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Practitioner Case Studies Demonstrating the Incorporation of Contextual Factors during Global Health Design*

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Incorporating contextual factors throughout a design process is necessary for successful outcomes in global health settings. However, additional tools are needed to equip engineering students with skills to investigate and incorporate contextual factors into their design processes. We developed in-depth narratives from three real design experiences to demonstrate how design practitioners incorporate a broad range of contextual factors into their global health solutions. Since incorporating context is not yet systematized in engineering design work, narratives provide necessary nuance and exposure to the concepts and approaches used by experienced designers. Our findings highlighted several ways engineering design practitioners incorporated contextual factors into their design processes, including regularly conducting first-hand observations, developing meaningful relationships with stakeholders, and using iterative and adaptive design approaches that allow for contextual factors to emerge throughout a design process. Ultimately, we recommend engineering educators encourage more consideration and incorporation of contextual factors into engineering design processes, particularly in global health settings. These narratives can be used in engineering classrooms to support novice designers' acquisition of skills related to incorporating contextual factors into engineering design processes.

Keywords: design practice; global health; contextual factors; narratives; engineering education

1. Introduction

Engineering designers are encouraged to develop products that are appropriate for their use contexts [1, 2]. Indeed, successful product design requires the incorporation of many relevant contextual factors, i.e., characteristics of a potential solution's broad context of use, such as institutional, political, and cultural environments. In the field of global health, designing for the appropriate context is especially imperative [3, 4]. Medical device "graveyards" are scattered throughout low- and middle-income countries (LMICs), filled with technologies designed in high-income countries that were never designed specifically for these contexts [5]. Existing literature provides numerous examples of products failing in a global health context due to a lack of appropriately incorporating factors of the context into the design [6–8]. Moreover, prior work has shown that engineering students hold a relatively narrow concept of "context," focusing more on technological and institutional context and less on broader socio-political factors, and lack intention with respect to incorporating contextual factors throughout their design processes [9, 10].

While some prior work has characterized how novice and experienced engineers incorporate some factors of context into early problem scoping [11, 12], studies have not investigated which contextual factors experienced global health designers consider and how they incorporate them into their design processes. And, while some work has characterized ways that global health designers conduct design processes [13–15], there is little focus on how they incorporate broader contextual factors into their designs. To address these gaps in the literature, our previous work focused on characterizing how global health design practitioners incorporate contextual factors throughout their design processes. Using semi-structured interviews with 15 experienced global health engineering designers, we investigated the types of contextual factors incorporated into engineering design processes in LMICs [16, 17]. An iterative thematic analysis identified 351 incorporations of contextual factors classified into nine mutually exclusive contextual categories as well as 32 subcategories. Our prior analysis showed that the experienced designer participants were consummate about taking context into account. They engaged a broad range of stakeholders to understand context; they visited and revisited contextual information, and they adjusted the scope of their projects, even to the point of terminating a project, based on what they learned about context.

In this study, we thoroughly examined the practices of three participants to develop in-depth

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narrative descriptions of how they learned about, considered, and incorporated context into design projects. Based on rich interview data with design practitioners based in three different global regions (North America, Europe, and Africa) with experience working on global health challenges, we set out to convey real examples that could be leveraged in engineering classrooms through case-based narratives. We chose to develop narratives since they are descriptive and can convey the uniqueness of experiences in depth. Additionally, narratives can outline a more detailed storyline, facilitating communication about the event or experience to the reader. These characteristics of narratives align with our goals to support broader awareness of strategies for incorporating contextual factors during development engineering design processes.

Our narratives include (1) an experienced medical device designer from North America designing a neonatal product intended for use in multiple LMIC contexts, identifying multiple contextual constraints that were incorporated into their design decisions; (2) an experienced medical device designer in Europe designing a monitoring device for use in multiple LMIC contexts, determining design specifications given competing contextual factors; and (3) an experienced electrical engineer from East Africa incorporating the political context into a design intended for use in one country. We draw out cross-cutting themes from the cases, highlighting how the participants made specific design decisions based on contextual factors, and suggest recommendations for use of the narratives in educational settings. Through these in-depth narratives from real design experiences, we aim to demonstrate how design practitioners incorporated a broad range of contextual factors into their global health design processes. The results from this study can be used by engineering design practitioners and novice engineering designers to improve the integration of solutions into their intended contexts within LMICs, with the ultimate goal of improved individual and collective health outcomes.

2. Background

2.1 Characterizing "Context" in Engineering Design

In engineering design, *context* is used to describe the broad conditions in a particular environment or setting in which the solution will operate [3, 11, 18]. The multiple factors that comprise a solution's broad use setting are termed *contextual factors* [17, 19]. Aranda-Jan et al. defined nine classifications of contextual factors: (1) economic, (2) environmental, (3) industrial, (4) infrastructural, (5) institutional, (6) political, (7) public health, (8) socio-cultural, and (9) technological [19]. Contextual factors can be *incorporated* into engineering design processes in many ways, including influencing problem scoping, detailed decisions (e.g., form, function, performance), and implementation considerations [10]. Incorporating contextual factors during design processes requires that designers effectively evaluate the intended use context, synthesize and prioritize contextual information, and apply relevant contextual factors to design and implementation decisions [20].

