Learning by Teaching: Key Challenges and Design Implications

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Benefits of learning by teaching (LbT) have been highlighted by previous studies from a pedagogical lens, as well as through computer-supported systems. However, the challenges that university students face in technology-mediated LbT—whether it be teaching oneself, teaching a peer, or teaching an agent—is not well understood. Furthermore, there is a gap in knowledge on the challenges that students encounter throughout the process of teaching (content selection, preparation, teaching, receiving and giving feedback, and reflection) despite its importance to the design of LbT platforms. Thus, we conducted a thematic analysis on results we gathered from 24 university students where they taught content that they had not fully grasped and their semi-structured interviews. Results demonstrate that the participants encountered the following challenges: psychological barriers relating to self and others, and lack of know-how. Furthermore, we illuminate design implications required to overcome these challenges and benefit from LbT without requiring prior training in pedagogy. In addition, we outline university students' perception on various tools and configurations a LbT platform could include.

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Chapter 1

Introduction

Learning by teaching (LbT) is a pedagogical method where a student is tasked to teach unfamiliar material typically to peers [**?**, 23]. It produces more enriching experiences than simply being taught the material and learning for oneself [23]. LbT can be organized in a collaborative learning environment where students achieve their learning goals via a group-based approach. Peer teaching materials to others has been observed to enhance the student's own learning of those materials (e.g., [30, 35, 71, 72]). More specifically, the benefits of LbT in a group include learning concepts more effectively, encouraging more participation, improving learning satisfaction, developing teamwork skills, and promoting higher-order thinking [20]. Furthermore, studies have shown that students who learned material with the expectation that they will be required to teach it performed better than students who learned to pass a test for themselves [7, 8]. Students have also shown to be more motivated to grasp the material and when their partner misunderstands the material, the student reflects on their teaching, notices their own misconceptions, constructs new explanations and knowledge on the material [71]. The partner who is listening to the student's explanation can also benefit from reciprocal peer tutoring scenarios when the explanations are conceptual, elaborate, and for the most part, are correct, and target the partner's own misconceptions [88, 90].

The phases of LbT can include preparing to teach materials, explaining the materials, interacting with peers, and self-reflection. Preparing materials with the purpose to teach them requires the student to learn something in order to develop educational materials [23] or requires, at a minimum, a basic understanding of the materials and a plan to convey them [14]. The reformulation of this gathered material also leads to getting a better understanding of it since this encourages organization and finding the basic structures of the content [31]. This makes the learned material more accessible in memory by associating

it with what is already known [97]. Then the explanation phase allows the student to test how their mind reviews and reformulates information into knowledge—similar to how we consolidate thoughts by explaining them to friends [23]— even when the listener is passive [96]. In addition, the student who is teaching participates in *reflective knowledge-building* which leads to recognising their areas of improvement, reorganising their own knowledge, deducing errors, repairing them, and producing better explanations [71]. Occasionally, the explanation phase has also been verbalized without peers which is known as "self-explanation" [62]. It consists of the creation of inferences that are instantiations of the principles and definitions introduced in the learned material, thus helping the student with problem-solving and grasping a better understanding of the material [17]. During the construction of self-explanations, learning happens during the identification of knowledge gaps which are necessary to learn in order to complete the self-explanation. This leads to constructive cognitive activities that usually culminates to the acquisition of new knowledge [62]. More specifically, self-generated questions [18] can be used to help identify knowledge gaps. These mechanisms that are used during self-explanations should also be involved when explaining to others [23]. This thesis aims to deepen our understanding of the challenges university students face, both when LbT alone and to someone else without guidance or instructions in each session.

Currently, there is a lack of technology that supports LbT in a peer-to-peer context, both in-person and online, where students select unfamiliar materials to teach with the goal of learning primarily for oneself. While prior work has focused on the effectiveness of LbT in various settings and forms (e.g., [71]), the challenges students face throughout the process of LbT, from the preparation phase to the feedback phase, has not been explored despite its importance to the design of LbT platforms. We therefore conducted an exploratory study—observing 24 university students teaching unfamiliar material online and interviewing them about their experience—to gain a new understanding of how they approach the preparation and teaching of the materials, and the challenges that they encounter during this process. Our focus on how the teaching happens among participants who have not been trained in teaching enables us to uncover the unique challenges they face, so that new forms of technology can be later designed to enable students to get the most out of LbT.

