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Rapid Assessment Procedure as a Tool for Front-End Stakeholder Needs Analysis in Engineering Projects

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ABSTRACT Front-end stakeholder needs analysis is increasingly recognized as an essential component of sustainable engineering projects, yet most engineering curricula only cover this topic superficially. Fields such as humanitarian engineering have long recognized the importance of stakeholder needs analysis for the success of development interventions, and researchers have developed best practice frameworks for engaging stakeholders that can be applied to systems engineering. These frameworks rely on established social science techniques, such as ethnography and inductive reasoning, and humanitarian engineering principles, such as contextual listening and sociotechnical thinking, to facilitate comprehensive needs assessments. While conventional ethnographies are often incompatible with engineering projects’ timelines and expertise, anthropologists have developed methodologies to overcome these limitations, such as rapid assessment procedure. While widely applied in the public health sector, rapid assessment procedure has been seldom integrated with engineering projects. Rapid assessment procedure, combined with humanitarian engineering principles, can help researchers quickly gain a nuanced understanding of relevant aspects of complex sociotechnical systems. This article seeks to introduce systems engineers to humanitarian engineering rapid assessment procedure as a concrete technique for conducting comprehensive front-end stakeholder needs analysis. In this article, a case study is presented on the teaching and implementation of humanitarian engineering rapid assessment procedure in a workshop with a group of undergraduate engineering students. We sought to analyze students’ perceptions of and learning outcomes from the workshop. Student engagement and learning exceeded expectations, positioning humanitarian engineering rapid assessment procedure as a potentially valuable tool for systems engineers to analyze stakeholder needs to inform system design.

INDEX TERMS Community-based research, engineering education, humanitarian engineering (HE), rapid assessment procedure (RAP), stakeholder needs analysis.

I. INTRODUCTION

The failure of engineering projects is increasingly attributed to complex social, cultural, economic, and political factors that engineers are rarely equipped to analyze as thoroughly as technical issues. Researchers and practitioners have long recognized that “decisions made in the early stages of a project have the most influence on the time, cost, and quality outcome” [1, p. 3], and moreover, that comprehensive stakeholder needs analyses can help resolve “ill-defined and conflicting needs” [2, p. 1] in complex engineered systems, such as software design [3], [4] and construction projects [2], [5]. Thus, the reported “systems-centric rather than user-centric view” [6] in systems engineering has led to calls for more concrete methodologies and frameworks to help engineers engage in comprehensive front-end stakeholder needs analysis. In engineering and project management, the "front-end" of a project is generally defined as the "phase of a project [when] the project idea is conceived [which] ends when the final decision to finance the project is made" [7, p. 1].

Comprehensive front-end stakeholder needs analysis must recognize stakeholders more broadly beyond individual clients [6], for instance, "people, groups, or organizations that are actively involved in a project, *are affected by its outcome*, or can influence its results [emphasis added]" [4, p. 210]. Fields such as humanitarian engineering (HE) have developed their own frameworks for stakeholder needs analysis that 1) include wider, often marginalized communities affected by engineering interventions [8], [9], [10] and 2) recognize the intertwined social and technical dimensions of engineering projects, or what scholars call "sociotechnical" [11]. This HE approach has resulted from decades of failures in humanitarian projects [12]. Engineers Without Borders USA estimated that 12% of the 190 projects they were monitoring in 2016 were "nonfunctional," 22% of projects were not maintained by communities, and 13% of projects were located in communities that lacked the capacity of sustaining projects in the future [13, p. 6]. These failures can be partially attributed to insufficient front-end analysis, such as "problematic assumptions about technology's role in community development [that] fail to grapple with the broader forces that direct—implicitly or explicitly—most development interventions" [14, p. 30]. For example, Young et al. [15] analyzed a case in Bhutan in which distributed renewable energy was found to be technically feasible but would "only be successful if there [was] broad community support for and understanding of the new system." Moreover, "the detailed design of any system will depend not only on the physical nature of local resources but also on the outcome of such community engagement" [15, p. 1008]. These concerns, which are commonly labeled as "nontechnical" but are better understood as sociotechnical, as described as follows, can include cultural norms, political systems, power dynamics between stakeholder groups, environmental factors and constraints, poverty, gender roles, histories of colonization and oppression, and so on. By starting with a preliminary understanding of the wider social context of stakeholder groups, engineers may uncover sociotechnical factors that play a significant role in the technical design or project management approach. These lessons on stakeholder needs analysis from HE may benefit other fields such as systems engineering.

Rather than reinventing the wheel, engineers can adopt established tools from other fields for front-end needs analysis. HE frameworks for best practice, such as Engineering for Sustainable Community Development [9], Engineering for Social Justice [8], [16], and Socially Responsible Engineering [10], rely on qualitative social science tools to realize a practice that is crucial to front-end stakeholder analysis: "contextual listening." Contextual listening is defined by Lucena et al. as:

> "...a multidimensional, integrated understanding of the listening process wherein listening facilitates meaning-making, enhances human potential, and helps foster community-supported change. In this form of listening, information such as cost, weight, technical specs, desirable functions, and timelines acquires meaning only when the context of the person(s) making the requirements (their history, political agendas, desires, forms of knowledge, etc.) is fully understood" [9, p. 125].

The process of contextual listening may shift the way engineers view people—not only as stakeholders but as citizens and members of larger systems [17]. This has the potential of ultimately enhancing the needs analysis process while building trust with communities [18]. To conduct contextual listening, anthropological methods are especially helpful, as explained in the following section.

