than students or novices [2]. Although Trevelyan’s research was undertaken within the Australasian context, many of the findings align with research in U.S. and U.K. contexts, such as those confirming engineers’ tendency to split the world between the technical and the social [10], [11].

It is not surprising that engineers and students perceive a divide between the technical and the social dimension of problems. During their engineering education, students receive few opportunities to practice sociotechnical thinking [7]. The engineering science curriculum, the component of the engineering curriculum comprising the most credits, favors the technical, which is often separated from the social via closed-ended, decontextualized problems [6], [8]. Inversely, courses in the humanities and social sciences generally favor the social, typically separated from the technical. While engineering design experiences can promote sociotechnical thinking, sociotechnical integration is often treated superficially due to the number and complexity of accreditation criteria design courses must often meet; also, design courses in most U.S. universities are often dramatically overshadowed by engineering science courses, which feature little to no social or sociotechnical content [19], [20]. Drawing on longitudinal survey data from students in four engineering colleges, Cech researched the degree to which students’ interest in public welfare concerns change over the course of their engineering education [21]. Research findings from that study show that engineering students’ are increasingly disengaged with public well being over the course of their undergraduate studies; this finding also supports the notion that the cultural emphases within engineering programs—including the stark separation of the technical and the social—impact students’ views of their futures as professional engineers [21].

A key source describing elements of the divide between the technical and the social, and especially social justice, in engineering education is Riley’s *Engineering and Social Justice* [22]. Riley describes the ways in which engineering mindsets contribute to the false dichotomy placing technical and social elements at odds with each other:

Generally, engineering students learn to think analytically only in certain ways appropriate to technical analysis. For example, we learn to break problems down into small parts, solve the individual parts, and then work back up to a solution. We typically do not come away with the ability to think critically, to question what is given, or question the validity of our assumptions, because we are too busy learning the essentials of problem solving. For this reason, we often cannot see the larger context of the problem we are working. [22], p. 41

Adams and collaborators also examined multiple perspectives of the engagement of future engineers [23]. One conclusion they drew was that there is a disconnection between engineering education's focus on technical knowledge acquisition, and the practice of engineering, which requires broader skill sets. Within Adams et al. [23], Stevens' essay "Toward a Socio-Technical Engineering Education" describes a strong inconsistency between engineering and people within engineering education, including a persistent view that academic disciplines focused on people have limited value compared to (technical) engineering.

Most U.S. engineering curricula insufficiently accentuate sociotechnical interplays, providing too little attention to the social. For instance within the engineering sciences, instructors often default to the same kinds of problems they encountered in their own engineering education: decontextualized problems that have only a single correct answer [7]. Although this practice facilitates the ease of grading and greater semblance of objectivity, it also conveys an incorrect message to students. Trevelyan's work indicated that due in part to their formative education, many practicing engineers were misled to think engineering was a technical rather than a sociotechnical profession [2]. When they began actual engineering practice, such engineers were troubled by the amount of ambiguity, necessary collaboration, sociotechnical complexity, and persuasion needed:

Many [of the interviewed engineers] felt frustrated because they did not think that their jobs provided them with enough technical challenges. Others felt frustrated because they thought that a different career choice might have led to a job that would enable them to make more use of the advanced technical subjects they had studied in their university courses. Many of them were actually planning to leave their career in engineering. In our research, we found that more experienced engineers, those who had stuck with it for a decade or more, had mostly realized that the real intellectual challenges in engineering involve people and technical issues simultaneously. Most had found working with these challenges far more satisfying than remaining entirely in the technical domain of objects. [2], pp. 49-51

Another example of this challenge is illustrated through the curricula at University A. In the electrical engineering (EE) and mechanical engineering (ME) curricula, approximately 90 of 129.5 (about 70%) and 88 of 134.5 (about 65%) credits, respectively, can be categorized as either engineering science core or the required mathematics and science prerequisites. In addition, engineering design courses, especially capstone design, are already tasked with teaching multiple complex concepts, processes, and methodologies such as design and iterative thinking, teamwork, communication, and much more, making it difficult to address sociotechnical skills in great depth. Since students create a hierarchy of coursework with

engineering science courses on top [4], [7], such courses are arguably most pivotal in shaping their professional identity. There is a great need for interventions in sociotechnical thinking and in a method for measuring impact in the engineering sciences.