1.1 Research Goals

Our thesis is designed to fill the gap in understanding, at the university level, students' process of teaching something unfamiliar, when teaching someone or when teaching alone. More specifically we investigate the following research questions:

- **RQ1:** Which challenges do students face during the LbT process and where do they happen?
- **RQ2:** Which tools can support the challenges students face when LbT?

1.2 Contributions

This thesis offers the following contributions to supporting LbT practices for the use of university students:

- An analysis of university students' unguided LbT sessions and semi-structured interview responses aimed at uncovering their response to the LbT sessions and potential feature design solutions;
- Design implications for creating online LbT platforms for university students that supports and encourages the effectiveness of the LbT method; and
- An outline of potential features that could be incorporated into LbT platforms and university students' perceptions of them.

The results of the thematic analysis were grouped into three main themes. The first theme explores three psychological challenges relating to the student's own self when LbT including cognitive dissonance, zero risk bias, and optimism bias. The second theme uncovers the psychological challenges relating to others (i.e. the students' peers in the LbT session) including impression management, the bandwagon effect, and the ambiguity effect. Lastly, the third theme outlined students' know-how challenges around content incomprehension and their teaching approach.

Based on the outlined challenges, the design implications include supporting a "crash and learn" environment where students become comfortable with the teaching material imperfectly and learning from it since participants were unfamiliar with the idea of teaching material to peers without having mastered it first. Additionally, design considerations should be made to support the online peer collaboration among the university students to best support peer matching (the grouping of students for a specific LbT session) and collaborative feedback from those peers.

Our work sets a foundation for researchers to adopt and explore new ways of designing LbT computer support tools for university students which influences the potential learning gains when using this pedagogical method.

1.3 Outline

This thesis is organized as follows:

- Chapter 2 outlines relevant research on pedagogical LbT practices, existing challenges with LbT in classroom settings, and systems that support this practice.
- Chapter 3 details the study design created to fill the gap in understanding university students' process of teaching something unfamiliar, when teaching someone or when teaching alone.
- Chapter 4 presents the method of analysis and results of 24 semi-structured interviews and 48 LbT sessions, grouped into the following three LbT challenges for university students: psychological barriers relating to self, psychological barriers relating to others, and know-how barriers.
- Chapter 5 describes the design implications and recommendations.
- Chapter 6 outlines participants' feature recommendations, their perception about features in terms of potential adoption and comfort with using them, and a web-based LbT platform prototype.
- Chapter 7 concludes by summarizing our work, outlining possible limitations, and discussing avenues for future work.

Chapter 2

Related Work

One of our goals is to understand what kind of tools and scaffolding would be required to support the process of teaching unfamiliar material on a computer supported platform. Therefore, the related literature is detailed through both a pedagogical and computer supported lens.

2.1 Challenges with LbT in the Classroom.

As previously outlined, LbT can be done by teaching peers which is closely related to peer tutoring—as a building block of LbT—and has been studied in the following configurations: teaching to one peer, teaching to a group of peers, and teaching with a group of peers (e.g. each member learns to become an expert at one specific topic [6, 80], this is also known as cooperative learning). In general, students who have mastered the material previously assist the development of understanding for struggling students [14]. Peer tutoring typically occurs in an environment where one student plays the role of someone who has the knowledge or skills of the materials to be taught, and others play the role of the learner [21]. The configurations and pairing of students can be an impacting factor on the learning outcomes of the students. For example, if a particular setup fosters peer question asking, this can impact the tutor's understanding of the content. Roscoe's study showed how peer's questions are a significant predictor of the tutor's knowledge building and suggested to further investigate how each member's level of understanding in a LbT scenario affect the amount of knowledge building [70]. Some factors that can contribute to limited question asking include a lack of motivation due to not being able to identify their own knowledge gaps [34], and various social influences [24] such as the fear of peers'

