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Supporting Engineering Students' Incorporation of "Context" into Global Health Design Processes

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Abstract

Incorporating relevant contextual factors, e.g., socio-cultural, environmental, and industrial considerations, during design processes are required to develop solutions that function appropriately in their intended use context, particularly in global health settings. Prior work has determined that "lacking the contextual knowledge needed" is a common reason for engineering projects' failure in Low- and Middle-Income Countries (LMICs). Our prior work has investigated *which* contextual factors engineering designers consider and *how* they incorporate contextual factors into their global health design processes. In this study, we extended this prior research to compare the design behavior of student and professional global health engineering designers. As part of this research, we conducted semi-structured interviews with fifteen experienced design engineers who work on health-related technologies in LMICs. We also conducted semi-structured interviews and reviewed final reports from six mechanical engineering capstone teams working on global health-themed projects. While students tended to aggregate many different "low-resource" contexts, professional global health designers exhibited a much more nuanced view of differences across unique LMIC contexts. We also identified that experienced designers regularly reframed their design problems and accounted for implementation decisions throughout their design processes. At the same time, novices viewed problem framing and implementation as mainly outside the scope of their projects. This study describes the preliminary conceptions of a framework that could support engineering design students during both curricular and co-curricular design activities. The framework guides students through multiple categories of contextual factors. It provides examples and prompts for incorporating contextual factors into decisions iteratively throughout their design processes in a curricular engineering design project. The findings from this work have implications for engineering design pedagogy and, ultimately, the potential to improve engineering graduates' abilities to develop contextually suitable solutions.

Keywords

Engineering design, Capstone design, Contextual factors, Global health, Student engineering teams

1 Introduction

Incorporating relevant contextual factors, e.g., socio-cultural, environmental, and industrial considerations, into engineering design processes supports the development of solutions that function appropriately in their intended use context, particularly in global health settings [1]–[3]. Indeed, engineers are encouraged to consider all factors necessary for successful implementation [4], including tailoring a solution to the broader context where it must function

[5]. Understanding and incorporating contextual factors is critical when designing health products since goals extend beyond technical performance to individual and collective well-being [6], [7]. Specifically, when designing for use in Low- and Middle-Income Countries (LMICs), exploring and understanding the socioeconomic, cultural, and industrial contexts are especially important [8], [9]. Engineers "lacking the contextual knowledge needed" is a common reason for the failure of engineering projects intended for use in LMICs [10], and neglecting to incorporate relevant contextual factors has led to many failures in global health design initiatives [1], [11], [12].

Although incorporating contextual factors throughout a design process is necessary for success [13], engineering education historically does not prioritize training engineering students to identify, synthesize, and apply contextual information to their designs. Some recommendations exist, for example, Contextual Social Awareness activities [14], immersive needs assessments [15], stakeholder engagement techniques and classroom case studies [16], [17], and requirements elicitation processes based on socio-technical considerations [18]. However, since prior work has identified that contextual factors can be incorporated iteratively and throughout the entire duration of a design process [19], existing recommendations do not provide the continuing, holistic scaffolding students may require to fully gain an appreciation and skill for incorporating contextual factors throughout curricular and co-curricular design projects. Moreover, existing recommendations lack comprehensive and detailed examples of specific contextual factors that may influence design decisions and outcomes based on the real experiences of professional engineers.

To fill gaps in student learning outcomes related to making informed judgments based on the broader context and incorporate contextual factors during engineering design practice, our prior work has investigated *which* contextual factors professional and student engineering designers consider and *how* they incorporate contextual factors into their global health design processes [19], [20]. Here, we extended this prior research to compare the design behavior of students and professional global health engineering designers to propose key learning outcomes related to acquiring knowledge and skills related to incorporating contextual factors into design processes and present a preliminary framework for use in capstone engineering design courses.

2 Background

The U.S. Accreditation Board for Engineering and Technology (ABET) lists key criteria that must have documented student outcomes, including that students gain an ability to "make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts" [21]. These learning outcomes are especially critical when designing for use in LMICs where failing to suitably incorporate social, cultural, political, and historical considerations can increase the risk of perpetuating neocolonial practices and harm vulnerable communities [22], [23]. Thus, engineers in global health and development applications frequently use participatory approaches and design methods to engage stakeholders and incorporate contextual information during their design processes [24], [25].

