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# Co-Design of Accessible 3D Printed Tactile Picture Books in Indonesia

## Abstract

The FabLearn task of creating 3D printable tactile picture books (TPB) for people with visual impairments provides rich learning opportunities for students and educators. In this paper we present a case study on the design and implementation of a FabLearn experience in Indonesia focused on the co-design task of creating 3D printable accessible learning materials with students and teachers with and without vision. The contribution of this paper lies in its descriptive qualities including; the workshop design process and the approach to creating a co-design experiences for sighted and visually impaired participants, the teaching and learning opportunities focused on the TPB design task, and the international collaboration. We provide suggestions for others who desire to run FabLearn experiences around the TPB.

## Author Keywords

Tactile picture books; critical making; 3D printing; education; co-design design; visually impaired

## ACM Classification Keywords

Design; Human Factors

## Introduction

As Fabrication Laboratories (FabLabs) are popping up all over the globe there are great opportunities to collaborate on the design and scaffolding of tasks to engage students in the use of digital fabrication tools. The affordances of 3D printing have been identified as a way to engage students in meaningful Fabrication and Learning (FabLearn) activities [3,4,7,12], as well as to distribute tangible learning materials e.g. [20]. However, to date there are few FabLearn activities that embody Critical Making, a notion which places emphasis on use of 3D modeling and printing tools to instigate new types of artistic and cultural expression, transformations of the notion of embodiment and materiality, renewed emphasis on the means of production, and the idea of a public good [17].

In this paper we present a case study on the design and implementation of an FabLearn learning experience, which focused on the co-design and production of 3D printable and accessible tactile picture books (TPB) for Indonesian students with visual impairments (VI). The design of the learning experiences occurred through the collaboration of a variety partners, located in Indonesia and the USA. We report on final activity structure, as well as the efforts required to develop a co-design workshop focused on the creation of accessible materials. Furthermore, we provide suggestions for how to position sighted and blind students and teachers as co-designers, and suggestions for how distributed teams can make design FabLearn experiences for students

## Background and Related Work

Accessible tactile pictures consist of tactile representations that convey information through the sense of touch to further a person's cognitive-affective and relational development [8]. Successful tactile pictures are important for people with VI to access information in a tactile manner such that they gain understanding of diagrams and pictures, confidence to explore their environments, and make associations through the sense of touch. Without access many miss the opportunity to learn from illustrated books; their perception is limited to what can be felt by the hand, seen within a limited visual field, and heard. Few studies have used co-design strategies to create tactile pictures with people with VI.

Of late, many caregivers and other stakeholders of children with VI have identified the opportunity of additive manufacturing to make low-cost, highly customized tactile forms, objects, and books containing 3D printed accessible tactile graphics and 3D printed accessible tactile pictures or illustrations [19]. The literature on using digital fabrication technologies to make tactile materials accessible currently centers on proofs of concept about the use of technology for this purpose e.g. [10, 20], the barriers to using the technology e.g. [5], the teaching and learning potential, the affordances of the 3D printed e.g. [13], and the emerging community of practice and teaching/

Facilitators/ Participants/ Partners	TPB Workshop Role
Idea consultant (A homeschooling parent of two young children, who instigated the collaboration)	WDT-Main facilitator (Indonesia)
DirEd. (Columbia University representative for the SAInS project)	WDT-Co-facilitator (Indonesia)
Researchers (2) from the University of Colorado	WDT-Workshop Consultants (USA)
Principle from SLB-A Pembina	Supporting Partner (Indonesia)
Head of FabLab IPB (representative for the SAInS project)	Supporting Partner (Indonesia)
Kornita High School principal	Supporting Partner (Indonesia)
Head of FabLab at Kornita High School	Supporting Partner (Indonesia)
8 Kornita high school students	Co-Designers (Indonesia)
2 VI teachers (1 music teacher and 1 other teacher) from SLB-A Pembina	Co-Designers (Indonesia)
2 Sighted teachers (1 middle school and 1 preschool teacher) SLB-A Pembina	Co-Designers (Indonesia)
2 VI college students (alumni of SLB-A Pembina)	Co-Designers (Indonesia)
1 Low vision high school student from SLB-A Pembina	Co-Designers (Indonesia)
3 Technicians from the STIR Center at IPB	Technical Assistants (Indonesia)
3 Computer Science Students from the University of Colorado	3D Modeling Support (USA)