In this article, we propose rapid assessment procedure (RAP) as a concrete strategy to formalize the activities of front-end stakeholder needs analysis. RAP is an established, mixed-methods tool widely used in anthropology and public health, yet seldom applied in engineering studies, that facilitates contextual listening, the bedrock of robust front-end stakeholder analysis. In our research project, we infused RAP with the HE principles described above, henceforth referring to the methodology as HE-RAP. We draw from our experiences teaching HE-RAP to engineering students in an intensive summer fieldwork session. In this article, we investigate the following research questions. 1) How did engineering students perceive the HE-RAP tool? 2) In what ways did students consider the sociotechnical dimensions of front-end stakeholder needs analysis during the HE-RAP training?

II. BACKGROUND: HUMANITARIAN ENGINEERING–RAPID ASSESSMENT PROCEDURE

Anthropology is a field that has the power to provide meaningful data for front-end needs analysis, given that it can provide insights into stakeholders' views and actions, including "the concepts and premises that underlie what people do – but that they are often unaware of" [19, p. 129]. This is fundamental for contextual listening as well, in which the goal is to not only understand what stakeholders' needs are, but why those needs exist in the first place. Ethnography is the main tool used by anthropologists to elicit these insights—an approach that consists of extended time immersed in the field with stakeholders conducting interviews and observations and iteratively generating and interpreting qualitative data through the lenses of ethnographic theory. While nonanthropologists may view ethnography as " 'just talking to people and reporting what they say,'...this is no more the entire task than system building is 'just typing' or medical diagnosis is 'just talking to patients' " [19, p. 131]. As such, engineers rarely possess ethnographic expertise and lack "the time [and] financial resources to engage in a traditional, lengthy ethnography" [20, p. 71], which can last up to years.

Fortunately, anthropologists have developed modified, rapid ethnographies that are accessible to nonanthropologists and can generate rich, targeted assessments of stakeholder needs in shorter periods of time. RAP is one such tool. RAP allows for relatively quicker ethnographic fieldwork by narrowing the research scope, relying on research teams, and employing multiple methods [21], [22], [23]. Fieldwork is usually conducted over a few days to a few weeks [24] by interdisciplinary teams of professionals as well as members of the target community itself, as compared to a single ethnographer in traditional ethnography. Data triangulation is a key component of RAP in which various observers use multiple methods to study the same phenomenon and then corroborate their findings [25]. While there is much flexibility in this mixed-methods approach, common RAP methodologies include interviewing, observation, surveys, and even GIS mapping [20], [24], [26], [27], [28]. Although anthropological expertise is invaluable in implementing RAP, a shortage of qualified professionals (especially in the rural healthcare settings where this tool was developed) coupled with economic and time constraints has resulted in RAP methodologies being streamlined and made explicit for nonanthropologists [22]. As such, RAP is "designed to produce highly focused sets of information and neither replace[s] nor render[s] redundant other longer term, more comprehensive research" [22, p. 839]. Conveniently, there are decades of literature and manuals published on best practices for RAP and similar techniques [21], [24], [29], [30].

RAP was initially developed for global public health interventions due to a "sense of the urgency for social science input in disease control programs," [22]. While RAP has been used primarily in health care studies [22], [23], [31], [32], [33], its utility for any project that relies on social context and stakeholder analysis has made it applicable to fields such as water and sanitation [26], [34], agriculture [27], [35], behavioral change [28], educational equity [36], disaster preparedness during COVID-19 [37], and urban park planning [38], to name a few. Although it is rare for RAP to be integrated with engineering studies, there are some notable exceptions. Burleson et al. [20] utilized a student-led RAP to investigate the end-user experience with a new stove technology in Uganda. Through interviews, participant observation, and focal tracking the researchers identified social barriers to the implementation of this technology. Sadler et al. [24] applied RAP to multiple U.S. military sites to assess the user experience with new collision-avoidance technology, utilizing in situ semistructured interviews, note-taking, and online surveys. In both studies, RAP revealed how key stakeholders perceived and interacted with engineered systems. Although these examples are steps forward for the integration of rapid ethnography, engineering, and stakeholder analysis, they do not align with HE frameworks or systems engineering objectives that prioritize stakeholder needs from the front-end of a project.

In our teaching, we use RAP as a tool for front-end stakeholder needs analysis that centers the HE practice of contextual listening (HE-RAP). This transdisciplinary work requires engineers to shift from "technically narrow" to "sociotechnical" thinking and from "deductive" to "inductive" reasoning. A narrow technical mindset assumes that technology and analytical approaches alone can solve problems [39]. An overreliance on technical approaches, such as the Engineering Problem Solving method, [40], [41] in engineering education may hinder engineering students' "abilit[ies] 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…we do not learn, with any depth, critical approaches from the humanities and social sciences" [39, p. 41]. A sociotechnical approach, however, not only recognizes that "social" factors are as important as "technical" ones, but rather that two cannot be separated, as "the technical is always already inherently social and vice versa" [11, p. 14], [42]. To give a concrete example, in Gibson's thesis research, they found that hydrological systems in rural Colombia are mutually shaped by climate change, agricultural livelihood decisions, and technologies such as chemical fertilizers and machinery [43]. The concept of sociotechnical integration is well represented by Fig. 1 and text from Smith et al. [11], in which holistic sociotechnical thinking is portrayed in the fourth image.