The current authors seek to address the challenge described above at University A and University B by embedding sociotechnical thinking into EE and ME courses. Courses at both universities will provide instruction using a comparable number of sociotechnical focused assignments and reflections from projects. Targeted interventions to improve sociotechnical reasoning are being developed and implemented; these interventions are described briefly below, and more detailed descriptions are planned for future dissemination. An immediate problem emerged as a result of planning the interventions: How would we know whether the students' sociotechnical thinking was impacted by these interventions? The remainder of this paper describes our key contribution: the process by which we have developed a pre- and post-survey instrument to measure shifts in sociotechnical thinking in EE and ME students in the intervention classes.

Target Population

Two courses, a first-year engineering projects course (Projects) and a third-year introductory electromagnetics course (EM), have been selected as treatment courses. The course innovations required to perform the research will impact up to 500 students per academic year across two disciplines, grade levels (first- through third-year students) and universities. The two treatment classes are being taught at University A and B, which represent different student populations. The Projects course is an introductory design course offered to all engineering students at University B, but over 50% of the students are in the ME Department. Projects students range in level, with 85% being first- or second- year undergraduates. At University A, EM is a third-year course that serves as an introduction to electromagnetic theory as applied to electrical engineering problems in wireless communications, transmission lines, and high-frequency circuit design. The theory and applications are based on Maxwell's equations, which describe the electric and magnetic force-fields, the interplay between them, and how they transport energy. This course is required for all EE students.

Proposed Interventions

Since these interventions are in the planning stages, they are proposed interventions rather than an actual account of what was implemented. To assess students' general understanding of an engineer's role, the EM course at University A currently integrates engineering applications situated in their broader context. This is accomplished by having students grapple with technical questions at home, and then structuring classroom discussions and assignments around the Engineering Grand Challenges. In this sense, engineering students identify potential stakeholders in a current problem, as well as appreciate why the problem matters and how it can be resolved. Sociotechnical thinking is also being engaged when students brainstorm in small groups on how common EM content, such as Maxwell's equations, can help address everyday problems. Several potential interventions are in the planning phase:

- Provide students with an EM-related "engineering failure," and have students examine what went wrong with the engineering design and emphasize which stakeholders were

affected by the incident. Students then work in groups to relate the incident to important EM concepts and identify salient lessons learned.

- Assign a mini-project so students can apply EM knowledge to a real(istic) scenario and the resulting consequences. Students focus on technical aspects and analyze social and technical consequences.
- Redesign classroom assessment rubrics to incorporate engineering habits of mind. Include sections for systems thinking (technical aspects), innovation (design aspects), adaptations and improvements (iterative processes), socio-cultural and ethical considerations (social aspects), communication (understanding the problem and considering multiple perspectives), collaboration (teamwork and fostering new strategies), and finally sociotechnical integration (understanding emergent factors).

The Projects course taught at University B, focuses on group work and project-based learning. Possible interventions in socio technical thinking for this course include:

- Design two workshops focusing on sociotechnical thinking to help guide students through their course projects.
- Challenge students throughout the semester with design constraints that foster sociotechnical thinking.
- Require students to keep reflection logs that document their technical and social reasoning, including for final projects.
- Structure grading to reflect the importance of sociotechnical thinking.

Sociotechnical Survey Development

The primary focus of this paper is the development of our survey instrument, which is designed to measure students' sociotechnical thinking before and after the course interventions. This survey has the following goals: (1) to quantify student self-reports on their ability to think sociotechnically, and (2) to measure students' perspectives on engineering habits of mind and the role of sociotechnical considerations in engineering practice. These goals and the theoretical framework previously discussed were used to guide our team's instrument development process.

Survey Question Generation Process

To facilitate survey development, each member of our research team reviewed our survey goals and the previous research. The research team consists of experts in sociotechnical research, engineering education and assessment, the instructors of the targeted engineering courses, and an undergraduate student who has taken EM and who will help with future course interventions and assessment. The team generated an initial list of important topics, and then collaboratively discussed these topics and extended this list as appropriate. This provided the initial framework for the generation of our survey questions.

