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Research article

"It feels different when blindfolded": Developing social empathy through inclusive designs in STEM

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Abstract: Narratives about STEM (science, technology, engineering, and mathematics) education are strongly connected with conversations about developing learners' humanistic knowledge and their ability to listen with understanding and empathy. This is challenging because learners need to find resonance through first-hand contextual experiences with the issues at hand. In this paper, we describe and discuss an activity that was enacted to actively engage 74 teachers from Thailand in constructing a prototype cutting device for the blind to prepare food themselves. This activity underscores important considerations for inclusive design and offers affordances for teachers to develop their learners' inclusive mindsets. Findings were generated from voice recordings of reflections and written reflections collected after the activity. We highlight the importance of creating opportunities for learning to listen and resonate with others' experiences and argue that such STEM activities can offer a platform for learners to develop humanistic qualities such as social empathy.

Keywords: humanism, social empathy, STEM, inclusive design, user-centric STEM

1. Introduction

Narratives about STEM (science, technology, engineering, and mathematics) education have been strongly connected with conversations about developing students' 21st century competencies [2]. 21st century learning entails humanistic knowledge such as social empathy, cultural sensitivities, and inclusive mindsets. Humanism underscores the agency of human beings as part of the larger ecosystem. Whilst important, imbuing learners with humanistic values cannot be done through indoctrination. Rather, learners need to find resonance through first-hand contextual experiences with the issues at hand. In this paper, we argue that STEM activities can offer a platform for learners to develop humanistic qualities such as social empathy, amongst others.

To that end, we describe and discuss an activity that was enacted to actively engage 74 teachers from Thailand in constructing a prototype cutting device for people who are visually handicapped. Through such an experience, the teachers made sense of the needs of individuals and incorporated their considerations into the design of the prototype to enable people who were blind to prepare food for themselves. The activity underscored design considerations and sensitivities to challenges confronted by people who were visually handicapped were honed. This inclusive design activity has the potential of developing learners' inclusive mindsets, an important precondition that learners should have to engage in meaningful dialogue about reducing inequalities [13] for all.

2. Inclusive designs for the blind

According to Morales [7], inclusive design considers the full range of human diversity with respect to ability, language, culture, gender, age, and other forms of human differences. He argued that inclusive designs are important because they enhance user experience and increase accessibility for all. By accessibility, we meant that no one is left behind and intentionally or systematically excluded due to their existing conditions. Accessibility is key to reducing inequalities around the world, especially for the approximately 15% of the world's population which experience some form of disability [11]. When accessibility is achieved, the margins where specific groups of people navigate due to limitations (e.g., lack of relevant funds of knowledge, physically impairments, social castes, etc.) becomes the mainstream of society. For instance, tactile paving foot paths at train stations are a common feature in many stations around the world to facilitate navigation for the visually impaired. Ramps are also commonly found at shopping malls, schools, and train stations of many cities for people who travel on wheelchairs.

While inclusion is desirable and perspectives of inclusivity can be inculcated in schools, a key question remains: How do teachers teach these ideas to students in a non-contrived and non-indoctrinating manner? According to Dewey [5], experiences and interpretations of objects and situations do not happen in isolation but in connection with the contextual whole. This implies that the concept of inclusion can be introduced to learners through authentic learning experiences that would afford them the context to acquire the situated knowledge of the topic and situated content knowledge of the discipline being put into use to problem solve. One way to change how students think about inclusivity is to create experiences for them to learn to listen with understanding and empathy [4]. Listening to differently abled people may promote "bridge-building, exploring experiences outside our own, so that everyone, disabled or not, gains an understanding of the others' concerns, perspectives and solutions" [8].

In this paper, we describe an activity where our learners are teachers in a larger three-year STEM teacher capacity building program in Thailand. A total of 74 teachers from eight schools from different regions in Thailand participated in a one-day workshop as part of a STEM convention. The workshop was a mini hackathon where teachers worked in teams to collaborate in the design and prototyping of a device that helps people who are visually impaired to cut vegetables safely. One of the schools had fewer teachers and hence, they collaborated and formed a total of seven teams. Details of the activity are provided in the next section. Data collected include photographs of the prototypes created by the teachers during the workshop, voice recordings of the teachers' reflections after the activity, and teachers' written reflections about a month after the event. We analyzed the data via an emergent coding approach to identify codes that were then consolidated into themes [9]. The constant comparative approach was also adopted by ensuring that whenever a new code was identified, the researcher returned to all the previously coded data to look for evidence that will fit the new codes [6]. The coding was independently checked by a coauthor to ensure 100 percent agreement in the coding.