Engineering students tend to follow strict problem-solving rules, focusing on objective characteristics and generally neglecting the larger context [26], [27]. Prior work has found that fourth-year engineering students consider contextual factors less during design compared to first-year engineering students [28], [29], suggesting that traditional engineering education may underemphasize the importance of context in design at the expense of technical content in fast-paced and packed curriculum and coursework. Some studies have shown that engineering students can elicit contextual factors throughout their design processes, for example, through stakeholder engagement and prototyping strategies. However, they tend to use such approaches in unintentional and unstructured ways [30], [31].

Scholars frequently investigate senior capstone engineering design teams to identify what knowledge students have gained and what gaps exist in their skill sets and practices [26], [31], [32]. Capstone requires students to implement multiple engineering concepts from their education and develop skills related to secondary and primary information gathering, synthesis, and application [33], [34]. Prior work has suggested that capstone courses can be used to encourage students to gain real-world stakeholder engagement and contextual investigation skills [35], [36], such as developing design requirements based on stakeholder needs and contextual factors [33]. However, engineering students incorporate broader global, social, economic, and environmental contextual factors into their design processes to varying degrees [37]. It is unclear to what extent current design project courses prepare engineering students for incorporating these broad contextual considerations in design.

3 Methods

We investigated how novice and experienced engineering designers incorporated contextual factors during global health design processes. The following research questions guided this work:

(1) What are the differences in how student and professional engineering designers incorporate contextual factors into their global health design processes?

(2) What are possible interventions for engineering design education to support students' incorporation of contextual factors into global health design processes?

3.1 Data sources

This analysis included data collected from two prior studies that investigated (1) engineering student practice in the context of a final-year undergraduate capstone design course [20] and (2) professional engineering practice in global health [19]. From the study of engineering student practice, we selected the subset of the total sample (six student teams out of twenty) that worked on global health-themed projects and participated in semi-structured interviews with our research team. Five interviews included only one student from the capstone team, and one interview included two students from the capstone team. From the second study, we included data from all 15 professional participants. In both studies, we conducted 90-minute semi-structured interviews to elicit detailed examples of incorporating contextual factors throughout their design processes. We also collected and reviewed the final capstone reports for the six global health student teams. In both studies, we defined "contextual factor" as a characteristic of the potential solution's broad use context and "incorporate" as an instance when a contextual factor influenced a participant's decision during their design process. Following a team-based consensus and negotiated agreement approach [38], [39], we coded transcripts of the interviews for evidence of incorporation of contextual factors, which we categorized into nine primary categories identified in the literature: Technological, Industrial, Institutional, Infrastructure, Environment, Economic, Public health, Socio-cultural, and Political [1]. Additionally, each contextual factor was coded with the corresponding design phase and resulting design choices. Excerpts across contextual factor categories and design phases were reviewed and iteratively analyzed to identify patterns [40], focusing on identifying rationale and approach for incorporating contextual factors.

Table 1: Summary of data.

Samples included in this study	**Sample size**	**Engineering design domains**	**Examples of global health design projects**	**Regions of design project contexts**	**Years of professional design experience**
Student capstone teams A-F	6 teams	Medical devices	Rehabilitation device; Obstetrics device	Central America; Sub-Saharan Africa	0-1 year
Professional engineers A-O	15 professionals	Medical devices; Information technology	Neonatal device; Mobile health technology	Central and South America; South and Southeast Asia; Sub-Saharan Africa	3-28 years

3.2 Comparative analysis

We followed a *variation-finding comparison* approach to identify differences and similarities across two or more samples related to a specific phenomenon [41], [42]. Variation-finding comparison requires that researchers identify a clear objective, cases for comparison (i.e., samples to compare), and the specific phenomenon or framework for comparison. Finally, specific data collection methods should be carefully selected to compare findings [43]. In our case, we examined professional and student engineering designers' approaches to incorporating contextual factors while designing for global health applications. Our prior studies' data collection and analysis methods were similar (90-minute semi-structured retrospective interviews about a specific design project and deductive and inductive coding for incorporations of contextual factors during design processes). To answer RQ1 regarding differences between student and professional practice, themes related to incorporating contextual factors during design processes from each prior analysis were directly compared to identify key differences. Then, to answer RQ2 regarding potential educational interventions for engineering students, these differences were synthesized and applied to the development of learning outcomes, and a preliminary framework for potential use within an undergraduate engineering design capstone course to encourage students to learn approaches that experienced engineers use when designing for global health applications.