To better understand sociotechnical habits of mind, we reviewed relevant literature. In general, *habits of mind* refers to any recurring action or activity that, through repetition, instills professional problem-definition and solving routine practices. The key question is whether those practices are effective. Whereas habits of mind encompass a broad array of actions, habits of mind related to sociotechnical thinking are more specific. The published literature accentuates

how engineering students have limited problem definition skills [4], a weakness exacerbated by the fact that (as noted in our literature review above) most problems in the bulk of the curriculum come to students well-defined, with given parameters. Since actual engineering practice often features negotiations of problem definitions between engineers and multiple stakeholders, including non-engineers [4], [24], we drew loosely from three strategies in Downey's Problem Definition and Solution (PDS) Model to assess the degree to which students account for social dimensions when defining and solving ill-structured, open-ended problems. Sample questions adapted from Downey's PDS Model include and focus on student outcomes that occur during problem definition and solution processes:

1) Knowledge Strengths and Limitations

To what degree

- a) do students identify and use both technical and non-technical bodies of knowledge?
- b) do students acknowledge the strengths and limitations of different forms of knowledge for solving diverse kinds of problems?
- c) do students recognize ambiguity and uncertainty, and what do they do when they encounter those issues?

2) Diverse Knowledge and Perspectives

To what degree

- a) do students demonstrate understanding of the importance of learning to work with people who define problems differently than they do?
- b) are project-relevant socio-cultural issues identified and used for practical reasoning?

3) Knowledge and Expertise Plurality

To what degree

- a) are students able to "function effectively as mediators among different types of engineering specialists" and non-engineers?
- b) do students render visible and legitimize "the human dimensions of engineering work alongside technical problem solving?" [4], p. 594.

These questions guided our thinking as we designed the survey instrument to assess habits of mind as they relate to sociotechnical thinking.

Next, we reviewed three assessment instruments. The first, "Assessment techniques for contextual competence: A resource for teaching and learning engineering design," included a survey to assess multiple indicators of contextual competence, including sociotechnical thinking [25]. Contextual competence refers to "the ability to recognize and consider the relevant interrelated aspects of a design problem's context, comprising the people, places, events, and socioeconomic systems that shape and are shaped by a particular engineering design process" [25], p. 3. Since this definition has significant conceptual overlaps with the definition of sociotechnical thinking, some of Atman and colleagues' survey questions were relevant to our survey. Furthermore, their survey assessment techniques were "developed on the foundation of

years of research on engineering design processes...and ha[d] been field-tested in several instructional settings” [25], p. 3.

The second assessment instrument constituted research on engineering students’ evolving engineering identities from the university to the workplace, including “how engineering students perceive social and technical dimensions of engineering ability and identity” [26], survey p. 1. This research drew from previous research, including Graziano and colleagues’ Person-Orientation/Thing-Orientation scale [27], [28]. Since sections of both assessment instruments had similar aims, we were able to use, in our survey, sometimes after minor modification, some of those authors’ assessment questions [25], [26].

The third assessment instrument was focused on students’ views of macro-ethics, specifically as they pertain to the social responsibilities of engineers and scientists [29]. This section of the survey was made up of four Likert-scale questions.

Additional survey instruments were considered for inclusion, but ultimately not incorporated for a variety of reasons. For example, Cech developed a survey instrument to longitudinally track students’ views of public welfare and the cultural emphases of their engineering education programs, to see if their beliefs about public welfare changed over time or because of the perceived culture of their educational institution [21]. We ultimately did not adapt any of Cech’s questions to our survey because capturing sociotechnical thinking, as our research sets out to do, is related but not synonymous with tracking students’ public welfare concerns, as was Cech’s aim. Another survey that we reviewed was developed by Fuentes *et al.* for use in a longitudinal study of students’ views of engineering ethics and social responsibility [30]. While references in this work pointed us to some of the instruments we ultimately adapted (those described above), we did not use any questions directly from Fuentes’s work because they did not directly measure sociotechnical thinking.

Each researcher reviewed these instruments and identified topics and questions from these instruments that aligned with our goals. These were then discussed and appropriate questions from each instrument were selected for consideration. Independently, we reviewed the resultant list and, once again, aligned the selected questions with our goals. Any questions that did not align with our goals were removed from consideration after a team discussion. When relevant, we aimed to keep all questions from these previously-developed instruments (or from the related section of the instrument), in order to maintain the survey’s validity.