2.2 Supporting Engineering Students' Incorporation of Context During Design Processes

Although the Accreditation Board for Engineering and Technology (ABET) states that engineering graduates are expected to "make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts" [21], specific guidance for incorporating context throughout design processes is scarce. Some recommendations for integrating contextual information into student design education exist, for example Contextual Social Awareness (CSA) activities [22]. While CSA activities have been shown to increase students' considerations of social dimensions during problem solving [23], the framework does not provide a comprehensive perspective across multiple contextual dimensions (e.g., institutional, political, economic). Other tools, such as first-hand observational assessments [24, 25] and stakeholder engagement techniques [13, 26], can provide students with support for gathering contextual factors, but lack guidance for analyzing and applying contextual information during their design processes.

To support the acquisition of design skills, tacit processes must be made visible to learners; first so that they can observe and second so they can practice them. Before students can practice complex design skills, it is recommended practice for instructors to first demonstrate the rationale and thinking process for students [27]. One approach for demonstrating complex skills, and thus making tacit processes visible, is through *case-based learning*, which is a guided inquiry approach that engages students through discussion and examination of real-world scenarios [28]. In case-based learning, instructors provide students with short, specific scenarios and facilitate collaborative discussions to analyze the situations. Prior work has indicated that students' conceptual understanding of new topics is greater when learning from case-based instruction compared to a traditional lecture [29]. Case-based learning can be especially relevant to design education where problems may be unstructured, complex, and without an obvious single-

solution [30, 31]. Specifically, narratives can be developed to communicate specific case studies, providing detailed description and context. Scholars also argue for the development of *theme-oriented* narratives as opposed to isolated ones, to help students observe multiple viewpoints and better internalize the concepts [32].

3. Methods

The objectives of this paper were to (1) provide in-depth descriptions of how engineering design practitioners have incorporated contextual factors into their design processes, and (2) discuss cross-cutting themes that could be used within engineering design education. This work was guided by the following research question: *How do design practitioners incorporate contextual factors into global health design processes?* To address our research question and present the findings in a way that could support students' incorporation of contextual factors in their own work, we selected three participants from an existing larger set of data collected from 15 global health design practitioners [16, 17]. We then chose to share their experiences in narrative form, which enabled us to convey the nuances of experiences in depth and detail [33, 34]. Since "context" is fairly abstract and largely under defined in engineering work, case-based narratives provide necessary nuance to the reader. Scholars have used narratives in engineering education settings to support learning and acquisition of design skills, such as strategies to engage stakeholders with prototypes [35], models for incorporating human-centered design principles into global health engineering [36], and frameworks to reduce harmful voluntourism in humanitarian engineering projects [37], among other applications.

3.1 Data Collection and Participant Information

A phenomenological approach [38] was used to develop a semi-structured interview protocol with questions aimed at eliciting rich descriptions of participants' experiences incorporating contextual factors during their prior design work. Design practitioners with at least three years of professional experience designing health solutions for use in LMICs (specifically medical devices and information technologies), were recruited using a purposeful and convenience sampling strategy [39]. Following the completion of the 90-minute interviews, transcripts were coded for instances when participants incorporated contextual factors into their design processes. We defined "contextual factor" as a characteristic of the potential solution's broad use-context and "incorporate" as an instance when a participant's decision during a design process was influenced, completely or in part, by a contextual factor. A combination of the aforementioned nine classifications of contextual factors (developed by Aranda-Jan et al. (2016)) and 32 contextual factor categories (developed by Burleson et al. (2023)), presented in Table 1, were used to deductively code the transcripts [17, 19].

The three participants chosen for inclusion in the narratives and analysis presented in this study were selected from the larger dataset because they shared compelling experiences related to incorporating contextual factors, had varied years of experience, and represented different geographical regions. Michael, Sarah, and Jacob (pseudonyms) were design practitioners with 20, 5, and 8 years of design experience in global health settings, respectively. Each worked from different regions (North America, Europe, and Africa) and had their work implemented in various LMICs. Table 2 presents important background for each of the participants.

3.2 Data Analysis and Narrative Formation

We constructed the narratives from the coded transcripts. Each transcript was reviewed to identify a specific story that conveyed one or more key

Table 1. Contextual factors identified in previous work; classifications (bolded) and contextual factor categories (bullet points)

Socio-cultural • Symbols • Cultural tradition and practices • Language • Education and literacy • Aesthetics • Stigmas and taboos	**Political** • Regulations and regulatory processes • Stakeholder power dynamics • Political systems and culture • Global priorities	**Institutional** • Existing practices and procedures • Capacity and capability of Institutional staff • Institutional financial capacity • Institutional resources • Indoor environment
Infrastructure • Utilities • Transportation & Road quality • Distance • Attributes of the built environment	**Economic** • Individual and household characteristics • Regional and national characteristics • Labor market characteristics	**Technological** • Available technologies in the context • Compatibility with the technical context • Availability of consumables
Industrial • Supply & Manufacturing • Maintenance • Distribution	**Environmental** • Weather • Natural environment	**Public health** • Healthcare system and practices • Health demographics