4 Findings and embedded discussion

Our analysis revealed key similarities and differences between how professional engineers and capstone student design teams approach incorporating contextual factors into their global health design projects. This section describes and interprets these findings with examples from both data sets, focusing on differences that may inform potential classroom interventions to support the incorporation of context in engineering design.

4.1 Similarities between novice and experienced designer approaches to global health design

Across both samples of capstone student teams and professional global health designers, there was an awareness of the importance of context and acknowledgment that contextual factors should be considered throughout their design processes. Participants from both samples recognized the importance of engaging with stakeholders and observing the context and often used prototypes to collect feedback from stakeholders related to relevant contextual factors.

While participants in both samples showcased being open-minded throughout their processes to collect any new information that may arise and be relevant, professional engineers did this much more intentionally than students. Professionals identified gaps in their contextual knowledge and sought partnerships to fill them. For example, some professionals worked closely with hospitals or organizations in the use context to identify relevant contextual factors that would apply to their design process. Student teams who intentionally sought relevant contextual information often did so through avenues considered unconventional in engineering capstone classes. For example, one student team designing a sensory aid for a country in Central America used social media groups to distribute surveys to learn more about the cultural contexts in their intended use setting.

Participants from both samples recognized the importance of engaging with stakeholders and observing the context to learn about contextual factors. Professionals regularly sought feedback and contextual information through many partnerships and connections throughout their design processes. Student teams were regularly instructed to meet with their project sponsor and relevant stakeholders and experts, and many students had the opportunity to travel and observe the intended use contexts. As such, many student participants described their appreciation for meeting with stakeholders and observing the context to identify critical contextual factors. For example, one student shared,

> *"We want to be able to bounce ideas off of the healthcare providers there. I feel like it would be tough to design for a hospital in [this Sub-Saharan African country] if you hadn't been there because I feel like there's a lot of things that you see [and] you can have a whole different appreciation for it."* - Participant from student team E

Across both samples, prototypes were regularly used to collect feedback from stakeholders related to relevant contextual factors. Students used prototypes with stakeholders frequently during conceptual and detailed design stages. Professional engineers described their need to "test out assumptions" about the context early and indicated that showing prototypes early and often to stakeholders brought out more nuanced and tacit contextual factors. For example, one professional participant shared,

> *"When we actually had [prototypes] that folks could react to, that's really when the conversations got real… We have this assumption around what a solution could be [in this context]. How do we now learn whether an assumption is true or not? Well, you got to have them react to something."* - Professional participant E

4.2 Key differences across novice and experienced designer approaches to global health design

Our analysis identified critical differences in how students and professional designers approached and incorporated contextual factors during their design processes. Table 2 provides an overview of the key differences identified.

Table 2. Summary of differences between student and professional approaches to incorporating contextual factors into global health design projects.

Type of approach	**Professionals' approach**	**Example or excerpt from professionals**	**Students' approach**	**Example or excerpt from students**
Iteration in character-izing contextual factors	Iteratively incorporated contextual factors	*"[This product] had so many iterations. We have like five batches now, and each batch there has been issues that we have solved."* - Professional participant F	Followed more linear approach with limited flexibility to make changes during later stages	*"[This contextual factor] is something that's really important to the people who are going to be using this [but] I think we weren't able to do anything about it to change that in the timeframe that we had."* - Participant from student team F
Character-ization of LMIC contexts	Acknowledged more nuance and differences across different LMIC contexts	*"There were lots of differences in context between [this South Asian country] and [that Sub-Saharan country] that did not directly transfer over."* - Professional participant J	Tended to broadly use "low-resource setting" when referring to LMIC contexts, often comparing to U.S. context	*"In low-resource settings you have different concerns… compared to the U.S., for example, that's not a high priority because they have so many resources."* - Participant from student team C
Information gathering and decision making when context-specific data were lacking	Relied on information from stakeholders and experts	*"You just need to have stakeholders, right? You need to have individuals who are going to be there with you through the whole process, who are willing to be patient, who will give you feedback along the way. And that will bring along a lot of the social, cultural, institutional, public health*	Used proxy data from other LMIC contexts	*"We didn't find data specifically for [this Sub-Saharan African country]...so we found data for [East Asian country]."* - Participant from student team B