We returned to our topic framework and generated original questions to address any missing topics. At this point, we had a complete list of topics and questions to be addressed through this survey. We reviewed the resultant questions and rephrased them to improve the internal consistency of the survey.

Expert Review

Our survey was presented to an expert team, consisting of members of our Advisory Committee, which consisted of engineers who have extensive experience in sociotechnical thinking and research. Feedback received from these individuals included recommendations to focus a few

questions more narrowly to our research questions, ensure the length of the survey was not excessive, increase consistency of the factors students were asked to consider across questions, and remove a set of potentially leading options from one particular question. In general, the feedback from our expert review was consistent with the recommendations stemming from the think-aloud activities with our students.

Think-Aloud Protocols

Once our initial set of questions were developed, we were ready to determine whether students interpreted our questions as intended. Using a cognitive validation process, four volunteer students, two from University A and two from University B, completed a think aloud protocol [31], [32]. Each session took 60-90 minutes and was led by one of the researchers. The student participants for the think-alouds were chosen to resemble the future research subjects for the project in terms of background demographics such as year in the program, etc. Subjects were recruited from both mechanical and electrical engineering.

The think-aloud protocol consisted of two parts. In the first few minutes of the session, the researcher provided a general introduction to the research project and the objectives of the think-aloud. Then, the students worked through the survey aloud. For each survey question, the researcher prompted the participants with questions such as:

What does this question mean to you?

Can you state this question in your own words?

Is there anything you find confusing about this question?

Why did you choose the answer you selected?

Following each think-aloud session, the researchers summarized the feedback received in a written document. When all four sessions were completed, this data was collected into a single document and used to refine the survey. Examples of changes are described below, and the full survey appears in the Appendix.

- When possible to do so without biasing responses, we clarified the meanings of or changed words that confused the students, including “manufacturability,” “multidisciplinary,” “firm” (when used as a noun), “ambiguity,” “uncertainty,” “novel” (when used as an adjective), “licensure,” and “methodologies.”
- The team used a common list of considerations for two related questions, one asking students to rate the importance of the considerations in the student’s future engineering practice and the other asking them to indicate how frequently practicing engineers incorporate such considerations. The modified list consisted of terms drawn from former ABET criteria:
 - Economic
 - Technical
 - Manufacturability

- Social
 - Environmental
 - Health and Safety
 - Ethical
- These terms were then used in a related question instead of the original, more extensive list of terms:
 - Costs/benefits, return on investment
 - Ethics
 - General economic conditions
 - Global events/trends
 - Health and safety
 - Industry events/trends
 - Natural environment
 - Political environment and events (local, regional, or national)
 - Product/service viability
 - Societal issues
 - Sustainability
 - Systems-level issues
 - User needs and interests
 - Your organization's policies, goals, or environment
 - We removed the following set of four potentially leading and clearly confusing options from a question that originally had eight options:
 - Practicing engineers who think engineering is completely technical work are a risk to the reputation of the profession.
 - Practicing engineers who think engineering is primarily technical work are a risk to the reputation of the profession.
 - Practicing engineers who think engineering is primarily sociotechnical work are a risk to the reputation of the profession.
 - Practicing engineers who think engineering is completely sociotechnical work are a risk to the reputation of the profession.
 - We combined all of the demographic questions at the end of the survey and ordered them such that the lower cognitive load questions were last.
 - We updated our set of options for gender-related demographic information based on recommendations from the Human Rights Campaign [33].

Survey Instrument

The survey that resulted from this process is displayed in the Appendix. The survey features three main sections:

- 1) questions revolving around the individual's perception of engineering practices,
- 2) questions relating to the individual's prior knowledge of engineering practice, and
- 3) demographic questions.

In section one, students are placed in the role of a future engineer and respond to questions about engineering practice. For instance, using a Likert-scale question, survey respondents rate the

importance of various given considerations in engineering practice, such as “Economic”, “Environmental”, “Health and Safety”, etc.