negative judgment [63]. The quality of the LbT sessions is not only impacted by peers' question asking ability but also by students' personality and cognitive style [54], motivation levels [67], and group dynamics in terms of contribution equity [76]. For example, when analyzing equity in collaborative learning discussions among students, those who perceived themselves as less competent in the subject at hand were dominated by their peer who perceived themselves as more competent resulting in reduced opportunities to learn [76]. There is some understanding of how peer groupings can impact LbT in various classroom settings, however, studies observing university level participants have been done without computer-mediated support and there is a lack of understanding how technology can play a role in supporting these challenges to generate better knowledge-building when LbT among this age group. While there have been computer-aided studies done with children students who were in the same class (e.g.,[10, 50]), learning processes and collaboration evolve with age which could impact the design of LbT tools. More specifically, in adults, the frequency of executively controlled learning increases [46] and metacognitive skills such as knowledge retrieval skills followed by failed attempts improve [27] as well as applying knowledge acquisition strategies increases [45]. By gaining a better understanding of the design implications for adult collaborative LbT, we aim to support the potential benefits of peer tutoring such as providing academic and motivational help for the learners, developing relationships between students, and engaging the teacher [83].

2.2 Peer Tutor Training

Related to LbT is the concept of peer tutoring, defined as "people from similar social groupings who are not professional teachers helping each other to learn and learning themselves by teaching" [84]. Specifically, as part of this thesis, we aim to investigate challenges faced by students in their teaching process in the context of LbT. Although no existing works answer this question directly, an indirect way to understand possible challenges is through the motivations and structures of peer tutor training programs. Since peer tutor training programs aim to equip peer tutors with skills relevant for teaching their peers, it is possible that students who did not go through such training would face similar issues while teaching in a slightly different context—LbT; while peer tutoring aims to educate both tutor and tutee [84], LbT focuses on the student's (i.e. tutor) learning [23].

When peer tutors are not trained, their tutoring might involve questioning behaviors that are limited in frequency, infrequent error corrections, and providing unsuitable feedback (i.e., uninformed and unconstructive [36]) [60]. In the context of writing, untrained peers were found to spend much time discussing the essay's subject without relation to the

actual writing [32]. Given the importance of peer tutor training, researchers have expressed diverse opinions on what peer tutors should be trained on, including: the content intended to be taught by the tutors [53, 28], the knowledge to apply tutoring practices rooted in theories [58], interpersonal skills (e.g., friendliness, rapport) [77, 66], the ability to deal with high-order concerns before lower-order concerns [66], their metacognitive skills, explanatory potential and awareness of behaviours related to the tutor's role (e.g., to observe the tutee attentively) [25], proper peer criticism practices and awareness of potential learning difficulties tutees might face [13]. Research also found the importance of having qualified trainers lead these training programs [19]. Training have been found to lead to many benefits, including greater learning gains and cognitive benefits of both tutors and tutees [78, 19], increased task engagement and commitment [81], the provision of higher quality feedback (e.g., addresses both low and high-level concerns) [81, 19], a deeper understanding of the material [9], and more accurate self-efficacy beliefs [25]. As such, peer tutor training has been recognized as being a core part of organizing peer tutoring programs [85, 25, 13]. Interestingly, Robin and Heselton found interactive tutor training to produce higher quality tutoring behaviour than training tutors using only a written handbook, albeit having no differences in tutee outcomes [69]. Since these studies have been conducted outside the context of LbT, we aim to fill the gap by first understanding if and where there are specific areas that university students may need training or support with their teaching approach, which can provide design implications for supporting such training.

2.3 Computer Support for LbT

Existing research on educational technology have investigated multiple types of software that are aimed at supporting the processes in LbT. More than two decades ago, Kumar et al. introduced the term Virtual Learning Environment (VLE), which allows students to "access a complete course, take tests, and interact with the professors as well as classmates" [47]. Another type of support technology is computer-supported collaborative learning (CSCL), which is a paradigm of educational technology that focuses on using technology to support peer interaction and sharing of knowledge and expertise in a collaborative learning environment [48]. Some educational technologies also incorporate the use of virtual agents, often conversational, in various educational settings [11, 10, 5, 52, 3, 65, 15, 49]. Moreover, there exists frameworks and studies on peer tutoring support tools that are relevant. We discuss how these technologies support different parts of the teaching process below.