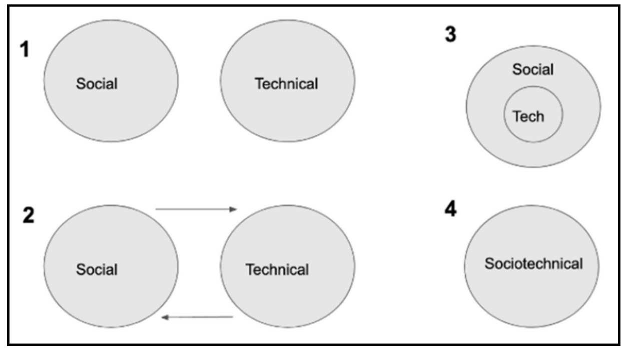

FIGURE 1. **"1. Recognition that engineering has both social and technical dimensions. 2. Recognition that the social and technical dimensions of engineering influence each other. 3. A social analysis of a technical issue. 4. Recognition that the social and technical dimensions of engineering necessarily imply and co-constitute each other: what appears to be technical is actually always social, and vice versa" [11, p. 14].**

For engineers engaging in anthropological, community-based work, it is critical to not only shift one's mindset but also the research approach. Deductive research, characteristic of the natural sciences and certain branches of social sciences, involves starting with a general principle and applying it to a specific case, while inductive reasoning, used by anthropologists and other social scientists, involves starting with specific observations and arriving at a general conclusion [44]. In other words, in inductive research "where to look next depends on what was just uncovered" [45, p. 12], as opposed to much scientific/engineering research that follows more linear processes such as the engineering design process or the scientific method. In HE-RAP, this inductive process is realized through semistructured lines of questioning (versus preformulated surveys, for instance), in which there is sufficient space for stakeholders to bring up opinions and concerns that may not have been anticipated by engineers, and for the project to adapt accordingly. In summary, these HE principles require engineers to recognize that 1) a purely technical, linear approach is insufficient to holistically define and solve problems and a sociotechnical approach is needed, and 2) that engineers can benefit from incorporating inductive approaches to contextual listening that allow stakeholders, especially marginalized groups, to express their own needs, concerns, and priorities.

The ability for HE-RAP to embody these HE principles and facilitate robust contextual listening hinges greatly on the *types of questions* that researchers ask. Intentional, robust question design in interviews is a significant part of what makes ethnography deeper than "just talking to people" [19, p. 131]. Anthropologists dedicate years of study and practice to develop expertise in the use of ethnographic questioning techniques, as well as complementary skills such as rapport and trust building with participants [46]. As this study was simply an introduction to these concepts, the question types and definitions summarized in Table 1 are by no means exhaustive. Moreover, all question types serve distinct purposes and, therefore, are not inherently "good" or "bad" if used intentionally by an experienced ethnographer. For instance, ethnographers discourage the use of highly structured interviews and surveys (especially in the initial stages of an investigation) because preformulated questionnaires often "ask the wrong questions" [19, p. 131]. Yet more closed-ended questions can be important for determining baseline constraints. Both "knowledge" and "attitude" questions can be useful in ethnographic interviewing, as they can provide insight into a person's understanding of a topic as well as their perspective on it, respectively. But for the sake of this introductory workshop and to encourage engineers to diverge from conventional engineering mindsets, we steered engineering students toward "open," "nonleading," "attitude," and "sociotechnical" question types. These are based primarily on ethnographic literature by the authors in [46] and [47], while the frameworks for sociotechnical questions draw on the work of Smith et al. [11].

TABLE 1. Descriptions of Question Types

Question type	Description	Example
Closed	"Yes/no" questions or questions that only require a one-word answer. These often preclude inductive data generation and reify the assumption that engineers already know what information to look for.	Do you like your job?
Open	Encourage stakeholders to elaborate on their own thoughts and experiences.	Can you describe your job to me?
Leading	Influence or encourage a desired response. Also preclude the organic and inductive sharing of stakeholders' opinions, and steer the conversation toward the priorities and opinions of the interviewer.	What is your favorite thing about this new development project?
Non-leading	Neutral question that allows respondents to freely express their opinions without being influenced by the wording of the question. Facilitate the inductive process.	What do you think of this new development project?
Knowledge	Used to gather information about a person's factual knowledge or understanding of a particular topic.	How many people work here?
Attitude	These are designed to elicit more subjective responses that reflect the respondent's personal beliefs, values, and attitudes.	What do you think of the working conditions?
Technical	Specific, often "closed" questions regarding technical specifications, materials, costs, labor practices, etc.	How much does plywood cost?
Social	Questions about relationships, socio-cultural-political systems, or personal experiences not directly related to technical systems.	How are decisions made in your community?
Socio-technical	Questions that acknowledge the inherent inextricability of social and technical systems, rather than viewing them as separate.	What materials are available, affordable, and culturally acceptable to build with here?

III. METHODOLOGY

All research was approved by the human subjects committee at the Colorado School of Mines and required strict confidentiality of the student participants and community stakeholders, thus precluding a more detailed ethnographic analysis of individual students and stakeholders that would compromise their anonymity.

A. WORKSHOP LECTURE

HE-RAP was taught to undergraduate engineering students participating in a two-week immersive summer session in which they designed low-cost equipment for Colombian artisanal and small-scale gold mining (ASGM) communities as a part of a larger interdisciplinary, international research collaboration between U.S. and Colombian universities. Due to the COVID-19 pandemic, the collaboration between U.S. students and Colombian ASGM communities was done virtually; however, students and professors from multiple participating U.S. institutions were able to meet in-person in Gunnison, Colorado where the HE-RAP workshop took place in July of 2021. The goal of hosting an in-person HE-RAP workshop was to equip the students with concrete tools to better engage (virtually) with the Colombian stakeholders in the design of ASGM tools. The student participants consisted of 12 undergraduate engineering students, six of whom provided informed consent for their data to be used in the present study.[1] The participating students were entering either their junior or

[1]The others could not consent due to policies internal to their institution that prevented them from doing so.