In section two, survey respondents answer multiple-choice questions on technical and social aspects of engineering, such as this question:

“Social responsibility is often expressed as:”

- a) Engineer’s obligations of the public
- b) Engineers using innovative experimental procedures
- c) How engineers should avoid scientific misconduct
- d) How engineers must protect their data

This question prompts respondents to consider social aspects of engineering and the possibility of it pertaining to an engineer’s role. Sections one and two end with a comment box so survey respondents can explain any prior answers or make other comments.

Section three focuses on survey respondents’ demographics and background information. Questions focus on prior engineering-related experiences (internship, etc.), post-graduation plans, major, minor, graduation date, gender, ethnicity, and international student status.

This instrument will be used as a pre- and post- assessment instrument in the Projects and EM courses in which we will embed sociotechnical thinking. The pre-administration will provide baseline evidence as to how the general population of mechanical and electrical engineers are likely to respond. Changes from pre- to post- assessment will help us understand the impact of the intervention.

Conclusion

A major challenge in engineering education is measuring the impact of instructional interventions on the target population. In our study, we seek to shift students’ perceptions of sociotechnical reasoning within engineering through a treatment delivered as part of two engineering courses. When we sought to identify a valid method for measuring change in students’ sociotechnical thinking in the research, we found none that aligned with all of our research goals. However, some instruments were aligned with a subset of the information we needed.

The development of assessment instruments is a form of research in and of itself. The start of the process is qualitative in nature. As was described here, we began the development of our survey by establishing a set of goals for our instrument. We then reviewed the research concerning sociotechnical thinking and prior instruments designed to address students’ reasoning in this area.

Our team, comprised of experts in sociotechnical research, engineering education and assessment the instructors of the targeted engineering courses, and an undergraduate researcher and EE student, selected and/or generated the desired survey questions and examined alignment with our goals. The resultant questions were revised to ensure consistency in our survey’s display and

design. Using think-aloud protocols, we determined whether the instrument was being interpreted as intended by members of the target population—mostly ME and EE students. Next, our instrument was reviewed and revised based on the feedback by experts in the field. The resultant instrument, which we will use during our first year investigation, is displayed in the Appendix.

In the next phase of instrument development, we will move from our qualitative development to our quantitative analysis. During the spring of 2018, we will pilot test this instrument on EE and ME students at both universities. Both the validity of each question and the instrument as a whole will be evaluated. A key component of this research is measuring change in student responses over time. By examining differences in scores and effect sizes, we will be able to determine the extent to which our instrument is sensitive enough to measure change over a semester. The results of the quantitative work will be the focus of future papers.

Acknowledgments

This material draws from work supported by the National Science Foundation under Grant No. EEC-1664242. 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.

Appendix

RFE Engineering Student Survey

This research team is studying sociotechnical integration in engineering education. The research is in support of a National Science Foundation research grant.

You are under no obligation to complete this survey, and your participation or non-participation will have no impact on your course grade. If you choose to participate, your responses will be anonymous. Your participation will help us to achieve the engineering education research goals.

This survey is expected to take approximately 20 minutes. By filling out the survey on paper or clicking to the next screen, you are indicating your consent to participate in the survey.

If you have any questions about the survey, please contact [blinded].

Section 1

Instructions: This set of questions asks about your perceptions of the field of engineering practice.

1. Think about **your future role** as an engineer. For each of the following, rate how important you believe each of these **skills** will be when you practice engineering as a professional. [Note: Likert scale will be available for each bulleted item.]

- Solve technical problems within familiar contexts
- Apply technical knowledge to novel contexts
- Work with people, including listening to and integrating the perspectives of both engineers and non-engineers, who define problems differently
- Approach problems which are not clearly defined or with uncertain parameters
- Identify project-relevant sociocultural issues
- Follow the rules established by local, national, and institutional authorities
- Work with people having a diverse set of backgrounds

Not at all Important	Somewhat Important	Very Important	Extremely Important
----------------------	--------------------	----------------	---------------------

2. Think about **your future role** as an engineer. For each of the following, rate how important you believe each of these **considerations** will be when you practice engineering as a professional. [Note: Likert scale will be available for each bulleted item.]

- Economic
- Technical
- Manufacturability*
- Social
- Environmental
- Health and Safety
- Ethical

Not at all Important	Somewhat Important	Very Important	Extremely Important
----------------------	--------------------	----------------	---------------------

*the ability to manufacture a given design

3. How often do you think practicing engineers incorporate each of the following **considerations** in their work? [Note: Likert scale will be available for each bulleted item.]