3. About the activity: A user-centric integrated STEM approach

The design activity was implemented with a group of 74 teacher participants, working in groups of between five to eight members. The activity, which was designed with reference to the user-centric integrated STEM approach proposed by Teo et al. [10], was completed in two hours. The approach entails specifying the context of use, requirements, or user goals, creating design solutions or prototypes, and evaluating designs.

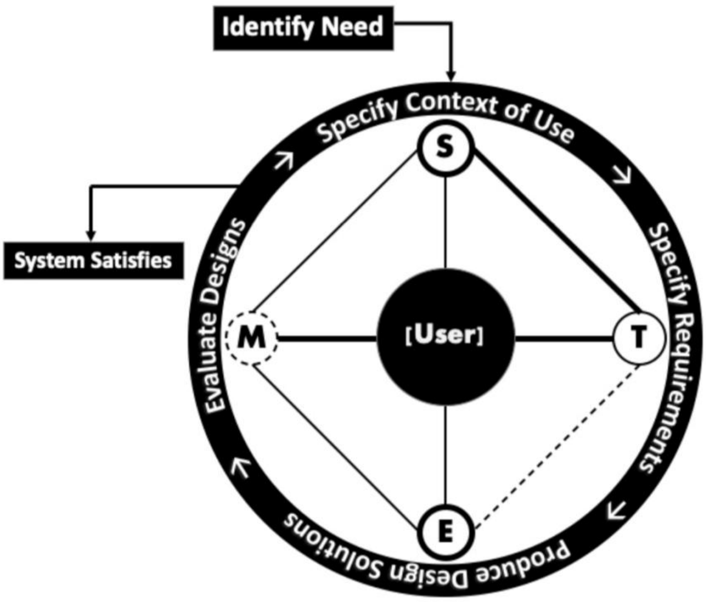

Figure 1. A user-centric approach to STEM integration [10].

As seen in Figure 1, the process begins with the user "to drive the iterative processes of understanding the user and context, ideating solutions for the user, creating solutions for the user, and evaluating solutions with the user" [10]. The idea is to focus on the user—how the user perceives about the problem, what the user wants, and what constitutes a solution for the user. The approach is iterative and engages learners in learning about the problems faced by the specified users in a particular context, validating and evaluating their proposed design solutions with the users so that the needs identified are satisfied [10]. By focusing teachers' attention on critical aspects of design considerations specific to the targeted group of users, we provide opportunities for them to" notice things that others do not" and "imagine solutions that are inherently desirable and meet explicit or latent needs”, which are the key characteristics of a designer with empathy [1].

At the start of the session, the context was presented to the participants in the form of a lecture. To appreciate the extent of the problem, the participants were told that in 2015, there were an estimated 253 million people around the world with some form of visual impairment. Many individuals with visual impairment long to lead independent lives but face challenges with daily activities such as preparing food, cooking, and lacing up their shoes. The scenario presented to the participants is in the form of a conversation between a group of community doctors and a team of innovators. The community doctors noticed that many of their patients who had visual impairment often sought treatment for cuts on their fingers, with some even needing stitches. These patients hurt themselves while trying to cut food for cooking. The doctors had approached the volunteers to create a device to help the visually impaired in the community stay safe while preparing food for cooking. The participants, in their groups, took on the role of a team of innovators who volunteer in the community in response to the requests by the doctors.