TABLE 2. Summary of HE-RAP Workshop Activities

Activity	Location	Time	Description
Lecture			
PowerPoint presentation by Gibson	Classroom	45 min	Interactive introduction to HE and anthropological frameworks; ethnography and RAP; and interviewing, observation, and archival research methodologies.
Mini-HE-RAP			
Divide into team design research plan	Classroom	15 min	Teams of three self-select “interviewer,” “observer,” and “archival researcher.” Brainstorm questions, points of observation, & potential archives. Review with professor or graduate student.
Fieldwork	Downtown Gunnison, near campus	1 h	Groups accompanied by professors and graduate students select stakeholders on the street to interview and observe. Archival researchers find and take notes on archival sources. Start with the question “why are people in Gunnison?,” but allow for the data to guide the lines of inquiry (inductive approach).
Data triangulation amongst teams	Classroom	15 min	In the groups of three, the interviewer, observer, and archival research discuss their findings and corroborate data, as well as interrogate any differences in findings.
Research dissemination and group discussion	Classroom	15 min	Discussion amongst everyone present. Groups share their findings with one another and discuss interesting experiences from the exercise itself.
Post-Workshop Assessment			
Writing prompts	Home	Varied but intended to be less than 30 min	Students were given four questions (see Table III) to evaluate their perceptions of the HE-RAP workshop as well as to generate questions for the upcoming (virtual) community visit with Colombian stakeholders. The responses were anonymized.

senior years and studied either chemical, civil, geological, or general engineering. Some participants were pursuing an HE minor. Five identified as female and one identified as male. None of the participants were members of the communities they were working with, although three out of six did speak Spanish as their native language, which facilitated communication with Colombian stakeholders. None of the students had studied ASGM systems prior to the summer field session. It should be noted that all students self-selected to participate in this summer course with the explicit knowledge that they would be learning and applying social science techniques for stakeholder needs assessment and HE community-based design. Given the relatively small number of students, caution is called for in generalizing the results of this study. The workshop instructor, Gibson, was an M.S. student in the HE program who had previously studied and implemented HE-RAP in their own fieldwork. The workshop was also attended by the U.S. graduate student observers and professors trained in community-based research from both social science and engineering disciplines.

HE-RAP was taught by Gibson to the students on one day at the end of the first week of the summer session during a 2.5 h workshop (see Table 2). In the workshop, students were first given an interactive lecture on HE frameworks, ethnography, and RAP. Because HE-RAP requires multiple research techniques, three ethnographic methodologies were presented in the lecture: semistructured interviewing, observation, and archival research. In the interviewing portion of the lecture, students were taught how to design different types of robust interview questions to elicit specific information according to the ethnographic interviewing strategies in [46] and [47] (see Table 1).

The lecture also included an overview of ethnographic observation strategies to combine with interviewing that focused on analyzing cues such as body language, tone and speed of speech, emotive expressions, and groupings of people using observational strategies outlined by Emerson et al. [48]. Students were asked to practice making observations about the social dynamics in the classroom itself with prompts such as “observe where people are sitting in this classroom, what this might tell us about social structure and status?”

For the archival research portion, we presented various examples of text sources outside of academic literature and newspaper archives, such as social media posts and memes, that can provide insightful social data. Students were asked to practice generating social observations from these images as well. The presentation was interactive, and students were continually encouraged to ask questions and practice the presented methodologies.

B. PRACTICE MINI-HE-RAP

In the following section of the workshop, students conducted a hands-on “mini-HE-RAP” exercise in order to give them practice with HE-RAP before interacting virtually with the Colombian stakeholders. They completed the mini-HE-RAP in the U.S. city where the workshop was held. Because travel to Colombia itself was not possible, Gunnison, Colorado was chosen due to its deep connections with mining livelihoods. In the mini-HE-RAP, students were prompted to investigate stakeholder ties to the local region with the broad “research”

TABLE 3. Data Sources and Strategies for Analyzing Student Perceptions of RAP (Q1) and Their Ability to Think Sociotechnically (Q2)

Data Source	Description	Analytical Strategy
Student lecture notes	Notes taken by students during the PowerPoint lecture. No instructions were given on how to take notes.	Analyzed which topics and keywords they from the lectures students considered important enough to write down.
Student mini-HE-RAP notes	Notes taken by students during the mini-RAP including their research plans, notes from the field interviews, observations, and archival research, as well as triangulated observations shared in the group discussion.	Analyzed the prefieldwork research plan and adherence to principles from lecture, which details from fieldwork students made notes of (demographics, body language, specific responses, etc.), and sociotechnical nature of triangulated observations
Video/audio recordings	A laptop with a webcam recorded video and audio of the in-classroom portions of the workshop.	Videos/audio were reviewed and notes taken. Transcription software not used due to background noise. Analyzed for evidence of student participation, understanding or confusion. Evidence of sociotechnical thinking noted based on sociotechnical frameworks from Smith et al. [11] (Figure 1).
Graduate student observations and notes	Notes taken by graduate student observers in both the classroom and during the mini-HE-RAP outside of the classroom. All observers had previously received sociotechnical and community-based research training (unrelated to HE-RAP workshop) that included ethnographic observation.	Graduate students were instructed to observe and make notes on student participation and engagement with the activity following a strategy based on Emerson et al. [48].
Post-workshop writing prompts for students	Take-home prompts with these four questions: ● *How do you expect to use these RAP methods in future engineering projects related to community engagement?* ● *Which methods do you think are least relevant or still confusing? Why?* ● *Which of these RAP methods will be most useful in the ASGM community visit (Monday)?* ● *List 3 questions that you can ask mining community members during the community visit on Monday.*	Student responses were analyzed using thematic analysis [49] to identify perceived benefits and shortcomings of the RAP methodology. Interview questions generated by students in the final prompt were analyzed in terms of their adherence to the different question types by Warren and Karner, Smith, and Spradley [11], [46], [47] taught in the workshop.

question: "why are people in Gunnison?" This general prompt was intended to serve as a starting point for students to practice stakeholder assessment and sociotechnical analysis in an inductive manner. The students left the classroom to talk to people on the street in Gunnison and collect data, which they then triangulated in groups to generate sociotechnical observations. These observations served as the foundation for a sociotechnical thought experiment that arose organically out of the group discussion and was guided by the workshop facilitator. In this thought experiment, students imagined that they were mining engineers establishing a new project in Gunnison and discussed the sociotechnical factors uncovered through the mini-HE-RAP that would influence the front-end design and project management decisions for this hypothetical mine. Finally, students were assigned a short writing prompt to complete after the workshop (described in the following section).