Table 2. Participant background information

Pseudonym	Michael	Sarah	Jacob
Region based in	North America	Europe	Africa
Race	White (North American)	Not provided	Black (African)
Gender	Male	Female	Male
Highest education	MS, MBA	MS	BS
Years of experience	20	5	8
Role	Engineering consultant	Engineering designer	CEO/Founder; Engineer
Size of organization	Small	Large	Small
Region(s) work is implemented in	Africa, Asia, North America, South America	Africa, Asia	Africa

themes identified in our prior analysis. Then, we selected relevant excerpts (i.e., quotations) from their interview transcripts that contributed to the storylines [40]. Following recommendations for constructing narratives [33], we included the necessary background information and framing for all the included excerpts. In the narratives below, we have marked instances of incorporating contextual factors in parentheses including the contextual factor classification and categories that were coded. For example, if a participant described changing the material of their solution based on the local humidity and temperature, we included: "(*environmental: weather*)." Following suggestions by qualitative research scholars, minor edits have been made to some quotes to improve readability and grammar (e.g., removing "um" and other filler phrases) while leaving the meaning and intention completely intact, a process called "light tidying-up" [41]. All specific product names and affiliations have been removed and mentions of specific countries have been replaced with broader regions to protect the identity of our participants.

We acknowledge that the experiences, expertise, and identities of the research team can influence the analysis and presentation of findings. All researchers on our team had experience in international development and global health, to varying degrees. Some authors had experiences designing and critiquing technological interventions in global health settings, and others as administrators and participants of global health design projects. We acknowledge that our research team does not include many of the identities and experiences found within the field of global health, particularly those from LMICs.

4. Findings

This section presents three narratives that describe participants' incorporation of contextual factors into their global health design processes. First, Michael's narrative provides detailed examples of incorporating many contextual factors from several countries to develop a solution for use in multiple contexts. Next, Sarah's narrative provides an account of incorporating multiple contextual factors into one design decision. Finally, Jacob's narrative presents examples of incorporating political contextual factors throughout a design process and navigating multiple stakeholders in a single context. To support student learning of the breadth of contextual factors that can be incorporated in design processes, the contextual factor classification and category are tagged throughout each narrative. A complete list of and description of the contextual factor classifications can be found in The Context Cards© [42].

4.1 Narrative 1: Michael

Michael is an engineering design consultant with 20 years of experience in engineering design. Prior to his current role as an independent consultant, Michael worked for a global health organization based in North America, he described,

> "We developed medical devices for low-resource markets. I ran everything product related. I didn't really do fundraising much and didn't do the policy advocacy. But the product designers, the manufacturing sales, all the things that related to get the product out the door I managed."

Michael described his experience working on a newborn therapeutic device that could be implemented globally. He described how he and his team spent time observing the various contexts where this product would be used, which were in neonatal intensive care units (NICUs). He shared,

> "We spent a lot of time going to NICUs at different hospitals. We did it mostly in South Asia because that was our launch market, but we also had people go to Southeast Asia. And then we also had people go to East Africa and look at NICUs in those different countries and we had people go to Central Asia and South America."

He and his team chose to work on a problem that aligned with international global health and philanthropic initiatives as a way to acquire funding and

support (*political: global priorities*). Michael described,

> "The UN had the development goals – infant mortality is one of them. We would try to connect our concepts and our products to those development goals because, frankly, that's what the Gates Foundation was funding. A lot of what we did followed the money, and the money followed the public health priorities that are political. We wanted to make sure we were doing work in areas that connected to priorities that the Gates Foundation set, because they have an inordinate influence on how money gets distributed."

As the project progressed, Michael and his team identified many different contextual factors to incorporate into their design. Some were more functional in nature, for example designing the product to use components that would last longer between replacements and were less difficult to procure in the area (*technological: availability of consumables*). Other decisions focused on user perceptions based on their experiences with technology in their context. For example, even though they could have made the device smaller, Michael designed the product to be larger and more similar to the existing solutions in their intended markets (*technological: available technologies*) even if it did not need to be so large. He shared,

> "We knew that it couldn't be totally radically different from what was already on the market. That comfort level came from something that's familiar. Part of the reason we think our prior product failed is that it looked too small. People weren't convinced that it worked well enough, even though it did. But it didn't look like other units, so they didn't trust it. We knew it had to look more like all the other units that were on the local market – as a selling point – so that it wasn't too unfamiliar."

Observations of the use context inspired many design choices, including one where Michael chose to redesign the electrical components to account for the fact that the nurses were constantly "wrestling" with many different devices and cords around the patient's bed (*institutional: existing practices and procedures*). Michael shared,

> "We watched the way the nurses worked in the NICU – you would see three or four different poles next to the bed. One is for the IV, one is for light, one is for a warming unit. The bed is surrounded by all this stuff. And it all has a cord – the nurses are constantly wrestling with, and tripping over, cords. We were thinking about that and trying to figure out how do we make the cord not dangerous. And, if someone trips on it, we need to make sure it doesn't pull the whole device over. In the old design, we had electronics in multiple locations with multiple cords – so we moved all the electronics to one spot so that the only thing that came out was just one cord. It just simplified the design."