**Table 1: TPB Workshop Facilitators, Partners, and Co-designers.**

learning needs [6, 9, 11, 21]. Few people are looking at the requirements involved in the design task of creating 3D printable TPBs. Prior work focusing on 3D printable TPBs focuses on introducing the design task to middle school students in a design and technology classroom [22]. To date, no efforts have been made with the co-design model [18] presented in this paper. Within the FabLearn community there a few studies that focus on fabrication and learning experiences in developing contexts [2, 14, 16, 23] let alone the opportunity to use FabLearn experiences to engage students in designing assistive technology or accessible media.

### Study Design and Methods

In the fall of 2015, the co-authors, referred to as the Workshop Design Team (WDT), came together around the design task of creating TPBs for children with VI using 3D printers. The WDT notion was that creating accessible reading materials could provide a meaningful context for participants to learn how to use 3D modeling programs and printers while engaging in co-design activities and practicing cross-cutting skills. The overarching aim was to provide Jakarta high school students and teachers with a meaningful problem-based learning experience at the FabLab at the Bogor Agricultural University (IPB) in Jakarta, Indonesia. Of note, the primary coordinator of the workshops is the Director of Education (DirEd) at Columbia University; She is stationed in Indonesia as part of a USAID-funded university collaboration between Columbia University and the Institut Pertanian Bogor (IPB) entitled "SAINS: School Action for Innovation in Science" which has a primary mission to improve and innovate instructional practices in Indonesia. (The program installed FabLabs in three partner high schools and at its Indonesian partner university campus within a new STEM Instruction Resource (STIR) Center there).

As the WDT started to plan the workshop, a research questions emerged from the collaboration: *How does a distributed team design a FabLearn experience,*

*focused books, that is inclusive for sighted and non-sighted students and teachers?*

Data presented in this case study was gathered throughout the planning and implementation of the workshops. Each of the WDT's planning and debrief meetings were recorded and transcribed in order to analyze how the team members conception of the design task transformed during the collaboration, as well identify how the implementation varied from the initial conception. During the workshops, the two facilitators (the Idea Consultant and the DirEd) observed participants' interactions and engagement in the design task, took pictures, and wrote field notes and analytical memos about the experience. After each workshop, the WDT gathered to debrief the experience. Over the course of the six-month collaboration, the WDT had two, two-hour workshop planning meetings, and one two-hour workshop debrief meeting over Skype. In addition the WDT exchanged approximately 35 emails containing discussions about workshop planning ideas, the scope of the research, resources for the workshop, and sharing of workshop images, 3D modeling files, web links, design feedback, reflection documents, and solving technical modeling problems. The WDT performed retrospective analyses of digital and physical materials generated during the workshop planning, the completed workshop, and the post modeling activity, including meeting notes, workshop plans, the story text, photos, and models. Reporting formally on the student learning outcomes is beyond the scope of this paper.

After identifying the design task, the DirEd contacted the director of the Jakarta School for the Blind (aka SLB-A Pembina) in order to gain support and identify participants (students and teachers). In addition, she gained support from the head of the FabLab at IPB (who is the IPB representative for the SAInS project), and the Principle and head of the FabLab at Kornita High School. Table 1 provides an overview of the WDT members, partners, teachers, and students.



**Figure 1. Students and teachers with VI exploring 3D printer objects**



**Figure 2. Participant modeling.**



**Figure 3. Student modeling 3D mousedeer.**

### Description of the TPB FabLearn Experience

The TPB FabLearn experience for students and teachers, sighted and VI, included three distinct phases: 1) a six hour co-design workshop; 2) offloading the complex 3D modeling tasks to US-based university students; 3) a series of 3D design workshops focused on creating the final 3D printable book compositions.