3.1. Specifying requirements or user goals

The device created needs to be low cost, easy to use, reusable, and did not take up too much space in the kitchen. The materials given to the participants included: (1) two empty large plastic bottles (1.5 liters), (2) three metal key rings, (3) five ice-cream sticks, (4) one glue stick, (5) five elastic bands, (6) two modeling clay, (7) one 30-cm ruler, (8) one roll of plasticine, (9) one penknife, (10) one cutting board, (11) one eye mask, and (12) a 15-cm ruler. Once the participants understood the context and the problem, they were given an eye mask, roll of plasticine, and a 15-cm ruler. The roll of plasticine simulated a carrot, and the 15-cm ruler simulated a knife. The participants were told to put on the eye mask and asked to put the plasticine into several even size pieces. As the participants were not able to see, we observed that many used their fingers as markers to identify where to cut. Once they had cut the plasticine into pieces, the participants removed their eye mask and were amused by the uneven pieces of plasticine. They realized that if the ruler was a real knife, they would hurt themselves. Given this experience, the participants had a better idea of the challenges faced by an individual with visual impairment. The participants were given two hours to complete their design and build a working prototype.

3.2. Creating design solutions or prototypes

The participants settled within their groups to brainstorm on possible designs of a device that would ensure that the knife does not touch the fingers of the user. They also considered where the food should be placed and the cutting mechanisms of their devices. The participants drew their design on paper with members offering ideas for improvement. While planning their design on paper, participants were seen touching and examining the materials provided. They considered the materials, focusing on the properties of the materials and how they can be incorporated into the final design.

We noted that of all the seven groups, only one group searched online for a possible solution. The rest of the six groups relied on their blind-folded experience for design. They positioned themselves as users of the device as they had just had the experience of trying to cut food while blindfolded. The participants proceeded to build the prototype after they completed their planning on paper. The building process with lively and participants cut, pasted, and assembled the various components of their device.

3.3. Evaluating designs: Focusing on “user” feedback

At the end of the two hours, participants were invited to bring their prototype to the front of the class to be tested by the third author who is blindfolded (henceforth known as tester). The tester was blindfolded before the prototype was presented to ensure that the condition of use of the device is as authentic as possible. Afterall, the visually impaired using the device would not have seen the device before using them. After the first group had presented their ideas, the participants were invited to challenge the previous group by bringing their prototype to the tester. The tester would compare the ease of use and the level of confidence he felt using each prototype after each try. During the testing, we observed that all the groups held the hands of the tester and guided him to feel the various parts of their devices. After they explained the parts, the tester was presented with a piece of plasticine to cut.

4. User-centric prototypes created by teachers

In this section, we describe and discuss the prototypes that were created by the seven teams of teachers. The seven school teams created different prototypes for safe cutting. The presentation took the form of a challenge where each group took turns to present if that thought that their prototype was better. Prototype testing was carried out by blindfolding one instructor who had not tried the activity. Each team sent a teacher to provide verbal instructions to the instructor to cut a piece of clay (i.e., “vegetable”).

Group 1 prototype (see Figure 2) was a cut up plastic bottle with a hole for the finger to hold the vegetable (i.e., clay). The plastic shielded the finger from the knife. This design was simple in providing control and protection to the fingers while the right hand holds the knife (i.e., ruler) for cutting.

Figure 2. Instructions were given by a teacher in Group 1 to the blind folded instructor to wear the prototype and cut a mold of clay. The prototype was a cut up bottle with an opening for the finger to feel and hold the mold.

Group 2 made two simple prototypes; the first prototype was made from paper provided for sketching of their designs (see Figure 3). They folded it into a quadrant for three fingers and a thumb to hold the vegetable. The second prototype was a plastic with an ice cream stick inserted to ensure that the vegetable was about 1.5–2.0 centimeters away from the shield. Below the shield was a holder for better grip. At the same time, it allowed for the fingers to hold down the vegetables for cutting.

Figure 3. Group 2 prototypes comprise the folded paper (left) and plastic shield with a horizontal ice-cream stick for distancing the knife.

Group 3 prototype (see Figure 4) was different from the other groups. The cutter was fixed to the plunger and cutting was done by pushing the vegetables through a sieve. This required more force and since the "sieve" was made of clay, the structure broke when trialed.

Figure 4. Group 3 prototype was a push cutter. The clay was used to make the sieves. However, these were not secure and hence, the sieve was pushed down together with the plunger. The concept on how the prototype worked, however, was communicated.