Because the hospitals were overburdened, Michael observed instances when multiple newborns were placed in the same therapeutic device (*institutional: existing practices and procedures*), which was designed to accommodate only one newborn at a time. Thus, he and his team designed their product to work for two newborns even though they still maintained it was for one. He shared,

> "The other thing that we often saw – that's sort of heartbreaking – is that, because a lot of the hospitals didn't have enough money to buy lamps, they would treat two babies with the same device. And that's bad because there's an issue with possible cross contamination if they have an infection. But they both have the disease, and they're both in pretty bad danger of brain damage – so they need the therapy too. At first, we struggled a bit with the user instructions. We were explicit to only specify that it treats one baby at a time, and we had pictures that showed how a baby should be prepared, but we knew that wasn't happening. The original design was only practical to treat one baby – but we decided to not do that – we decided to change the specifications to deliver enough therapy for two babies. Even though we didn't instruct people to use it for multiple babies, we knew they would do it anyway. So, we designed the product to accommodate it, but not make it an explicit claim, and not make it an explicit instruction."

Another detailed design change was inspired by the way hospitals operated their NICUs – keeping the room dark to allow babies to sleep. Michael chose to include an LED controls display so that healthcare workers could read the screen in the dark (*institutional: indoor environment*). He shared,

> "The rooms are usually dark because they're trying to help the baby sleep – even in the middle of the day the rooms are dark. Our initial design had an LCD on it, but it wasn't lit, so it was very hard to read the LCD in the dark. So we removed that and put an LED on display, so that the LEDs are always lit and it's much easier to read it in the dark."

Michael also had to accommodate for unreliable electrical grids in the various use contexts where they aimed to implement (*infrastructure: utilities*) and described his process to include an automated shut-off feature to protect the longevity of the device when power fluctuations would inevitably occur. He shared,

> "The power grids were bad, and we would go to hospitals and see brown outs happening while we were there. And in general, they would prioritize the NICU – so that was good. But we knew that the power supply was going to get beat up quite a bit. We bought expensive power supplies that had pretty robust tolerance to brownouts and to blackouts so that they wouldn't burn out by having the power cut off unexpectedly often. Because even getting less power, not full power, is bad for a power supply unless it's built and shielded to be resistant to the fluctuations. Basically, it shuts itself off when it doesn't have enough power,

rather than letting the fluctuations in the power damage it.''

During a later stage in his team's design process, they had to narrow down their target market, and could no longer target rural hospitals that did not staff overnight (*institutional: capacity and capability of staff*). By placing a prototype into rural contexts, he uncovered new information that would drastically impact the potential success of their technology. In this case, he learned that many rural hospitals do not provide 24/7 care, requiring his team to pivot and focus on urban hospitals that operated during all hours. He shared,

> ''So, we built this idea. We built a prototype. We went to a handful of small clinics in South Asia and Africa. And the short answer was, nobody wanted it. And the reason was that we thought the remote hospitals were the best fit for it. We went to a bunch of remote hospitals – they all said, 'we don't have 24/7 staff, so we have no overnight patients. So if a baby shows up with this disease and needs 24/7 therapy, we don't have anybody here overnight to watch them. We have to refer them elsewhere.' We had no idea that that was the case. We didn't know that even though these remote hospitals had beds and looked like a regular hospital, they didn't have 24/7 inpatient care. They were basically just outpatient hospitals. And they really didn't explain that to us until we watched them and talked to them. So the whole idea didn't work because the remote hospitals we wanted to reach were not structurally set up to do inpatient care for babies. So that was good to find out.''

When deciding the name of his team's product, Michael became aware that one of their ideas was also the name of a political movement in Africa (*political: political systems and culture*). He described,

> ''I think at one point [redacted name] was a concept. And there was an uprising in one of the African countries that was the [redacted name] uprising. And we were like, 'Oh, we better cross that one off!'''

Since this product was being implemented across multiple countries, Michael described developing instructions that incorporated less language and more graphics (*socio-cultural: language*). He shared his team's difficulty with getting their product's instructions translated into multiple dialects, which led to changing the instructions to include more pictures,

> ''We thought quite a bit about the instructions and how much the instructions needed to be in pictures instead of words, because we were translating stuff. When we went to Southeastern Asia and had to translate into different dialects. That was horrible: expensive, messy, and we did it wrong. So the more pictures we had, the better.''

Overall, observations and time spent in the different use contexts enabled Michael and his team to identify a variety of different contextual factors that they incorporated into their design. Michael's experience highlights the value in spending considerable time with stakeholders in their context to uncover nuanced and otherwise tacit contextual information that, if gone undetected, would ultimately cause the product to fail or not achieve the intended health impact. He shared,

> ''It is so ingrained to go out to talk to the people that are going to make the decisions and use the product and get the concept in front of them or watch how they use existing solutions. It's really hard to learn any of these [contextual factors] without going there and being with the people. And so, that is that context, that connection, the personal trust. It's hard to prioritize any [contextual factors] over the others . . . I think a lot of people, though, don't work on the industrial and don't work on the institutional stuff early enough. They work on the technology – and really, really focus on the technology. And that's good because that's what their skills are. But they end up designing themselves into problems because they don't know the other [contextual factors].''

Michael's story highlighted many ways contextual factors influenced the design of his solution's features, such as how its cords were managed, the size of the device, and its specifications. While some of the contextual factors described in the narrative were functional in nature (e.g., expanding the device to accommodate two newborns), others were social (e.g., the perception of quality based on the size of the device). It is important for students to understand that both functional and social contextual factors are critical to a solution's success–even though the size of the device did not change how it functioned, it resulted in greater user acceptance among stakeholders within Michael's intended use context.