**1) Co-Design Workshop:** The first workshop occurred at the Indonesian university in November 2015 where the DirEd and the IC welcomed all members. A teacher from the school for the blind gave participants the real-world context for the project: the necessity of tactile books for VI students. Participants were coached on how to interact with people with VI, and the group discussed how best to support each others' learning and communicate effectively. Examples of 3D printed models created in the university FabLab were passed around and the participants with VI became interested in touching the 3D printers and learning how they worked. After the DirEd introduced the design task, the IC read aloud a classic Indonesian folk story "The Mousedeer and the Alligator" a story about a clever mousedeer<sup>1</sup> who tricks alligators to help him cross a river, without being eaten up, and guided the participants in identifying the most important elements of the story which should be represented with 3D images. The large group identified five main elements to model: a mousedeer, an alligator, a river, trees and shrubs, and a cucumber garden. As the group discussed the elements, conversations about perspective and orientation arose. The facilitators drew on a white board, and then verbally described visual ideas and modeled low-fidelity examples in clay to demonstrate the concepts to the participants with VI.

The participants then split into five groups, each collaboratively modeling multiple versions of one assigned story element. The participants with VI

assessed how well the models represented each element, whether they could be easily recognized, and selected the best versions of the models. In some cases the participants wanted to combine characteristics from different models. For example, the VI participants selected one alligator model as the best overall, but wanted to add the detail of a clawed toe that another model included. During a second modeling session the sighted participants refined the models while the others spent more time learning about the 3D printer and discussing how it could be used to support education at the school for the blind. The final models were documented with photos and descriptions, which were subsequently sent to the US-members.

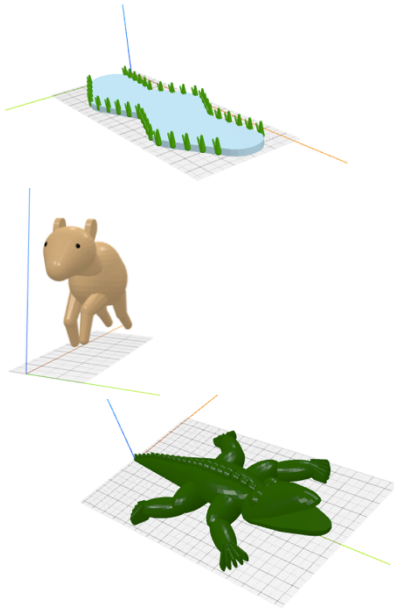
**2) 3D Modeling:** The US-members received images and descriptions of the Mousedeer models in December 2015. Three US-based undergraduate computer science students started 3D modeling the five objects in an xml-based 3D modeling program that is being developed at the US-based University. The completed computer models were sent to the Indonesia-members and an interactive process of user feedback and model refinement was repeated 3 times.

**3) Book Composition:** All but one of the original participants from the local high school joined the composition sessions, which took place over 5 days, outside classroom time, at the high school campus. These meetings provided time for the sighted high school participants to refine and compose the 3D models—digitally and physically-- into a final book. One high school participant emerged as the leader due to his prior experience with TinkerCad, causing some of the students to passively allow him to make relevant decisions. Therefore, he suggested that each student be assigned to complete one book page so that every participant would be required to tackle the full gamut of design and applied tasks. The group chose the size of the pages—discussing trade offs between portability and convenience, and legibility of the tactile materials. In order to make sure the raised models on each page would fit into a book format, they decided to create a frame for each page that would protect the 3D objects and ensure the pages lay flat. This, and other aspects

<sup>1</sup> The Java Mousedeer (*Tragulus javanicus*) aka chevrotain. [http://animaldiversity.org/accounts/Tragulus\\_javanicus/](http://animaldiversity.org/accounts/Tragulus_javanicus/) University of Michigan Museum of Zoology.



**Figure 4. VI teacher exploring 3D printer objects.**



**Figure 5. 3D modeled features of Mousedeer. (Top) River. (Middle) Mousedeer. (Bottom) Alligator.**

and milestones of learning and problem solving were explicitly pointed out to the teacher and the students so that they would recognize and appreciate the conceptual effort and skills they were applying.