From Group 4 onward, the prototypes became more complex. Figure 5 below shows Group 4 prototype that provided a tube that is scaled using rubber bands to provide the "feel" and estimation of equidistant cutting. The end of the tube had claws for the vegetables to be gripped. The vegetables could be chopped by pushing down the knife. The knife would return to its original position automatically when released.

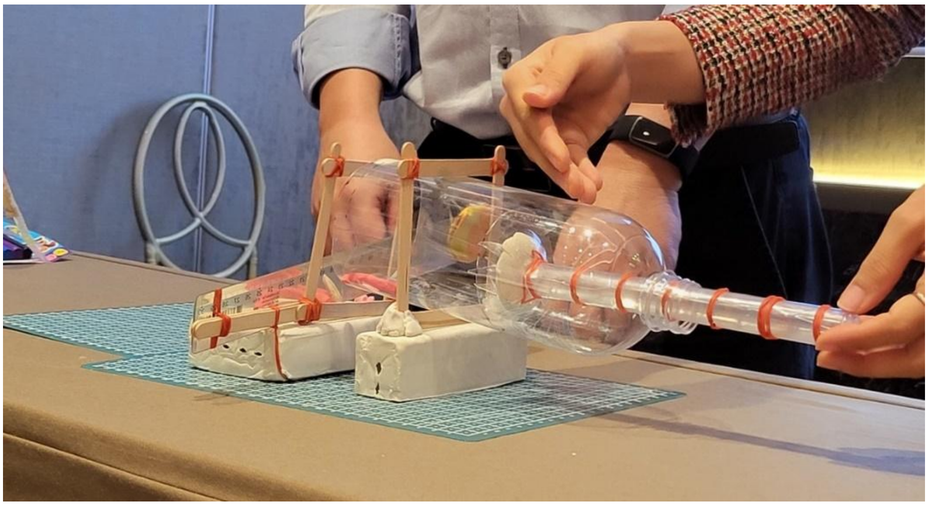

Figure 5. Group 4 prototype comprised a horizontal plunger with claws to hold the vegetable. The rubber bands were equally spaced to ensure the cut vegetables were equal in sizes. The knife could be pushed down as the vegetables were pushed horizontally across from left to right.

Group 5 prototype (see Figure 6) was similar to that of Group 4 with the main difference in the handle of the knife. A T-shaped handle was added as an extension to the knife so that the instructor could find the handle to the knife more easily. However, the horizontal plunger did not have rubber bands. Hence, the sizes of the cut vegetables may be unequal. Additionally, the knife would not automatically spring up at rest position. This was a safety element that was not present in Group 4 prototype.

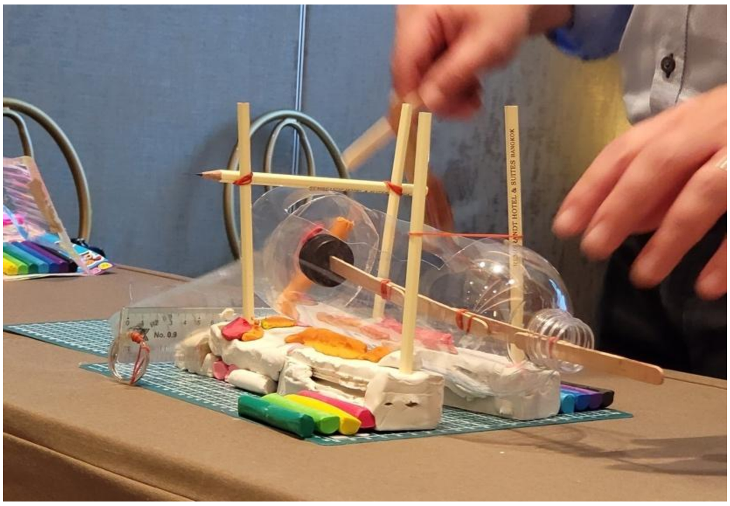

Figure 6. Group 5 prototype that was similar to Group 4 prototype, but it did not have rubber bands. The rest position of the knife was parallel to the table.