C. DATA COLLECTION AND ANALYSIS

Multiple methods, data sources, and analytical strategies were utilized to answer our research questions, as summarized in Table 3.

While this workshop was a preparatory exercise for students' upcoming virtual community visit with Colombian stakeholders, an assessment of the actual interactions with those stakeholders and the development of prototypes was beyond the scope of this study, as these were outcomes of the more comprehensive two-week summer session. Publications focusing on the broader summer course can be found in [50] and [51]. That said, as given in Table 3, the questions students generated for Colombian stakeholders in the postworkshop prompts were within the scope of the HE-RAP workshop and are analyzed in detail in Section IV in order to evaluate students' preliminary attention to front-end sociotechnical factors.

IV. RESULTS

A. STUDENT PERCEPTIONS OF HE-RAP

In the postworkshop written reflections, students unanimously acknowledged the utility of HE-RAP for analyzing community stakeholder needs to inform a complex, systems-oriented engineering design. Participant 1 wrote that they "expect to [use] RAP methods to find out what [stakeholders] really want and need instead of just gathering data on them." Participant 2 wrote that in the future, they would "use RAP as a tool to approach community problems in a more integrated way considering social and technical factors …RAP helps us to analyze problems in a way that we are aware of the many factors that should be considered while designing a solution, especially in community engagement." The students' commentary during the lecture and their written responses demonstrated that they all valued the importance of social factors in designing technical systems. Participant 6 wrote that through RAP, "I will be able to include community knowledge in engineering design and decision making. I will be able to access information that would have otherwise been missing in a purely technical study." Beyond engineering project success, four out of six students described stakeholder needs assessment through HE-RAP as a way for engineering projects to actually help communities, aligning with best practice frameworks from HE. Participant 1 wrote: "[RAP] will be very helpful to gain insight on what techniques will positively impact the community," and Participant 5 wrote that "the data gathered in the RAP would be analyzed in order to determine whether or not the project is helpful for that community." Participant 6 acknowledged the temporal benefits of HE-RAP versus conventional ethnography, stating that HE-RAP "allow[s] for a better understanding of community perspective and social development, particularly because it will be difficult to justify an extensive ethnographic study in most cases." Participant 3 went so far as to question "why they do not do RAP in normal engineering projects. I understand there are time limits and budget constraints, but RAP is a much quicker way to do ethnography—why have engineering firms failed to integrate this into their standard procedures? Do you think they ever will?" These responses indicate that students conceptualized ASGM as a complex sociotechnical system in which stakeholder needs analysis was critical for successful design, and that HE-RAP was a helpful tool to assess those needs.

We also found that students could identify specific HE-RAP techniques that would be useful to them in their studies and future careers. This required students to distinguish between the different ethnographic methods presented in the lecture and their utility in distinct situations. Two out of six respondents expressed that all of the presented methods were "helpful in unique ways" (Participant 6). As far as which methods were considered to be most useful for their specific projects, the students had distinct responses and justifications (see Table 4). These responses indicate that students prioritized building trust with community stakeholders and assessing their needs inductively. They emphasized the importance of a holistic understanding of systems to design helpful and stakeholder-appropriate engineering solutions. Two participants (1 and 6) recognized the limits of virtual collaboration with stakeholders as opposed to traditional, in-person ethnography. Students' lecture notes further corroborated their understanding of the different methods. For instance, Participant 3 noted that "engineers usually go for knowledge questions," something that was not explicitly stated in the lecture, indicating not only an understanding of what "knowledge questions" are, but also comprehension of the specific ways they have been trained as engineers that differ from anthropologists, for instance.

Two participants expressed concerns in the written prompt on which HE-RAP methods were "least relevant" or confusing, with Participant 6 stating that "I think that RAP methods are all helpful in unique ways, although the use of archival research is heavily dependent on the availability of archives to study. If this is not available, this method is not relevant." Indeed, in the post-mini-HE-RAP group discussion (analyzed as follows), the conversation was dominated by discussions of the interviews and observations rather than archival findings.

TABLE 4. "Most Useful" HE-Rap Techniques Identified by Students

Participant	"Most useful" technique from RAP	Justification
1	Rapport building	"Since we do not have boots on the ground, we will have to focus extra hard on getting the community to trust us."
2	Open-ended questions	"...let the community tell us about themselves, to tell us about their necessities, their day to day life and with that in mind create prototypes that solve a current problem."
3	Contextual listening	"Staying attentive and receptive to the answers of ASGM community members will help build a rapport with them...to fully understand what challenges and benefits the community members experience during their ASGM processes."
4	Open/closed questions mix	"I will use the open-ended questions to know more about them and how they work and what can benefit them, and for closed it would be a little bit more technical…for knowing particular information that I think is relevant for the project."
5	Open-ended questions	"...that would give us an opportunity to have a better understanding of their culture, community and their job. An open-ended question would allow the stakeholders to explain anything they want to us depending on the question asked."
6	Interviewing and observation	"...they are the easiest to do in a virtual setting."