The DirEd and the IC observed that the participants initially laid out their modeling pages/compositions in aerial perspective, and then designed the image elements in full 3D. This would result in a “doll house” effect with frames populated by figurines, as opposed to raised tactile graphics. This was pointed out to the students, and with the help of the DirEd, the participants created cross sectional models of many of the components that would be adhered to the page. Enthusiastic, and possibly driven by their desire for a visually appealing layout, participants started to add additional model images to the pages—beyond what was agreed upon during the initial workshop. The IC reminded them that their VI co-designers had advocated simple models and landscapes with prominent identifying features: “For an alligator we want claw feet and the ridges on the back. That’s all we need.” Adding “extras” might also add confusion. The DirEd also reminded participants to keep the 3D models at an appropriate scale for the models to be tactilely meaningful and “legible” to young VI user hands. She said, “[The HS students] are used to being told what to do, so when you give them free rein they go crazy. Which is great, but then we just say, “You have free rein within your design constraints. So let’s think about what it means for the users if you start adding stuff.” In addition to these concerns for the end-client, the facilitators were aware of the cost of printing multiple versions of the models due to time and cost.

## Findings

### WDT and Partners Motivation

WDT Motivation: Each of the WDT members joined the collaboration with a different motivation, albeit each member was inspired by the opportunity to create much needed accessible learning materials for students with visual impairments. The IC had brought her children to the school for the blind to introduce them to social initiatives in their community, and to teach them the value of giving back to society. She said, “When we

went to a school for kids who are blind, it was really depressing because they only had braille books, but no embossed illustrations. An important part of early literacy is for kids to see and feel the pictures.” The DirEd at CEES was motivated to engage in the TPB project as she saw it as an opportunity to use 3D printers in the program Fablabs to engage high school students and teachers in authentic project based learning. When reflecting on her efforts in Indonesian high schools, the DirEd noted, the difficulty in finding ways to integrate the FabLab into school curriculum due to teachers’ pressure to prepare students for exams, and their limited understanding of how and why to apply project-based learning. She conversely reflected on the successes of the FabLab on the IPB campus: “We have done a lot of good work with robotics and the Natural Sciences departments, but, I want the teachers and the students to get more practice thinking in meta-cognitive ways: to see that we have a problem to solve, to question why we are solving it, and why we are trying to solve it in a FabLab.” The US-based university WDT members viewed the collaboration as an opportunity to better understand the interests and needs of the Indonesian-members, teach about designing accessible materials, to develop strategies for creating co-design experiences for people with VI, and to study how to apply the TPB project into developing contexts.

Partners’ Motivation: The local high school administration wanted their students to gain experience using their schools FabLab, and helped determine the best strategy for engaging their students. When the director of the school for the blind was approached to participate, he became enthusiastic about the project as a way to provide much needed tactile materials. (The school has extremely limited funding and equipment, and viewed this as a way to create a proof of concept needed to write a grant to the Indonesian government for a 3D printer.)

### Workshop Plan Iteration

Prior to the collaborative workshop planning, the Indonesia- based WDT members initially planned to run a six-hour workshop for the high school participants,





focusing on how to transform the 2D images into 3D representations. The goal for the day was for participants to master creating 3D representations using TinkerCad. Following the workshop, they anticipated that the group would work for 2-3 weeks (20 hours total) transforming existing images from “The Mousedeer and the Alligator” and creating a physical book combining printed text, braille text, and 3D tactile images. They intended to give the book to the school for the blind to use it as proof of concept to seek funding for a 3D printer. At this time the Indonesia-members anticipated that participants with VI would attend the workshop but not directly engage in the 3D modeling process due the lack of 3D computer modeling environments accessible for VI users. They anticipated the primary design challenge to be creating in-filled, raised line models into a physical book form. When the WDT first met to discuss the project the members shared insight with each other to create a shared understanding about the cultural context for the workshops and to develop an understanding about tactile design.

Aligning Understanding of the Cultural Context: For the WDT to appropriately design the experience, it was important for all team members to understand the teaching/learning context. The IC shared that in her opinion many Indonesians books are valued exclusively for formal education and preparing for exams; a culture of personal reading is undeveloped. She also explained that in Indonesian society, it is not common for students to actively and spontaneously participate in unstructured activities; rather they tend to carry out explicit tasks as directed. This triggered a discussion to identify ways to help the group become more comfortable with each other and with explorative activities. These strategies included creating a group agreement at the beginning of the workshop and designing icebreaker activities that both VI and sighted participants could be involved in. Furthermore, she noted that due to the multitude of languages spoken in Indonesia literacy levels in the national language are inadequate, and there is a dearth of children’s books of any kind—accessible or not. For this reason the WDT chose to design the workshop around a classic Indonesian folk story “The Mousedeer and the

Alligator”. The tale is hundreds of years old, fully in the public domain, therefore not subject to copyright limits.