- Economic
- Technical
- Manufacturability
- Social
- Environmental
- Health and Safety

- Ethical

Not at all	Once or twice a year	Once or twice a month	Once or twice a week	Daily
------------	----------------------	-----------------------	----------------------	-------

*the ability to manufacture a given design

4. Based on your understanding of engineering practice, indicate the degree to which you agree with the statements below:

- Practicing engineers primarily engage in technical work.
- Practicing engineers primarily engage in nontechnical work (e.g., social, cultural, etc.)
- Practicing engineers primarily engage in sociotechnical (integration of technical and social elements) work.
- Social concerns are outside an engineer's responsibilities.

Strongly disagree	Slightly disagree	Slightly agree	Strongly agree
-------------------	-------------------	----------------	----------------

5. When solving most engineering problems in engineering practice, it is **most appropriate** to [Select one]

- Identify all of the technical considerations and separate them from the nontechnical considerations
- Recognize project-relevant interplays between technical and nontechnical considerations
- Integrate all of the technical and nontechnical considerations
- Partner with a social scientist who can handle nontechnical considerations

6. Are there any clarifying remarks you would like to make about your answers to the questions in this section?

Section 2

Instructions: This part of the survey has four questions. For each question, select the one response you think is best.

7. The most important reason that scientists and engineers have professional obligations to society is [Select one]
- Codes of ethics make mandatory statements about social responsibility.
 - Science and technology can affect the public in profound ways.
 - Licensure (the obtaining of a professional license) of scientists and engineers requires attention to social responsibility.
 - Social responsibility is required by the U. S. government.
8. Technical decisions can have long lasting social consequences because [Select one]
- Technical decisions can quickly change research methods
 - Technical decisions often result in privacy issues
 - Once technical decisions are in place, it often becomes difficult for scientists and engineers to change them
 - Technical decisions can have short-term effects on how research is carried out.
9. Social responsibility is often expressed as [Select one]
- Scientists' and engineers' obligations to the public
 - Scientists and engineers using innovative experimental procedures
 - How scientists and engineers should avoid scientific misconduct
 - How scientists and engineers must protect their data
10. Scientists and engineers have special obligations to society because [Select one]
- Scientists and engineers often have special expertise in fields that ordinary citizens do not have
 - Science and engineering research must comply with applicable environmental laws
 - Employer reputation depends on the work of scientists and engineers
 - Science and engineering research is often backed by federal funding
11. Are there any clarifying remarks you would like to make about your answers to the questions in this section?

Section 3

Instructions: this final set of questions seeks demographic and background information:

12. Relevant prior experience: have any of these experiences impacted your answers in this survey? [Select all that apply]

- Employment as an engineer or engineering intern/co-op
- Employment at a for-profit company
- Employment at a government agency (federal, state, local)
- Employment at a non-profit or NGO
- Research assistant
- Teaching assistant
- Work-study student
- University-sponsored extracurricular activities
- Other (please specify): _____
- Briefly tell how any of these experiences have impacted your perspective in this survey. [text box]

13. Future employment: immediately following graduation, which of the following are you most likely to pursue as your primary position? [Select one]

- Working for a “traditional” engineering company (at least 50% focus on engineering practice within one engineering discipline)
- Working for a multidisciplinary company (no single engineering degree field accounts for 50% or more of the company’s activities)
- Working for local, state, or federal government
- Working for a non-profit or non-governmental organization
- Entrepreneur/start your own company
- Graduate school in engineering
- Graduate or professional school in a field other than engineering
- Military service
- Other (please specify) _____

14. What is your major? [Select all that apply]

- Aerospace Engineering
- Chemical Engineering
- Civil Engineering
- Computer Science
- Engineering Physics
- Engineering Plus
- Electrical Engineering
- Mechanical Engineering
- Technology, Arts, and Media
- Other _____

15. If you have a minor, please write it here [Text box] _____

16. When do you expect to graduate? [Select one]

- | | |
|-------------------------------|-------------------------------|
| <input type="checkbox"/> 2018 | <input type="checkbox"/> 2022 |
| <input type="checkbox"/> 2019 | <input type="checkbox"/> 2023 |
| <input type="checkbox"/> 2020 | <input type="checkbox"/> 2024 |
| <input type="checkbox"/> 2021 | |