Group 6 prototype (see Figure 7) was the most unique as it used the idea of a box for cutting. The vegetable would be placed in the box and the cover containing the blades would cut the vegetables when pushed down. This design did not require the hands to be in direct contact with the knife and vegetables. However, safety concerns about the exposed blades when opened were raised.

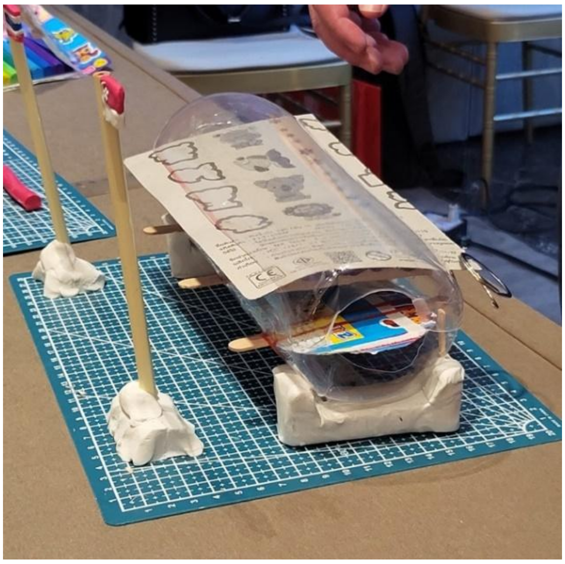

Figure 7. Group 6 prototype was a container cutter. The blades were on the inside and upper cover.

Group 7 prototype (see Figure 8) was similar to Group 4 and 5 prototypes as there was a shield and the vegetables were being pushed across the bottle. Similar to Group 5 prototype, the rest position of the knife was parallel to the table. However, unlike Group 4 and 5, the prototype did not have claws to hold the vegetables.

Figure 8. Group 7 prototype that was like Group 4 and 5 prototypes. However, the vegetables would not be attached to the pusher.

4.1. Group 1 and 3 prototypes differed from Group 2, 4, 5, 6, and 7 designs in two aspects. First, the hand, knife and vegetables were in closer proximity in Group 1 and 3 prototypes. Design elements for enhanced user-centricity

The instructor could feel and touch the vegetables that were being cut. However, the fingers were separated from the vegetables by another medium in Group 2, 4, 5, 6, and 7 prototypes. The direct contact between the fingers and vegetables was lacking. Although adding an additional medium between the knife and fingers may seem to provide an additional safety measure, the instructor who was blindfolded also felt a loss of control. Because of this, design elements that offered additional feeling of control, such as the additional grip on the ruler in Group 5 prototype, was preferred.

Second, Group 1 and 3 prototypes that allowed for protection and direct contact between the fingers and vegetables were more parsimonious in design and the use of materials. While each group was provided the same set of materials, the challenge could be levelled up by judging the quality of design based on the amounts of materials used. If a price were tagged to each material given used, this could result in different designs as students will learn to optimize the materials given to create the most cost effective and efficient prototype. Such judging criteria could bring about important learning lessons for students as they learn to design based on economics and optimization. They will learn that while people and industries know that there are better solutions, these may not be accepted commercially due to other considerations such as material availability, cost, and complex manufacturing processes.

Notably, the context of designing for people who were visually impaired resulted in safety being a major factor in deciding the winning design. As such, the winning prototype was the quadrant created by Group 3. Although there were controversies about the use of materials, the instructor picked the quadrant prototype because it was easier to handle, and he could feel the grip on the vegetable. In other words, simplicity and “feel” became the two main deciding factors in his judging.

We wish to qualify that these criteria may differ for people who were visually impaired as needs were not always the same between those who were and were not visually impaired and among those who were visually impaired. While this activity exposed the teachers the idea of user-centric designs by considering the needs of people who were visually impaired, we were cognizant of the fact that the experiences of someone who was born blind and those who became visually impaired would be different [12]. Some groundwork needed to be done to better advise on the judging criteria. This could be built into the design of the hackathon with more time as the participants could conduct inquiry to better understand the real needs of specific groups of learners and to design their solutions specifically for them without losing the potential of scaling up to reach other groups of users. Given more time, the teachers could revise their prototype after gathering more insights (e.g., through interview or researching online) about the needs of these two groups of users.