Aligning Understanding about the Design Task: One of the most critical, yet challenging aspects of the TPB design task is developing understanding about how people with VI interpret tactile graphics: tactile graphicacy [1]. The US-members walked the Indonesian based members through the basic concepts of transcribing tactile art, including symbolic representation and consideration of the prominent features or characteristics of characters or objects in a story, and the selection of story elements to transcribe. One of the researchers said, “*When you have an existing image, you start breaking down and decoding the image so that the most important aspects of the image are transcribed into something tactile that VI people can recognize and interpret.*” This was a core concept to help participants make decisions on which visual images to transcribe into tactile form, as well as which transcription technique to use to insure 3D images are meaningful to touch. The WDT thus discussed the difference between transcribing pre-existing images, versus the creation of tactile materials from scratch or the imagination. US-members suggested that the Indonesian-members focus on creating an inclusive experience, where both VI and sighted participants focused on creating new content through their tactile experiences during the workshop, as opposed to relying on visual reference materials that would only be accessible to some. The workshop agenda was modeled after a series of design workshops previously held by the US group, with different stakeholder groups [21]. In turn, the WDT decided to include activities where participants would work together to create content based on listening to a story and developing physical objects to communicate their interpretations.

Finally, the WDT discussed the challenge and opportunity to create activities for people to explore how objects or concepts can be represented in multiple ways, and through different modalities. This would be an important instructional focus for the activity, promoting meta-cognitive skills and requiring an iterative design process responsive to VI-user needs.

**Figure 6. 3D Printed Pieces for the Mousedeer Story (Top to Bottom: Shrub, Alligator, Palmtree).**

The WDT thus intended to introduce participants to how texture and form may be used in different ways to express a similar idea, including using clay or play dough as the main medium for exploration as it can be easily manipulated, absorb textures, and be rapidly refined. The WDT also discussed the importance of designing the story images with an Indonesian aesthetic. For example in Indonesia the prototypical trees are tropical palms and bananas, whereas in North America deciduous trees may be more common in the visual vernacular, and we should ensure our images reflect the local understandings. It was agreed that a primary task of the facilitator was to engage the participants to identify ways of conveying the specific attributes of (for example) a palm tree in a tactile form that is universally recognizable.

Refined Workshop Based on Collaboration: During the course of planning, The WDT expanded the goals of the workshop to include 1) introducing inquiry-based exploration of visual vs. tactile representations of objects; 2) developing empathy as part of the design process; 3) supporting participants to develop a shared vocabulary and methods for communicating ideas in tactile form. The participants would still gain technical experience with 3D modeling and printing, however parts of the 3D modeling task would be offloaded to the US-members. The DirEd was concerned with time: *"The way I had been envisioning it before, was quite literal. We were going to have a picture of an alligator, and we were going to raise it up so that its a shape of an alligator raised up with maybe some scaly skin and his bulky eyes and his teeth. Much more literal and much more visual."* It became clear that the design task would be more complex and require significant learning and conceptual understanding by the students. There might not be time to teach how to create 3D computer models from scratch. Therefore the US-members suggested that experienced modelers at CU could convert the 3D models into digital models so that the Indonesian participants could spend more time working on the overall design together.

A major change from the original workshop conception was the inclusion of VI students and teachers from the

school for the blind in the actual design process. The WDT opted to provide all participants with the opportunity to 1) explore and gather tactile materials; 2) collaboratively model each of the story characters and settings; 3) provide feedback to each other and select the models that created the most meaningful tactile experience for the VI users. During parts of the workshop, participants would work together in multiple small teams, using visual and tactile abilities to determine the design. In order to help participants become comfortable with one another we developed a "sound machine" game where participants created an imaginary "machine" represented by the combination of vocal sounds from each participant. Key intended facilitation moves included: 1) creating a safe space and agreement that all ideas, are good ideas; 2) explaining the TPB project; 3) read aloud the story and identify the critical aspects of the story grammar (characters and setting elements to represent in 3D); 4) breaking into teams and make prototype models from dough; 5) coming back together as a group and critique each model through the sense of touch with special attention given to the input of the VI participants as our "experts" on VI use experience; and 6) plotting out the story elements into specific pages and identify the various page compositions.