4.2 Narrative 2: Sarah

Sarah is a design engineer for an international healthcare technology company based in Europe. She has five years of experience working on medical device implementation and design for use in LMICs. She described her experience working on different teams in the company,

> ''I spent three years working on the team trying to understand how to implement products. I think when you consider that, then it really shapes how you design products because you see: What are the barriers to adoption? What are the challenges that you might come across, based on the systems they're implementing, and based on the users' context? Now I'm working as a designer in the development team, and really taking my experiences from implementation to help shape the design of the different products and solutions we make.''

Sarah had been working on various monitoring devices to be used in labor and delivery wards

within hospitals in LMICs. She and her team worked closely with healthcare providers across multiple countries in Africa and South Asia throughout their design process. She described the need to narrow their target use setting early in their design process because of differences in contextual constraints among various settings. She shared,

> "If it's an urban hospital that's more resourced – one that has a lot of doctors present who 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 and stable electrical power. Whereas if we were talking about more rural areas where some of these products are particularly needed – like more than in the high-resource, urban hospitals – and solutions are needed more in the rural – there's less training, less exposure to electronic devices, less stable power, all these things come into mind when deciding the goals of the product."

Sarah recounted a series of critical questions she and her team had to answer as the design progressed. At the time, they were addressing the design question: *How should we design the way our monitors are stored and charged?* Sarah described how this one question required her to consider multiple contextual factors. She shared,

> "The idea is that, when the time comes, you quickly grab the device. You need to access it within five seconds in order to get the full value of it. So, for example, when we developed the monitor, we made it so that you can hang it up in a labor ward – but then there's a lot of little things to consider."

First, Sarah described that to design the device so that it could be stored on the wall, she needed to identify what types of wall attachments would be available in their target contexts (*industrial: supply and manufacturing*). She shared,

> "Then the question was, 'do people have screws?' That was a question, whether we should or should not provide the screws and whether people have their own and we decided people can find and have their own."

Then, Sarah needed to know if hanging the device on the wall was a common and acceptable storage practice at the types of institutions where they were aiming to implement in (*institutional: existing practices and procedures*). She shared,

> "Would they be willing to attach something to their walls in the first place? Like, is that okay to pierce their walls with screw attachments? And I think that was a big question. In some hospitals, they're okay with it, but we didn't know if this was universal."

Next, she had to consider the layout and organization of the hospitals. If the device needed to be accessed within five seconds, it needed to be nearest to where births were taking place. Therefore, she had to investigate if births occurred in one location or multiple locations within the different hospitals (*Institutional: existing practices and procedures*), which could require the product to be able to be stored in multiple locations. She described,

> "Trying to put it on a wall made sense in one context we designed it for because the hospitals had dedicated rooms where the mother is delivering, and the baby is one meter away after they're born. It made it easy to put it on the wall there. But in other contexts, with different labor rooms set ups, that doesn't work well. Do you put the device in the labor room where the mother has given birth, or do you put it in the neonatal resuscitation unit where the baby is going to be treated?"

Since the product was electronic, she then needed to consider how the product would be charged while it was stored. She had to assess availability of electricity in general (*infrastructural: utilities*), and the prevalence of wall sockets in rooms throughout the hospitals (*institutional: institutional resources*). She asked,

> "And the idea is that wherever you place it, it's chargeable at all times. But then the question is, do you have sockets in the place that you would want it? And, do you have a socket available where you expect people to keep it?"

She quickly learned that since electricity was unreliable in many contexts, it would be important to design the product to last a while between battery charges. She described,

> "We designed the device to take a few hours to charge and then you can use it for months. Because of lack of reliable electrical supply and because we know wall sockets are rare, and you don't want the device to fail when you really need it. We made sure that the battery has a good lifetime."

Sarah then had to consider how the product might look if it was hanging on a wall in a clinic. She shared a story of a prototype being used in a South Asian clinic where they locked it away in a drawer because the healthcare workers believed it looked very valuable (*socio-cultural: cultural tradition and practice*), and worried that someone might try to steal it. She shared,

> "It's a pretty big investment for the hospital, and to have it on the wall means to have it untethered and just easy for somebody to just pick it up and take it away. Because we're designers, we like to make things look quite nice, we designed it so it's very sleek – but because it looks very sleek, it also looks like something expensive. But, if you lock something up like that, when the time comes and you need it, it's a little bit hard to get it out of like a cabinet and use it."

Ultimately, she and her team chose to make the way the product was stored flexible, she described,

> "We made it so that the attachment can be something

you put against the wall or you can just put it on the table. It sits up in a certain way so that you have the option of putting it on a table or you have the option of putting it on a wall.''

Overall, Sarah highlighted the importance of considering how multiple different institutions use and store their product, so that they could make sure to design accordingly for all the potential use contexts. She described,

''I think it's always important when you're designing to take into account multiple different contexts and make sure that what you're building works for all of them – or, understanding which specific contexts you're building for. Previously, I think we were doing this thing where you look at one low resource context and expect the same in other contexts and I think it doesn't really match up.''