5. Reflections by teacher participants

Here, we will share three key learnings from the teacher participants’ reflections on the user-centric STEM activity—the importance of listening, creating resonance, and developing key 21st century competencies.

5.1. Listening in

The teachers learned from listening to the other school presentations. They were “listening in” in an evaluative manner as they identified criteria that could be used to evaluate their own prototype while comparing the different prototypes. Below are some excerpts from written reflections by the teachers.

> *After listening to feedback from other groups, each group's prototype has its own strengths depending on the context of the real problem. Creating a good prototype means taking the*

problem that actually occurs around us as an urgent problem that needs to be solved and being able to use the prototype created to solve the problem that has arisen. I think our group's prototype is good because it is easy to use and suitable for visually impaired people. (School NS, written reflection, 31 March 2023)

After listening to the other groups, we think the prototype was quite good, but it was not the best. It was similar to some groups; we used the same principle that is the lever exerting force on the tip of the knife creates resistance force in the middle and has a fulcrum point at the end of one side. Although our prototype was quite good, but it would be better if we developed it. It is like the simulated blade area our group has a handle to prevent danger from the blade. Moreover, one of the most important things that we have learned from the demonstration during Ban Heng tried to use any prototype if we were blind, we couldn't see anything at all, so we have to design thing we should be aware that a product make them feel because the strong sense of the blind it may be touching. They use their sense to imagine what they did. (School PS, written reflection, 31 March 2023)

After listening to the other groups, I believe that my prototype was moderately responsive to user needs, but there is definitely room for improvement. In particular, I think that the prototype could be made more user-friendly and secure. These are important considerations that can greatly affect user experience and the overall effectiveness of the product. As such, I plan to take this feedback into consideration and make the necessary improvements to my prototype. (School BS, written reflection, 31 March 2023)

The three excerpts illuminated the teachers' evaluative lens that they were listening in for comparison to their own work. This suggested the active engagement of the teachers as they were not simply "listening to" the presentations; rather, they were actively listening for the purpose to identify criteria that could be used for judging their students' prototypes should they replicate this activity in their own schools. Such skills could be imbued in students when they are asked to listen to presentations. In so doing, teachers can create learning experiences for their students to rethink about their own assumptions about disability and become more aware of the need to develop empathy and understanding of differently abled persons [4]. As highlighted by Payling et al. [8], "inclusion is not about producing solutions to meet a particular range of needs; it is about a change in our thinking".

5.2. Creating resonance

The teachers were cognizant that not all students would resonate with the topics. Although the problems may be authentic, students may not have the necessary experience to understand the problem. As such, they would have to inquire and learn from the community. For example, one school team reflected:

To raise awareness of the importance of the problem, students will learn outside the classroom and experience the real-life situation through interviews with residents, community leaders, and government officials involved with people with disabilities. They will then research the long-term impact if the problem is not addressed and how it can lead to harmful consequences. To ensure *that students receive comprehensive knowledge, the teaching process will involve a PLC (Professional Learning Community) approach, with expert guidance to advise on the teaching process in the classroom and ensure that students understand and gain the most knowledge possible in each subject area. (School NS, written reflection, 31 March 2023).*

As adults with broader worldviews [3], the teachers also found challenges in understanding the needs of those who were visually impaired. This raised an important point that while topics that were presented to students may be authentic and important, it may not necessarily resonate with students because of the limited worldviews and life experiences. As mentioned by the teachers from School NS, it would be necessary to provide support for students, like the PLC that teachers were engaged in to learn as a community in a peer support manner.

5.3. Developing a repertoire of STEM competencies

The teachers also commented that the activity would support the developing of diverse competencies and many of these were identified as 21st century competencies espoused in several documents (e.g., OECD, etc.):

This activity is really great. It's organized with a variety of activities that focus on active learning, where learners are important, and teamwork is emphasized. Students adjust themselves when learning together and can use the knowledge gained and the prototypes created to continue with science experiments. They can also pass on their knowledge to students, teachers, and school personnel who are interested in the prototypes created and the diverse teaching activities. I have also applied various techniques in the classroom, such as motivating students with interesting materials and creative questions. This activity is easy, takes little time, and at the same time creates awareness of others in society, reduces prejudice, and is not forgotten some group of people… The activity aims to raise awareness among students about the diversity of people in society and the importance of understanding and empathizing with those who are different. (School NS, written reflection, 31 March 2023).