Participant 5 wrote that "leading and nonleading questions are kind of confusing for me. Are they like open- and closed-ended questions?" This uncertainty expressed by Participant 5 was corroborated by the analysis of the questions designed by students (described as follows) in which students posed several "closed" and "leading" questions for Colombian stakeholders despite being advised to steer toward "open" and "nonleading" questions. Therefore, future HE-RAP training could provide more extensive instruction on the different question types and their purposes, as discussed further in the following.

Observational notes of student participants by graduate student observers also corroborated their self-reported assessments of the HE-RAP tool. Student engagement with the workshop exceeded expectations, with one workshop observer noting that the students "seem energized [and] excited," they "engaged with each other, [and] nobody [was] just zoned out…everyone [was] really interested in responding" to the questions and prompts. An observer commented to Gibson that this workshop was the "most engaged students ha[d] been all week." Although students initially appeared hesitant to answer questions in the lecture related to unfamiliar ethnographic methods, they "participat[ed] even if [they were] uncertain." For instance, the video and audio recordings of the lecture revealed how students engaged in the critical observation of stakeholder dynamics in the room when prompted. One student observed that the students were majority women, leading to a group-wide discussion about how gender dynamics related to interests in community-based projects. Another student analyzed the physical separation of professors, graduate students, and undergraduate students in the room as a reflection of power dynamics amongst these stakeholder groups. This engagement also demonstrates students' willingness to think deeply about social factors, as examined in the discussion. A workshop observer recorded in their notes increased participation and relaxation when the methodologies were made relatable to the students, such as analyzing memes as examples of unique sources of archival social data. From the recordings, student participation notably increased during the triangulation/group discussion portion of the workshop (post-mini-HE-RAP) as compared to the lecture portion, indicating that students were energized by the opportunity to get out of the classroom and practice the HE-RAP skills in a "real-world" context.

B. STUDENTS' ABILITIES TO CONSIDER THE SOCIOTECHNICAL DIMENSIONS OF FRONT-END STAKEHOLDER NEEDS ANALYSIS

1) MINI-HE-RAP IN GUNNISON

We evaluated the students' abilities to collect data from stakeholders, analyze it through triangulation with their research teams, and generate qualitative findings on stakeholder needs via the mini-HE-RAP in Gunnison. In a short time, students were able to generate rich data on stakeholder needs that could inform the direction of a hypothetical mining engineering project. We provided them with the broad research objective to analyze "why people are in Gunnison," but the students engaged far beyond the prompt with their evaluations of stakeholder needs and concerns. In 1 h, they were able to identify issues of economic inequity, social class, and threats to local identity that were discussed in the group dissemination portion of the workshop. For instance, all the student groups uncovered concerns around the influx of new, "outsider" residents and tourists, perceived to negatively affect the local identity, housing prices, and access to resources and services. In their interview notes, students wrote that "housing [prices] are kicking people out," and that "the tourists are turning into full-time residents." One student, serving as "archival researcher" had the idea to analyze license plates of cars downtown, noting that the newer, nicer cars were mostly from out-of-state. From students' notes and statements, local stakeholders lamented how "resources run out quickly due to the tourists." While respondents "took pride in being local," the local identity seemed to hinge greatly on being born in Gunnison. Participant 2 described a stakeholder who self-identified as a transplant despite living in the area for over 50 years. Moreover, stakeholders were perceived to "[take] pride in standing up against major changes," including changes to the social fabric and environment. Archival researchers corroborated the prioritization of outdoor recreation and environmental conservation by locals with references like a 2013 newspaper article on "outdoor activities for elders," as well as by taking notes on keywords and images used in storefronts and advertising geared toward the outdoors industry. These findings on stakeholder attitudes and priorities were consistent amongst the groups, despite each team asking unique questions and speaking with different stakeholders, indicating successful triangulation of these preliminary qualitative conclusions.

The students designated as "observers" in the teams were able to contextualize stakeholder responses through observational analysis. They noticed how subjects' tone of voice, speech velocity, and body language changed when they talked about these contentious issues, indicating frustration and passion, as opposed to subjects' behavior while discussing more neutral topics. These observational skills are critical to ethnography, stakeholder analysis, and contextual listening because the manner in which people express themselves is equally as important as the content of their statements. One of the interviewing students shared with the group how they guided the interviews based largely on these nonverbal cues, steering toward the topics of greatest import for the stakeholders themselves.

We found that this inductive, open-ended approach to analyzing stakeholder needs in Gunnison was conducive to students engaging in a sociotechnical thought experiment on local development dilemmas. During the group discussion, the students were prompted to imagine themselves as mining engineers planning to develop a new mining project in Gunnison. They brainstormed how to meet community stakeholder needs and priorities to facilitate the success of their new mine, concluding that the company could offer subsidized housing for the workers and their families, hire local employees, and dedicate extra time and resources towards minimizing and communicating the environmental impacts of the mine. Some students hypothetically opposed the idea of building a new mine in Gunnison given the community's environmental values. This thought experiment was an example of students applying sociotechnical analysis, as the community's environmental values would shape the design of the mine (e.g., an "open pit" mine versus a less obtrusive option), and a technical mining project would require a labor force that would change the town. This nuanced understanding of stakeholder values and concerns is necessary for contextual listening and must be established before technical specs and designs are considered.