		stuff." - Professional participant G		
Incorporat-ing qualitative contextual factors	Frequently used qualitative verification methods	*"We were able to send [our initial product] to a few different hospitals along with some trainers and coaches and say, "Okay, let's see how you use this. Does it meet your needs?" Use that feedback to then go into the next round."* - Professional participant G	Sometimes ignored qualitative constraints when they were not able to develop a specification	*"We went through a whole process of trying to find pothole depth data…we were trying to find a way to quantify that to fit in our requirements and specifications, and I think it was hard to find data specifics in [this Sub-Saharan African country]. I'm not sure if there's a lot of people specifically measuring potholes in different places of the country."* - Participant from student team B
Incorporat-ing contextual factors into implementati on and use consider-ations	Viewed implementatio n and use decisions as a key part of their design process	*"The only thing that we see that people don't think about, which has to do with design, is sinking further ahead to shipping, logistics, and pricing…We just see a lot of idealism, and that people don't take that into account…These are the kinds of things that actually make quite a big difference in the end."* - Professional participant B	Sometimes viewed implementation and use considerations as out of their scope	*"FDA approval is something you have to think about…but that's all related to implementation, not design of the device."* - Participant from student team C

4.2.1 Iteration in characterizing contextual factors

Professional participants followed a more iterative approach to identifying and incorporating contextual factors into their global health design projects. They were (nearly) continuously looking for new contextual information and were open to adjusting throughout their processes. On the other hand, student teams followed a more linear approach, collecting most contextual information up front during their problem-scoping and requirements development phases. Some teams incorporated additional contextual factors during later stages by including criteria for down selection and consulting with stakeholders for feedback. However, other student teams ignored additional contextual factors, mainly because they did not have the time to make the adjustments required to incorporate them fully. Although students could not always change their design when last-minute contextual factors were identified, professional designers did this often. For example, one participant shared,

> *"I mean, obviously we had to completely iterate [after we discovered a manufacturing process wasn't available in this context]. Find aspects of the physical design to make it more*

manufacturable. I mean, what dimensions we have, what tolerances we have…I think that was probably a pretty natural thing." - Professional participant C

Professional participants were open and willing to redefine and rescope their design problem based on competing contextual factors. For example, some experienced designers described needing to select between designing a medical device for hospitals in rural versus urban settings due to the differences in contextual factors, which made it difficult to account for all requirements. Unlike professional participants, who had more time and flexibility, student teams did not have enough time to consider potential problem refining during the later stages of their design processes. Meanwhile, professional participants often reflected on ways they narrowed down their target context and target users and acknowledged settings in which their solutions should not be implemented. For example, one participant described:

"There's such a vast diversity of context that patients receive care…it is an extremely complex and varying group…I mean there are lots of cases where [this product] either can't or shouldn't be used."- Professional participant C

4.2.2 Characterization of LMIC contexts

Experienced designers acknowledged more nuance and differences across different LMICs and within them than students. In general, student participants used terms like "low-resource context" broadly when describing the requirements in their use context. In addition, most students directly commented on the differences between these contexts and their own experiences in the U.S. However, professional engineers were more specific and nuanced when describing unique features of their use contexts. Notably, experienced designers aimed to identify critical contextual constraints that may be competing in one or more of their target contexts so that they could either rescope their target context or develop solutions that addressed all important contextual factors. For example, one professional participant described,

"We work mostly in Sub-Saharan Africa and South Asia, which is where the maternal newborn burden is highest…I think it matters which hospitals we're catering to within those contexts. So if it's an urban hospital that's more resourced, that has a lot of doctors present who kind of understand how to use electrical devices and things like that, I think it's much easier because they usually have the resources, like the cleaning supplies. They have the training expertise, they have sockets on the wall, like stable electrical power. Whereas if we were talking about more rural areas where some of these products are particularly needed, more than in the high resource, urban hospitals. There's less training, less exposure to electronic devices, less stable power, all these things that come into mind." - Professional participant F

4.2.3 Information gathering and decision making when context-specific data were lacking

Some student teams struggled to find accurate contextual information, such as local public health and anthropometric data, for their intended use context. They described that they were encouraged by their instructors to find data from other LMIC contexts to use as a proxy instead of using data from the U.S. or other high-income countries. On the other hand, when large-scale contextual data were lacking, professional participants relied on information from stakeholders, partners, and experts of their use context; we did not identify a situation when an experienced designer used proxy data from another context.