17. From which university do you expect to graduate in the year you selected?

- [University A]
- [University B]
- Other: _____
- Prefer not to answer

18. What is your gender? [Select all that apply]

- Male
- Female
- Female-to-Male Transgender
- Male-to-Female Transgender
- Non-binary/third gender
- I prefer to self-describe: _____
- I prefer not to respond

19. How would you describe yourself? [Select all that apply]

- African American
- Native American Indian
- East Asian
- South Asian
- Hispanic
- Native Hawaiian
- White
- Multi-racial
- Other: _____
- I prefer not to respond

20. Are you an international student? [Select one]

- Yes
- No
- Other: _____
- I prefer not to respond

References

- [1] J. Trevelyan, "Towards a theoretical framework for engineering practice," in *Engineering practice in a global context: Understanding the technical and the social*, Boca Raton, FL: CRC Press, 2013, pp. 33–60.
- [2] J. P. Trevelyan, *The making of an expert engineer: how to have a wonderful career creating a better world and spending lots of money belonging to other people*. Leiden, The Netherlands: CRC Press, 2014.
- [3] R. Stevens, A. Johri, and K. O'Connor, "Professional Engineering Work," in *Cambridge handbook of engineering education research*, New York: Cambridge University Press, 2014, pp. 119–137.
- [4] G. Downey, "Are engineers losing control of technology?: From 'Problem Solving' to 'Problem Definition and Solution' in engineering education," *Chemical Engineering Research and Design*, vol. 83, no. 6, pp. 583–595, Jun. 2005.
- [5] D. H. Jonassen, "Engineers as problem solvers," in *Cambridge Handbook of Engineering Education Research*, New York, NY: Cambridge University Press, 2014, pp. 103–118.
- [6] J. Huff, "Humanizing Signals and Systems: A Reflective Account," in *ASEE Annual Conference and Exposition*, Seattle, WA, 2015.
- [7] J. C. Lucena and J. A. Leydens, "From sacred cow to dairy cow: Challenges and opportunities in integrating of social justice in engineering science courses," in *American Society for Engineering Education Annual Conference Proceedings 2015*, Seattle, WA, 2015.
- [8] J. Leydens and J. Lucena, *Engineering justice: Transforming engineering education and practice*. Hoboken, NJ: Wiley-IEEE Press, 2018.
- [9] National Science Foundation, "Research in the Formation of Engineers (RFE)," 2018. [Online]. Available: https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503584. [Accessed: 05-Feb-2018].
- [10] W. Faulkner, "Dualisms, Hierarchies and Gender in Engineering," *Social Studies of Science*, vol. 30, no. 5, pp. 759–792, 2000.
- [11] E. A. Cech, "The (mis)framing of social justice: Why ideologies of depoliticization and meritocracy hinder engineers' ability to think about social injustices," in *Engineering education for social justice: Critical explorations and opportunities*, J. C. Lucena, Ed. Dordrecht; New York: Springer, 2013, pp. 67–84.
- [12] W. E. Bijker, T. P. Hughes, and T. J. Pinch, *The social construction of technological systems: New directions in the sociology and history of technology*. MIT Press, 1987.
- [13] National Academy of Engineering., *Grand challenges for engineering*. [Washington, D.C.]: National Academies, National Academy of Engineering, 2008.
- [14] E. Cech, "Great Problems of Grand Challenges: Problematizing Engineering's Understandings of its Role in Society," *IJESJP*, vol. 1, no. 2, pp. 85–94, Nov. 2012.
- [15] J. R. Herkert and D. A. Banks, "I Have Seen the Future! Ethics, Progress, and the Grand Challenges for Engineering," *IJESJP*, vol. 1, no. 2, pp. 109–122, Nov. 2012.
- [16] D. Nieuwsma and X. Tang, "The Unbalanced Equation: Technical Opportunities and Social Barriers in the NAE Grand Challenges and Beyond," *International Journal of Engineering, Social Justice, and Peace*, vol. 1, no. 2, pp. 137–151, 2012.