## **Discussion**

Markers of Success: This international collaboration demonstrates the potential for creating critical making tasks that breakdown many different types of boundaries. When the DirEd exclaimed *"This workshop was exactly what I wanted from a pedagogical perspectives; a chance for teachers to experience and witness project-based learning and get beyond initial fears and uncertainty!"*, she was referring to the obstacles of introducing FabLabs to a conventional educational system with limited resources for project-based learning.

Throughout the workshops the Indonesian WDT observed the high school teachers gaining confidence with problem-based learning. At first the teacher said, *"Can the kids do it? I think I have to learn this first before I can teach it to the kids."* Initially he felt he

would have to have 100% mastery of all concepts and skills and lead the students step by step through each task. However we reminded him that this was “learning by doing” and that the tech-savvy students would use the skills they already have to explore the software and teach themselves. In the end the teacher observed the participants in amazement as they worked independently of him and trained each other by sharing discoveries and skills along the way

The WDT also found the TPB task to be an opportunity for us to expand our skillsets and perceptions about digital fabrication and design. The DirEd said, *“In the past, I’ve been a little bit above the fray when it comes to 3D modeling. This is the first time I sat down with TinkerCad... I’m in there with the kids trying to figure out how to model as well”*. The Idea Contributor reflected on her learning with people with VI. *“This design task made me really realize that we have to think from their perspective and not ours.”* The US-members valued the opportunity to collaborate, across the world, to create a meaningful experience and extend the context of the TPB research.

International Collaboration: Suggestions for how distributed teams can make design FabLearn experiences for students, while utilizing the affordances and mitigating the challenges of digital fabrication in emerging contexts, include: (1) Identify the most appropriate ways to incorporate FabLearn experiences into the local teaching/learning context by directly engaging with schools, (2) Allocate time and resources for facilitators to learn the principles of designing accessible materials and digital fabrication through hands on experiences, (3) Support teachers and students equally in the learning about the design task and digital fabrication tools, (4) Retain in-country team members who coordinate local partnerships, and (5) Work with culturally relevant stories.

Bring Sighted and Non-Sighted Students Together: The task of creating TPB for and with people with VI presented a challenge and opportunity for the WDT. In order to make an co-design experience for students with VI, the WDT adapted and revised the workshop design in order to find ways for every participant to

engage in the design task as well as contribute new understanding to their peers. We attempted to refine the activities so that they would not privilege sight over the sense of touch. However, there were instances where we observed the students with VI were less engaged than the sighted students, and the students with VI were still positioned as representative of “the client” who the books were being designed for. However, we believe this was a first step towards creating FabLearn tasks supportive of co-design of accessible tactile materials. Suggestions for designing a FabLearn design experience that is inclusive for sighted and non-sighted students: (1) Ensure all supporting partners have a buy in concerning the potential benefits of the project, (2) Ensure representatives from schools for the blind and other supporting organizations are present during the workshop, (3) Allocate time and resources for facilitators to learn the principles of designing accessible materials and digital fabrication through hands on experiences prior to workshops, (4) Engage teachers and students equally involved and develop all activities so that they adhere to universal design for learning principles, (5) Provide reminders to all students about the co-design process, (6) Adhere to group agreements and design decisions made during co-design activities, (7) Anticipate limitations of inaccessible 3D modeling programs, and (8) Create co-learning opportunities and support participants in creating a shared vocabulary.

While the task of creating TPB may be complex, the participants, WDT, and the project partners walked away satisfied. There are great opportunities for using the TPB task as a way to create inclusive design experiences, where students become familiar with digital fabrication hardware and software, all the while contributing to the social good.

## **Conclusion**

We present a case study on the design and implementation of a FabLearn activity focused on the co-design of 3D printable tactile pictures by students and teachers with visual impairments and without. We identified strategies used by a geographically distributed team aligning their understanding about the

design task, iteratively plan the activities, ensure the workshop was culturally relevant and supported co-design activities between a variety of participants. The findings and discussion presented in this paper can assist educators who aim to work with distributed teams, and/or facilitate FabLearn experiences that encourage co-design of accessible TPB.

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