Rather than always relying on documentation (e.g., specified requirements) of all this contextual information, professionals often relied on their heuristics or shortcuts to incorporate broad, qualitative contextual information, frequently referring to their “intuition.” For example, one professional described this intuition,

> *“It's less a report that you could synthesize in terms of things you observe and more an intuition that you gain and an ability to reject other hypotheses and ideas that people bring…And certainly there are colleagues that I have that are way more immersed than I am. I mean, they really go and study for the majority of their time in such communities and they just have an ability to see an idea and then say, ‘Oh, that'll never work because of X, Y, Z thing,’ even if they've never written it down.”* - Professional participant C

4.2.4 Incorporating qualitative contextual factors

Professionals often used qualitative verification methods and did not express pressure to quantify contextual constraints if they deemed it unnecessary. Meanwhile, students described a struggle to quantify every requirement due to the course's guidelines for developing specifications (which required quantitative units) for all requirements. If students could not quantify a requirement, they sometimes ignored it but acknowledged that they would need to address the constraint if the solution were to be implemented. For example, one student working on a project intended for use in a Central American country shared her experience struggling to verify their requirement to "have an aesthetically appealing design," sharing:

> *“[We sent out] two different surveys to gauge whether something was an appealing design…but it's just really hard to quantify. And also hard to understand, especially through surveys. Like what is this that's not exactly appealing?”* - Participant from student team F

4.2.5 Incorporating contextual factors into implementation and use considerations

Professional participants viewed implementation and use decisions as a critical component of their design process. When professionals could not incorporate a contextual factor into their conceptual or detailed design decisions, they often incorporated the information into implementation and use considerations. For example, multiple professionals described local stigmas related to the health conditions within their use contexts. These participants incorporated considerations such that the product could be used privately and discreetly while also working with local community health workers and other influential people to help reduce stigma through education and awareness. However, some students explicitly claimed that implementation and use considerations were "for later" and not related to design decisions, which is very different from the way that professional participants viewed implementation decisions: as something co-constructed and related to design decisions. For example, one professional participant decided later in their design process to consider implementing within a specific region that required stricter regulations. He described wishing he had considered these implementation considerations earlier:

"Since now we are [aiming for local regulatory approval], there are a lot of changes that we have to make. I wish we had them done early, at the stage when we were deciding the design parameters in the key dimensions. That would have been better." - Professional participant H

5 Implications: Developing a framework for use in curricular engineering design courses

5.1 Learning outcomes for incorporating contextual factors into curricular design projects

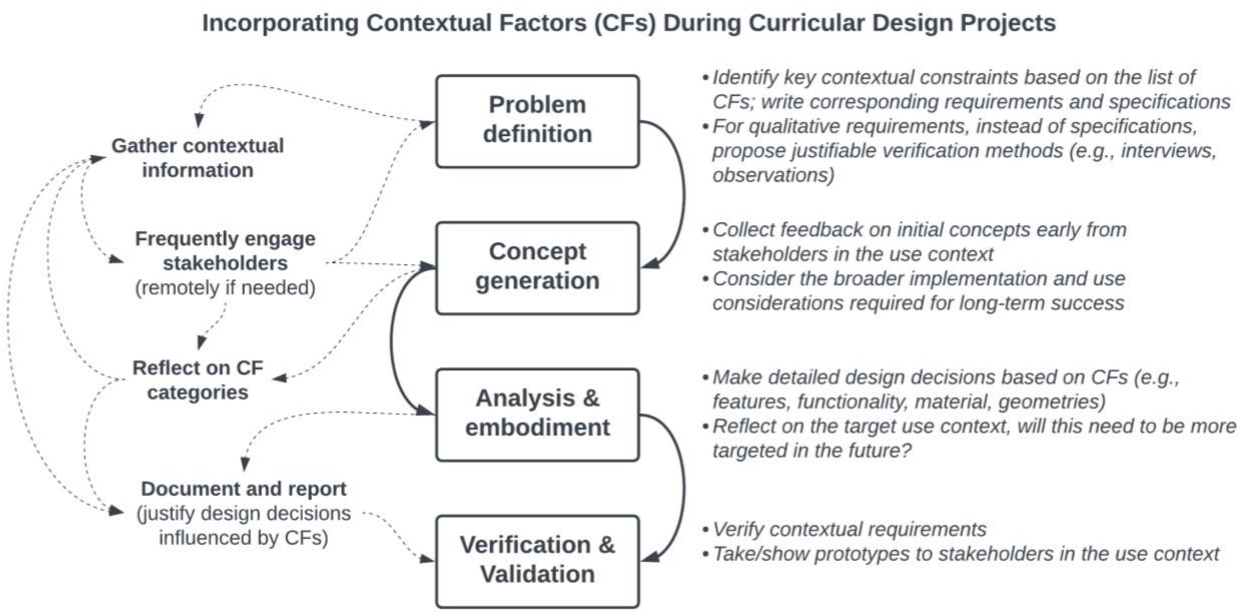
Based on these findings, we set out to develop an initial set of learning outcomes as well as a preliminary framework for use during design engineering curricular projects, such as capstone, particularly for projects with a global health theme, to support the acquisition of skills related to incorporating contextual factors into engineering design. ABET lists a key criterion: students must be able to "make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts" [21]. As such, the proposed framework aims to contribute to this ABET criterion by equipping students to incorporate contextual factors into their design process, potentially making the final solution more contextually suitable and (ideally) more successful. We identified the following learning outcomes and considerations for interventions based on findings from our comparative analysis and existing literature.