Sarah's story demonstrated the ways multiple contextual factors can influence critical use considerations that ultimately impact design decisions, in her case the design of the storage mechanism. Her story highlighted how the hospital practices, layout, resources, access to electricity, and cultural perceptions of ''expensive'' all played a role in her team's decisions. One design decision can require multiple contextual factors to be considered – in her case, she evaluated if attaching the device to the hospital wall would be appropriate across hospitals universally or if a more flexible product (i.e., attachment for walls and tables) would be needed for different contexts. Sarah's story demonstrated her understanding that either the design or its intended use context can be adjusted to ensure a proper design-context match.

4.3 Narrative 3: Jacob

Jacob is an electrical engineer from Sub-Saharan Africa with eight years of design experience. Several years ago, he co-founded a company to develop technologies to improve health outcomes of vulnerable communities. He led the development of a device and information system to diagnose a prevalent disease in a specific country in Sub-Saharan Africa. His project started out as a diagnostic tool and then transitioned into a larger information service. He shared,

''As we were working on a diagnostic device, we realized that there is an opportunity, as requested from our patients, to digitize the processes because most of the healthcare processes are paper-based, right? We realized as we were collecting feedback and doing field testing with the device that a lot of data was being lost in that process. We saw this as an opportunity and said we could capitalize on building out digital surveillance systems specifically for the spread of this disease – where we have a patient come in and all that process is digitally mapped out and can be recorded, which can help the health facility get all those details and report to the district in a more organized manner. So, after realizing that, we created these digital tools, and we rolled them out in some of the network hospitals that we've been working with. Then, we saw people starting to use the tools to organize their documents at the point of care. Also, hospitals are starting to use these tools to help them report in their weekly reports to the Health Ministry.''

As Jacob described, although his original plan was to develop a diagnostic tool, he identified an additional opportunity to improve data management for patients and the hospitals, as well as to help with reporting to the local health ministries to improve local datasets. Because of the nature of this project, Jacob focused on engaging with local government officials throughout his design process. He described,

''In Africa, by policy, most of our healthcare is subsidized by the government. So, the government writes most of the policies of healthcare and most of the money going into healthcare in Africa is from development aid handled by the government. This makes the government a key critical player in any healthcare intervention or innovation that you're trying to create.''

Early on, Jacob was sure to identify any relevant laws that his project would need to comply with (*political: regulations and regulatory processes*). He described new regulations related to healthcare data storage that drove the direction of some of their product decisions. He shared,

''In my country, we have a new data act that came out a few years ago that defined that all healthcare data belongs to the patients, and it shouldn't be housed on international servers and things like that. So, in these contexts, if you understand this before you start developing, it will influence the direction of your product. But, if you do not know that, then you'll have to readjust your strategy to fit into their policy frameworks.''

Jacob worked closely with government officials and treated them as partners to design *with*, rather than clients to design *for*. In this way, he was able to engage with them more deeply and receive advice and clearances. He shared the need for their support and connections to local hospitals,

''When you look at the government, others look at having the government as their clients. But it's hard to have the government as a client in healthcare, I would rather have the government as a partner, so that they buy in. We started by trying to engage at a district level and tried to get the district health officers or officials involved. And then these district health officials were able to give us clearance to go and work. Also, some of them are able to advise in the hospitals that we work with. So, they were able to give us this clearance and a list of a few hospitals that we can reach out to and see how we can partner with them.''

He engaged with government stakeholders during the early stages of his design process.

Jacob described the need to build rapport to get their interest and support (*political: stakeholder power dynamics*), which ultimately enabled him to move quickly in his design process. He shared,

> "It takes time. It's not that the first time you go in is the first time they're going to listen to you. So, you need a lot of continuous back and forth to make sure that you get tangible support. Because if you get, for example, a recommendation from a ministry, that's going to help you move into any district and get a full out signature from a district health commissioner and then move into any health facility as you wish. So that top-down approach helps you lift a lot of weight and then helps your implementation move a little bit faster."

Importantly, Jacob clarified the importance of remaining neutral with respect to local political figures and parties (*political: political systems and culture*). Even though he had invested a lot of time engaging with local government officials, he was careful to not attach his product and service to a particular politician or political movement that may change or lose political power. He described,

> "You have to be as neutral as possible for any products that are going to last in this economy because if your product is depicted as a product that is pro-some-politician and that politician leaves, then other people will not use that product ever again. So you have to be very, very careful. Because, to the politicians, they want a good product to come up as their initiative and many start-ups fall for that."

In addition to government stakeholders, Jacob frequently met with domain experts to identify future directions for his company's services. He organized quarterly stakeholder meetings to bring in people with various experiences that could inform his design. He shared,

> "We have those continuous engagements at the different levels. The other quarter we met with different experts trying to pick their brains on what they think the future looks like when we talk about digital disease surveillance and how can that be made better."

Another critical stakeholder group for Jacob was hospital administrators. He paid close attention to them to get their buy-in while he was designing the diagnostic device (*political: stakeholder power dynamics*), and later to identify additional requirements for the device and service based on the needs and constraints at the hospitals (*institutional: existing practices and procedures*). By engaging with hospital administrators, he uncovered their need to regularly share information with the government, who was funding them. Jacob described his process for incorporating this contextual need,

> "To the hospital administrators, their main worry is, 'how do we make sure that we serve patients better and how do we report better,' because that's their main role. If it's a government facility, they have to make sure that the processes are all right. So, they need that data weekly to make sure that they can report their cases that are coming in and they can do procurement for medicines and other kits that they want. The easier you make that for them the better. So we have improved that, we've rolled out things like SMS notification, every Friday we send out messages of the total number of disease cases each hospital got that week. We also do the same landscape report for the country's health demographic program, send them a debrief of how the week has been and of cases versus the cases that have been received last week. This has actually helped us increase engagement at the hospital level – of course, adoption is always slow but they started realizing this value – all those insights are from our continuous engagements."