In our point of view, this activity was good to teach STEM based on design thinking. The activity required various skills such as problem solving, creativity, collaboration, and etc. The main goal of solving problems is to help people with disability. So, this activity showed us how STEM education serves and give benefits to our community. (School TSS, written reflection, 31 March 2023).

It's a very good activity. we have learned Working as a team, sharing ideas, solving problems from situations and assigned materials which is an everyday situation Equipment used to manage learning is cheap and easy to find locally. We can integrate learning activities in our classrooms. Learned the skills of critical thinking, problem solving, and working in groups. design thinking prototyping, testing, evaluation, including communication skills (School BS, written reflection, 31 March 2023).

As seen from the reflections, a user-centric STEM approach to learning provides a natural platform for students to develop these skills. User-centric problems such as designing for the disabled are, in themselves, highly relevant and meaningful. Although students may not always empathize with the disabled due to their limited worldviews, teachers can think more deeply about adapting the activity so that aspects of listening and developing empathy can be foregrounded. In addition, a repertoire of skills, knowledge, and experiences were mentioned as possible competencies and learning gains for students. While this activity as designed to provide the teachers with the experience to design and enact a user-centric STEM activity, they had identified many different possible affordances of this user-centric curriculum that introduced the idea of inclusive design. This suggests that richness of such topics that could potentially support the development of humanistic values and skills, as well as other skill sets and knowledge important for the holistic development of a 21st century learner.

6. Recommendations for adapting this activity for students

In Table 1, we summarized some recommendations for teachers who wish to enact this activity in the classroom:

Table 1. Recommendations for teachers.

Considerations	Reasoning
Provide students with opportunities to interview a potential user or experience the problem for themselves	This will encourage students to inquire and deliberate on their ideation by focusing on the specific needs of the target user. This can also mitigate issues related to their limited worldview and life experiences.
Provide criteria for judging that are related to the context e.g., safety, cost, ease of use, etc. This can be discussed with the students or user-centric approaches such as interviews	Working out the judging criteria with the targeted users provide guidelines for students to evaluate their designs when making their prototype. What makes a successful design? The answer to this question should come from the user. Incorporating both users' perspectives and students' voices would result in greater consensus building as a community and ownership of the entire process.
Allowing time for revision of prototypes after evaluation with the targeted user	Giving students time to revise their prototypes would allow them to evaluate and improve on existing ideas. But giving them opportunities to revise their ideas based on user feedback would empower them to appreciate the nature of STEM inquiry as an evolving process subjected to change when new materials and ideas become available. It would also allow them to understand that no solution is perfect.
Asking students to justify their design and consider alternative viewpoints based on user feedback	Justification of designs is important in making thinking and thought processes clearer to the students. By including the user in the process would hone their communication and reasoning skills. The inclusion of users' perspectives and feedback can prompt students to consider multiple (even opposite) viewpoints. This would make their thinking more comprehensive and a holistic product would result.

7. Conclusions

The key strength of a user-centric approach to integrated STEM lies in its focus on developing humanistic values through thinking about the applications of science, technology, engineering, and mathematics to solve problems from a user's experiences [10]. As we have demonstrated from our experiences in carrying out this activity, emphasizing the need to empathize by learning to listen is the key to changing mindsets about inclusivity [4,8]. STEM activities, such as the one described in this paper, provide the means for learners to expand their experiential space. By experiencing what it means to be blind, albeit to a limited extent, the activity provides a springboard for learners to think about design from the user's perspective. While it may not always be possible to experience what others may go through to design solutions for them, adopting a user-centric mindset in design-based STEM activities will provide the platform for learners to think about different ways to understand others and open their minds towards embracing inclusivity.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare that there is no conflict of interest in this paper.

Ethics declaration

The research data collection was approved by the Institutional Review Board of the Nanyang Technological University, Singapore (IRB-2020-02-036).

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