TABLE 5. Types of Questions Generated by Students

Participant	Number of questions generated	Open/ closed	Non-leading/ Leading	Attitude/ knowledge	Social/ technical/ sociotechnical
1	4	0/4	2/2	2/2	3/0/1
2	13	7/6	8/4	8/5	10/3/0
3	7	6/1	6/1	3/4	2/3/2
4	3	3/0	2/1	1/2	1/2/0
5	4	2/2	4/0	2/2	2/1/1
6	4	3/1	2/2	2/2	1/2/1
Total:	**35**	**21/14**	**24/10**	**18/17**	**19/11/5**

2) COLOMBIAN PROJECT

The mini-HE-RAP exercise served as the foundation to prepare students to engage with Colombian stakeholders later in the summer session. Here, we analyze the types of questions that students generated to ask the Colombian stakeholders Table 5. As explained in the background section, the types of questions that interviewers ask are the crux of robust, HE-RAP, and front-end stakeholder analysis. While each question type serves a distinct purpose, we encouraged students to use primarily "open," "nonleading," "attitude," and "sociotechnical" questions to challenge the ways they had been taught to think as engineers (technocentric and deductive).

The questions generated by students reflected many of the learning objectives from the workshop, yet there was opportunity for improvement. See Table 5 for a summary of the types of questions generated by students in the exercise. Engagement with this writing prompt was high, as five out of six students generated more than the three questions that were required. Encouragingly, there was a preference for open-ended questions over closed questions. Respective examples of closed and open questions were: "What do you do for a living?" versus "Why are you involved in ASGM?" Many of the closed questions were also knowledge questions, such as "What materials are easily accessible to you and inexpensive?," while many of the attitude questions were open-ended, e.g., "What are things you do not like about 'project' and why?" There was a relatively even distribution of knowledge and attitude questions, which could reflect the students' unfamiliarity with the Colombian mining context and the need to understand concrete contextual details in addition to stakeholders' opinions. The number of nonleading questions designed by students exceeded the number of leading questions, but the prevalence of leading questions that could easily have been modified to be nonleading indicated a need for further practice in this area. For instance, instead of asking "What are the current barriers or problems with using the sluice box and gold pan?," which assumed that there were problems with current tools, this student could have asked "Can you describe your experience using the sluice box and gold pan?" The latter question would allow stakeholders to organically express any concerns with the system, as well as provide space to share the ways they interact with the system and possible attributes that they like about it.

Most of the questions were nonsociotechnical (either "social" or "technical"), indicating the need for further instruction in this area as well. There was a preference for "social" questions (e.g., "Is the community united or divided? Is there anyone you do not trust?") over "technical" ones (e.g., "How many grams of gold do [you] produce in a week?"), which is still a positive deviation from a conventional, technocentric engineering mindset. That said, many questions were indeed "sociotechnical," e.g., "Do you work together with your family or other community members during mining?" and "What materials are easily accessible to you and inexpensive?" It is encouraging that students could practice different types of question generation so that their future work can utilize and hone these tools to be more attentive to robust front-end stakeholder needs analysis.

V. DISCUSSION

In this study, our focus was on engineering students because undergraduate training is a crucial moment for the professional development of engineers. Pedagogical research has indicated that an overreliance on engineering problem solving during undergraduate training can preclude engineers from considering alternative ways to define and solve problems [40]. HE-oriented programs aim to open students' minds to distinct epistemologies, frameworks, and methods from the social sciences. The engineering students in the present study were open to and engaged with this transdisciplinary training. Despite the limitations of this study and the distinct nature of HE from other engineering disciplines, the concepts and frameworks presented here show the potential for success in fields that require more comprehensive, front-end stakeholder needs analysis, such as systems engineering.

The high levels of student engagement with the HE-RAP workshop demonstrate potential for the successful teaching and implementation of HE-RAP in other academic contexts and professional engineering settings alike. From a pedagogical standpoint, the students responded well to the interactive nature of the workshop, especially when they left the classroom and talked with stakeholders face-to-face during the mini-HE-RAP, after which they were excited to triangulate, contextualize, and disseminate their qualitative findings. Hands-on activities around stakeholder engagement have shown improved learning outcomes in other studies as well [52], [53], [54]. When the otherwise ambiguous and abstract process of stakeholder needs analysis was made more tangible by teaching HE principles (contextual listening), a specific framework (HE-RAP), and concrete methodologies (interviewing, observation, archival research, question design), the students seemed empowered to engage deeply with the process. We speculate that the concrete nature of the RAP methodologies [21], despite being distinctly anthropological, makes them more accessible to engineers than conventional, more open-ended ethnography and aligns well with the step-by-step problem solving methods engineers are accustomed to following [9], [39]. However, this would require additional investigation.

Students grasped the importance of prioritizing sociotechnical stakeholder needs analysis from the front-end of a project, as demonstrated in the mini-HE-RAP thought experiment on the mine dilemma. This finding diverges from prior engineering studies that used RAP to evaluate engineered prototypes after decisions and preliminary designs had already been made [20], [24]. Considerations of the Gunnison stakeholders' environmental values influenced students' opinions on how and if the hypothetical mine should be built. This conversation echoed the third and fourth tenets of the Socially Responsible Engineering framework on "collaboratively identifying opportunities and limitations of creating shared social, environmental and economic value for all stakeholders, especially those who are marginalized," (Tenet 3) and "adapting engineering decision-making to promote those shared values, acknowledging situations in which this is not possible and engineering projects should not move forward" (Tenet 4) [10, p. 9]. While Riley critiqued engineers for often "los[ing] sight of the big picture" [39, p. 41], this was not the case for the engineering students in the present study, illustrated by their analyses of themes, such as local identity and the economic challenges in Gunnison. Students recognized that some of these concerns could not be addressed by the engineering design itself, but rather, through corporate social responsibility (CSR) strategies that would nonetheless be important for project sustainability.