When pitching to different groups of stakeholders to collect investments, identify future clients, or develop partnerships, Jacob emphasized the need to thoughtfully frame and focus on different aspects of the project (*political: stakeholder power dynamics*). Although his solution was designed to meet multiple needs, he intentionally chose which features and intended outcomes he discussed with different stakeholders to ensure that he was discussing aspects that mattered most to each stakeholder group. He described the differences,

> "It is different if you're talking to a person in the 'development and aid world' versus a person in the private sector because their needs and interests are different. In the 'development and aid world,' it's more about impact and numbers of lives saved. So, the way you pitch such a person to get, let me say, a possible client with a possible partnership is very different."

Although his work to date has focused on one country, Jacob has deliberately considered international standards that would allow him to potentially scale his product in different contexts in the future (*political: regulations and regulatory processes*). If he only concentrated on meeting the regulations in one country, he would face problems later on if he chose to implement in other countries, including potentially needing to redesign features and navigating recertification processes. He shared,

> "And for us, in our context, when we talk about standards – both at the hardware level and software level – you realize that if you want to do a multinational business and you're only targeting a country-level standard, it's hard to scale. That means you will be filing for a standard check in every country. So, for us, strategy-wise, what we have been able to do is go back and look at what global standards are acceptable in the countries that we want to eventually deploy in – then try to see what it means to go after that standard, that certification."

Jacob emphasized that identifying many of these contextual factors, particularly those related to the political environment, was critical during the early design stages to define the solution space and identify pathways forward. He described,

> "It's always key to think about contextual factors as early as possible. I think these hold a very key position in the success of a business. And it doesn't mean you can't iterate and come back and try whatever things, but it helps you know the direction you want to take from the point where if you look at it from this global view. We should be thinking about those things at an early stage so that we can judge the pros and cons of each, understand them, and define a pathway."

Jacob's story presented examples of incorporating the political context, by engaging with decision-makers across multiple levels (e.g., hospital administrators and government officials) and deeply understanding the formal (e.g., regulatory) and informal (e.g., connections and rapport) political structures in place. His story suggests that in countries where the government is deeply involved in healthcare, designers should pay careful attention to political stakeholders – those who hold decision-making power and can help progress or hinder a design process. Engaging with powerful stakeholders is not only necessary to identify additional constraints and requirements for the solution, but also important to help streamline and progress the process, ultimately helping designers integrate their solutions into existing social and political structures.

5. Discussion and Implications

Scholars recommend that design practitioners in global health settings deeply understand the context where they aim to implement [3]. Our case-based narratives presented detailed accounts of how experienced practitioners have investigated context and incorporated contextual factors into their design processes. The practitioners in these narratives followed design processes that focused on conducting meaningful engagements with stakeholders and developing deep understandings of use contexts. While designing devices for use in multiple countries, Sarah and Michael engaged with hospitals in different global regions to identify critical contextual constraints. Jacob, who developed a solution for one specific context, worked closely with government stakeholders and carefully considered the political context in that region. Our prior analysis [16] identified several fundamental approaches used by design practitioners when designing within global health settings. For example, they engaged with a broad set of stakeholders to identify critical contextual factors and incorporated these considerations into their products' features and implementation strategies or by narrowing the target context to find a suitable "match." Participants were also iterative and reflective throughout their design processes and remained attuned to new contextual information that may affect their design outcomes. The findings in this study, presented in the form of narratives intended to be used in educational settings, expand on these themes and add additional nuance and depth. The narratives can be used in educational settings to expose novice engineering designers to examples of ways design practitioners incorporate contextual factors during design work.

5.1 Themes Across the Narratives

The narratives highlighted the importance of building relationships and engaging with stakeholders across multiple levels. Michael's story showcased an example of paying close attention to the needs of direct stakeholders, such as the nurses who operate his device. By closely engaging with these stakeholders, Michael identified key contextual constraints to integrate into his solution's features. Jacob's story highlighted an example of considering various stakeholders, such as funders, government officials, and hospital administrators. Jacob was attuned to the visions and goals of each of his stakeholders and carefully integrated their needs into his solution. He saw his stakeholders not as clients, but as partners. Indeed, partnerships are critical for progress towards the UN Sustainable Development Goals (SDGs) [43], such as SDG 3: Good Health and Well Being. Scholars suggest that good partnerships include commitments to developing strong relationships to build trust, grow inter-organizational understanding, and encourage the coproduction of solutions [44, 45]. Our findings add that building relationships and rapport with stakeholders across multiple levels enables identification of context-specific needs and constraints during design processes.