- [17] D. Riley, "We've Been Framed! Ends, Means, and the Ethics of the Grand(iose) Challenges," *IJESJP*, vol. 1, no. 2, pp. 123–136, Nov. 2012.
- [18] A. E. Slaton, "Engineering Improvement: Social and Historical Perspectives on the NAE's 'Grand Challenges,'" *IJESJP*, vol. 1, no. 2, pp. 95–108, Apr. 2012.
- [19] O. Pierrakos, E. Pappas, R. Nagel, and J. K. Nagel, "A new vision for engineering design instruction: on the innovative six course design sequence of James Madison University," in *Proceedings of the American Society for Engineering Education Annual Conference and Exhibition*, 2012.
- [20] G. L. Downey and J. C. Lucena, "When students resist: Ethnography of a senior design experience in engineering education," *International Journal of Engineering Education*, vol. 19, no. 1, pp. 168–176, 2003.
- [21] E. A. Cech, "Culture of Disengagement in Engineering Education?," *Science Technology Human Values*, vol. 39, no. 1, pp. 42–72, Jan. 2014.
- [22] D. Riley, *Engineering and social justice*. San Rafael, Calif.: Morgan & Claypool, 2008.
- [23] R. Adams *et al.*, "Multiple Perspectives on Engaging Future Engineers," *Journal of Engineering Education*, vol. 100, no. 1, pp. 48–88, 2011.
- [24] G. L. Downey, "PDS: Engineering as Problem Definition and Solution," in *International Perspectives on Engineering Education*, S. H. Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, and B. Newberry, Eds. Springer International Publishing, 2015, pp. 435–455.
- [25] C. J. Atman, K. Yasuhara, and D. Kilgore, "Assessment techniques for contextual competence," University of Washington, Seattle, WA, Technical Report 14–03, 2014.
- [26] J. Huff, "Psychological Journeys of Engineering Identity from School to the Workplace: How Students Become Engineers Among Other Forms of Self," Ph.D. Dissertation, Purdue, West Lafayette, Indiana, 2014.
- [27] Ngambeki I.B *et al.*, "Person-thing orientation as a predictor of engineering persistence and success," *ASEE Annu. Conf. Expos. Conf. Proc. ASEE Annual Conference and Exposition, Conference Proceedings*, 2011.
- [28] W. G. Graziano, M. M. Habashi, D. Evangelou, and I. Ngambeki, "Orientations and motivations: Are you a 'people person,' 'thing person,' or both?," *Motivation and Emotion*, vol. 36, no. 4, pp. 465–477, 2012.
- [29] Heather E. Canary, Julie L. Taylor, Joseph R. Herkert, Karin Ellison, Jameson M. Wetmore, and Carlos A. Tarin, "Engaging Students in Integrated Ethics Education: A Communication in the Disciplines Study of Pedagogy and Students' Roles in Society," *Communication Education*, vol. 63, no. 2, pp. 83–104, 2014.
- [30] Fuentes D.S, Warnick G.M, Jesiek B.K, Davies R, and 123rd ASEE Annual Conference and Exposition, "A longitudinal study of social and ethical responsibility among undergraduate engineering students: Preliminary results," *ASEE Annu. Conf. Expos. Conf. Proc. ASEE Annual Conference and Exposition, Conference Proceedings*, vol. 2016-June, p. 2016, 2016.
- [31] S. A. Karabenick *et al.*, "Cognitive Processing of Self-Report Items in Educational Research: Do They Think What We Mean?," *EDUCATIONAL PSYCHOLOGIST*, vol. 42, no. 3, pp. 139–151, 2007.
- [32] Trenor J.M, Miller M.K, Gipson K.G, and 118th ASEE Annual Conference and Exposition, "Utilization of a think-aloud protocol to cognitively validate a survey instrument identifying social capital resources of engineering undergraduates," *ASEE Annu. Conf.*

Expos. Conf. Proc. ASEE Annual Conference and Exposition, Conference Proceedings, 2011.

- [33] Human Rights Campaign, “Collecting Transgender-Inclusive Gender Data in Workplace,” *Human Rights Campaign*, 2016. [Online]. Available: <http://www.hrc.org/resources/collecting-transgender-inclusive-gender-data-in-workplace-and-other-surveys/>. [Accessed: 21-Apr-2018].