These critical contextual factors may not have been identified if students had taken a more deductive, technical, engineering-based approach to questioning. For instance, the questions students wrote for the Colombian stakeholders demonstrated preliminary abilities to distinguish between and generate different types of ethnographic questions to elicit sociotechnical data. Although there was room for improvement, especially regarding the use of "leading" questions, the questions students designed would still enable them to begin to gather data on stakholders' "history, political agendas, desires, forms of knowledge" [9, p. 125] required to conduct contextual listening. Moreover, students viewed these questions, and HE-RAP overall, as an opportunity to understand stakeholders' day-to-day lives and to build rapport and trust. Research has indicated that trust between engineering experts and stakeholders, in addition to good technical design, is essential to the sustainability of engineered systems [8], [9], [16], [55].

While HE-RAP's speed is certainly an asset for engineering projects with limited timelines and budgets, social scientists call for caution with rapid "quasi-ethnographies" conducted by nonanthropologists. Much of the rigorous theoretical and methodological work that goes into ethnography, as anthropologist D. Forsythe argues, is "invisible to the untrained eye" [19, p. 127]. As a result, Forsythe cautions that "the work of untrained ethnographers tends to overlook things that anthropologists see as important parts of the research process." Some common misconceptions identified by Forsythe include: "anyone can do ethnography—it is just a matter of common sense"; "since ethnography does not involve preformulated study designs, it involves no systematic method at all"; and "doing fieldwork is just chatting with people and reporting what they say" [19, p. 130]. The authors agree with Forsythe that "work based on these misconceptions is likely to be superficial and unreliable" [19, p. 127], which is why it is critical to not only teach ethnographic methodologies to engineers but also to educate them on the distinct anthropological mindsets and epistemologies that are foundational to robust ethnographic research. We do not presume that one workshop will turn engineers into expert ethnographers and agree with Manderson and Aaby [22] that RAP should not be seen as a replacement for more comprehensive, longer term research. Yet we do maintain that transdisciplinary methods such as HE-RAP can provide valuable insights into stakeholders' needs.

While our findings were encouraging, there is a need for caution in generalizing the results of this study as the number of student participants was small, the workshop was limited in time, and there were additional factors that likely contributed to students' positive perceptions of and engagement with HE-RAP. The students had all self-selected to participate in the intensive summer session which focused on marginalized Colombian mining communities, indicating prior interest in transdisciplinary, community-based research that other engineering students and practitioners may not share. In addition, previous workshops in the first week of the summer session were geared toward community-based research and stakeholder engagement [50], [51], likely enhancing students' abilities to think sociotechnically. Finally, in the mini-HE-RAP, engineering students were accompanied by professors and graduate students who were trained in HE principles and community-based research. This added diversity to the teams and likely resulted in more nuanced reflections. This illustrates why interdisciplinary research teams are a critical part of well-designed RAP [22]. It is recommended that future RAP or HE-RAP studies include social scientists, anthropologists, engineers from different fields, and stakeholders (when possible) as research team members to provide different perspectives and strengthen the sociotechnical findings.

VI. CONCLUSION

In this article, we advocate for transdisciplinary stakeholder needs analysis that combines systems engineering with fields such as anthropology and HE to characterize, analyze, and productively intervene in complex sociotechnical systems, which include stakeholders. We illustrated how HE best practices, such as contextual listening, draw from social science frameworks so that engineers do not have to "reinvent the wheel" for stakeholder analysis. Students and practitioners can instead expand their own problem definition/solving toolkits with established qualitative techniques (such as ethnographic RAP) that resolve some of the ambiguity around the often abstract process of stakeholder needs analysis. In combining HE principles with RAP, we proposed the "HE-RAP" framework and taught it to a small group of engineering students. We analyzed 1) student perceptions of the HE-RAP tool, and 2) in what ways students considered the sociotechnical dimensions of front-end stakeholder needs analysis during the HE-RAP training. Despite limitations in the workshop's size and scope, the results suggested numerous potential benefits of teaching and integrating HE-RAP for front-end stakeholder needs analysis.

The students were keenly engaged with the workshop and expressed the utility of RAP for both academic and professional engineering projects. They were able to quickly learn and apply concepts from HE and ethnography in a mini-HE-RAP to identify interesting, nuanced stakeholder concerns about economic inequity, social class, and threats to local identity in the city where the workshop was held (Gunnison, CO, USA). Students theorized how these stakeholder needs could not only influence a hypothetical engineering project's design but also guide decisions such as hiring practices and CSR initiatives. The mini-HE-RAP in Gunnison helped students prepare for a virtual visit with Colombian stakeholders. Students designed robust questions for the Colombian stakeholders according to the question types from ethnographic literature taught in the workshop to facilitate contextual listening.

These encouraging results confer the need for future research on the implementation of HE-RAP in other engineering education and practice settings. In future studies, we suggest teaching and applying HE-RAP with engineering students or practitioners with minimal prior experience in anthropology, ethnography, and/or community-based research. This would allow for a clearer assessment of the learning outcomes from HE-RAP itself. Future studies could also examine the influence of stakeholder needs from HE-RAP on engineers' actual design decisions, which was unfortunately out of the scope of the present article. More comprehensive studies could reveal additional barriers and/or opportunities for engineers to pragmatically integrate HE-RAP with their projects. Moreover, future research could compare RAP and/or HE-RAP to other methods of stakeholder needs assessment. It is important to recognize that no single research approach can capture all aspects of a complex issue. So, although we argue here for the benefits of qualitative stakeholder needs analysis, future work could investigate tools, such as HE-RAP, in conjunction with more "technical" model-based needs analysis approaches. Given that engineering curricula are often already overloaded with courses, educators could experiment with integrating HE-RAP into universities' "general education" requirements, creating opportunities for engineering, social science, and humanities departments to work more closely together to develop courses or experiences. A course on HE-RAP could also support the Accreditation Board for Engineering and Technology's student outcomes criterion for "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors" [56].

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