The narratives also described how first-hand observations of the use context were critical to identifying contextual factors that would otherwise be undiscovered. Indeed, prior work has demonstrated the value that first-hand observations bring to global health interventions [46]. Our narratives highlight some key examples of this value in engineering design processes. For example, Michael witnessed nurses placing two newborns under a single therapeutic device, which would typically lead to ineffective results. To fit this practice, which in part was due to the hospital being overwhelmed with patients, Michael redesigned the device to accommodate two newborns being treated by the device at one time. Like many contextual factors, they may appear subtle, yet they have the potential to lead to critical differences in health outcomes related to their use. It is important to note that Michael chose to address this practice by changing the device's design versus assuming that the end users would always follow on-label use

standards [47] or by trying to change the end users' behaviors. Instead, he recognized a root cause of the end users' behaviors, which was that the hospital was overburdened, and accounted for this contextual factor when developing specifications.

The practitioners presented in the narratives visited the use contexts regularly during their design processes, letting contextual factors emerge rather than follow prescribed contextual frameworks. Sarah's story highlighted how bringing prototypes into the use context enabled additional considerations to emerge, allowing her design team to explore a critical design question: How will the device be stored and charged? Jacob's story highlighted how his openness and regular engagement with stakeholders in the use context led to identifying additional value propositions, in his case, to incorporate a digital service alongside the diagnostic device. Ultimately, these adaptive approaches led the practitioners to develop solutions that would be more usable and thus have a more positive impact in their intended contexts.

Additionally, the narratives showcased examples of intentionality when identifying use cases and designing for their contextual constraints. Sarah and Michael had to choose between urban or rural hospital settings due to differences in resources and hours of operation. They looked for a ''match'' between contextual factors, stakeholder needs, and their solutions. Ultimately, they made explicit statements regarding the contexts in which they recommended their products be used. These findings contradict some traditional approaches in global health, particularly the Appropriate Technology movement, which emphasized creating solutions ''cheap enough'' to be used by everyone, assuming universality that often neglects other social and institutional contextual factors [7]. Instead, these narratives highlighted how designers applied rigorous design processes in global health settings and intentionally identified suitable use contexts; they also acknowledged the limitations of their solutions and did not oversell their products' potential use scenarios.

All narratives highlight how engineering designers balanced universal and context-specific design considerations. For example, although Jacob has only worked on implementing his solution in one country, he intentionally followed international guidelines so that he does not have to adapt some design aspects if he chooses to scale to other locations in the future. Additionally, Michael's narrative highlighted the work and effort he put in to developing a device that could work across multiple contexts while also recognizing that some aspects (e.g., instructions and labels) needed to be context-specific, aligning with prior literature that recommends the development of culturally-suitable instructions and graphics for global health solutions [48]. Sarah's narrative provided an example of designing a feature to be adaptable by users so that her team did not need to develop customized features for multiple use contexts.

While these narratives offer only a small window into these participants' approaches to developing solutions and incorporating contextual factors, it is important to note that each participant did not consider every possible contextual factor. Instead, they focused on allowing contextual factors to emerge during stakeholder engagements and first-hand observations. Participants regularly brought prototypes into the context and followed an open-minded and adaptive approach to iteratively incorporate contextual information as it arose. This finding builds on prior work that suggests that engaging stakeholders with prototypes is one way to identify relevant contextual information [13, 26, 49]. Participants also focused on building relationships within the use context and remained attuned to stakeholder values and contextual constraints. Each participant's story highlighted different ways to adeptly consider contextual factors within engineering design, emphasizing that incorporating contextual factors is not a prescriptive process, but a nuanced and iterative one.

5.2 Design Education Implications

Each narrative provided a unique perspective and real example of navigating complex contextual information. Since engineering students face various challenges when trying to incorporate contextual factors into their curricular and co-curricular design processes [50, 51], the narratives provide instructors with a specific tool that presents examples of practitioners navigating broad contextual information and deciding when certain information should be incorporated into their design work. For inexperienced designers, we recommend instructors follow a case-based learning approach to facilitate interpretive and analytic discussions with the narratives, focusing on how the characters gathered, synthesized, and applied contextual factors into their design processes. Alongside the narratives, instructors can use The Context Cards [42], which include the full list of contextual factor classifications and categories identified in our prior work.

5.3 Limitations

This study design did not allow us to connect participants' methods to specific design outcomes or make claims about their ultimate design success, and highlighted incorporation of contextual factors by a limited number of participants. Findings presented in this study may not be representative

of the broader field of global health design practice and may not be transferable to other design domains. Further, we collected data through retrospective interviews and participants likely did not recall all examples of incorporating context.

6. Conclusion

Our findings provide in-depth examples of three design practitioners' experiences incorporating contextual factors into global health design processes. We sought to develop narratives that could be used during case-based learning approaches to present examples of practitioners navigating broad contextual information and deciding when certain information should be folded into their design process. The aim for developing these narratives was to expand the existing tools and techniques available to teach incorporating context into engineering design curricula. We recommend that early-career engineering designers, especially those who aim to work in global health settings, learn from the experiences presented in the narratives to inform their own mindsets and methods. Designers should be aware and knowledgeable of the different types of contextual factors that may influence their design process and outcomes. Specifically, design practitioners should regularly conduct first-hand observations, develop meaningful relationships with stakeholders, and use iterative and adaptive design approaches that allow for contextual factors to emerge throughout a design process. The three narratives can be used in case-based learning settings to help demonstrate how contextual factors can be incorporated in design processes, and expose students to the breadth of contextual factors that may influence their work. The findings from this work have implications for engineering design pedagogy and, ultimately, the potential to support engineering students' acquisition of skills related to incorporating contextual factors into design processes.

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