A framework to assist with improving students' abilities to incorporate contextual factors must:

1. Provide a comprehensive list of potential contextual factors that have been shown to impact design processes and/or design outcomes
2. Highlight the iterative nature of identifying and incorporating contextual factors during design, often through stakeholder feedback and reflection on potential contextual gaps
3. Encourage students to identify and incorporate contextual factors iteratively throughout their design process by advising that students:
    a. Conduct both secondary and primary research to identify relevant contextual factors
    b. Intentionally develop requirements based on relevant contextual factors
    c. Select and design features that are influenced by contextual factors
    d. Consider broader implementation and use considerations if they cannot incorporate a contextual factor directly into design features
4. Fit into existing processes used in typical engineering design courses since these are typically a very packed schedule, including complying with:
    a. Existing data collection methods (e.g., secondary research, stakeholder engagement, and (if available) observations of the use context)
    b. Existing design activities (e.g., requirements development, concept generation, and selection)
    c. Existing reporting structures (e.g., design reviews and final reports)
    d. Existing timelines (e.g., clear 'start' and 'end' within a few months)

5.2 Preliminary framework for incorporating contextual factors into curricular design projects

Guided by these learning outcomes, we have developed a preliminary framework to provide insight into how contextual factors can affect design decisions, including *which* contextual factors could be considered, based on previous findings [19]. The comparative analysis presented here has informed the development of recommendations for *how* students can incorporate these contextual factors and *when* these activities could occur during their design process within in a curricular context. The preliminary framework is presented below in Figure 1. In the process diagram, the thick lines represent a traditional linear structure that curricular design projects typically follow. In contrast, the thin dotted lines show optional pathways based on how iterative professional engineers were while identifying and incorporating contextual information. Bullet points on the upper right are design-stage recommendations for incorporating contextual factors based on how professionals incorporated them.



Contextual Factor categories

Economic	• Individual and household characteristics • Regional and national characteristics • Labor market characteristics
Environ-mental	• Weather • Natural environment
Industrial	• Supply and manufacturing • Maintenance • Distribution
Institutional	• Existing practices and procedures • Capacity and capability of institutional staff • Institutional financial capacity • Institutional resources • Indoor environment
Public Health	• Healthcare system and practices • Health demographics

Infrastructure	• Utilities • Transportation and road quality • Distance • Attributes of the built environment
Socio-cultural	• Symbols • Cultural tradition and practices • Language • Education and literacy rates • Aesthetics • Stigmas and taboos
Techno-logical	• Available technologies in the context • Compatibility with the technical context • Availability of consumables
Political	• Regulations and regulatory processes • Stakeholder power dynamics • Political systems and culture • Global priorities

Figure 1. Preliminary framework to support the acquisition of skills related to incorporating contextual factors into curricular design projects.

5.3 Limitations & future work

This work builds on prior data collection from 15 professional engineers and six student capstone teams, all working on projects intended for use in LMICs and global health contexts. Much of the findings likely apply to design projects outside global health settings, but this has yet to be investigated. Additionally, the preliminary learning outcomes and framework presented here should be validated in engineering design settings and with capstone team projects to suggest improvements.

6 Conclusion

While prior work has studied, at a high level, the ways students and professional engineers consider context during their design, studies have thus far not investigated the differences concerning specific intervention opportunities during global health capstone engineering projects. The preliminary learning outcomes and framework presented in this study can guide students through multiple stages where incorporating contextual factors is relevant and provide prompts for reflection and methods to do so iteratively throughout their design processes. The findings from this work have implications for engineering design pedagogy and, ultimately, the potential to improve engineering graduates' abilities to develop contextually suitable solutions.

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