2.3.1 Support for Preparing Materials.

Cheng and Yen introduced the VLE developed by the University of Hong Kong; it supports course instructors in producing course material using a "Preparation Room" [16]. In a comparative study of ten VLEs, Al-Ajlan observed that VLEs support the process of designing curricula with various features [2]. These features include course templates, instructional design tools, and ways for sharing and reusing content [2, 1]. However, these systems are meant to be used by instructors, and not peer tutors. In designing a peer-tutoring orchestration tool, Phiri et al. suggested three specific tasks, including activity management (for specifying metadata associated with the teaching activity), resource management (for uploading and organizing materials) and activity sequencing (for specifying the order of materials according to the teaching activity) [61]. Moreover, multiple types of materials were supported, be it PDF documents, videos, or audio files for increased flexibility. Although this tool was evaluated using student tutors, participants did not prepare their own materials; official course materials were used instead [61]. Within the peer-tutoring literature, Walker et al. extended the Cognitive Tutor Algebra (CTA) system to support peer tutoring and help prepare tutors by first asking both tutor and tutee to individually solve an equation and then providing questions to the tutor to help them prepare tutoring questions (e.g., "A good question asks why something is done, or what would happen if the problem was solved a certain way." [87]). Our work aims to contribute to this by investigating how to design tools supporting material preparation, specifically in peer-to-peer LbT contexts. This is especially important since i) peer tutors usually have inadequate tutoring expertise without proper support or training [25], and ii) in-the-wild peer-to-peer LbT might involve materials and topics prepared by peers, instead of predefined alternatives (e.g., existing course materials).

2.3.2 Support for Explaining Materials.

Many learning environments with teachable agents also have features aimed at supporting the process of explaining educational materials. For instance, Betty's Brain helps users "develop structured networks of knowledge that have explanatory value" through the activity of building concept maps that relate causal effects between concepts (e.g., river ecosystems) [11]. Curiosity Notebook, on the other hand, provides conversations of different types, including one aimed at asking the user to generate explanations for relationships between entities and characteristics (e.g., if an animal lays eggs) [49].

In peer tutoring contexts, Walker et al. designed an adaptive tutor support system that enhances tutors' explanation skills when providing tutees with conceptual help (i.e.,

"explaining a problem-solving step using a domain support") [88]. Particularly, the support system prompts the tutor (using non-critical wording that avoids threatening the tutor's authority) to provide extra conceptual explanations when it detects tutor chat messages that lack conceptual reasoning. It also sent encouraging messages to tutors when they successfully explained concepts during their tutoring sessions.

2.3.3 Support for Interacting with Peers.

The VLE introduced by Cheng and Yen supports interactions between students, and also between students and teachers so that students can get organized feedback [16]. Discussion forums are a common feature used by VLEs for supporting student interactions [2]. Similarly, CSCL also enables a diverse group of collaborators to each contribute their opinions and knowledge in a project [98], hence allowing interactions between learners, teachers and peers.

Peer tutoring tools could support peer interactions by allowing tutees to request tutoring sessions from specific tutors for a particular course according to tutors' self-reported expertise [1]. Westera et al., on the other hand, built an online self-organized peer allocation mechanism to pair peers for peer tutoring purposes [93]. Instead of manual requests by students, the system automatically selects the most appropriate peer, based on tutor competency and workload fairness (i.e., workload distribution should be fair over all competent tutors). Based on a pilot study, they made several suggestions; specifically, such a system is more suitable for online learning contexts where there are a large number of students (100 or more) who do not know each other. Moreover, the system should "foster group awareness and community feeling" [93]. To investigate methods of supporting peer tutors in the context of learning algebra on CTA, Walker et al. built two methods of support—fixed and adaptive domain support [87]. Specifically, peer tutors could see tutees' attempt at solving an algebraic equation live, and interact with tutees by either marking the tutees' steps (in solving the problem) as correct or wrong, adjusting the value of the tutees' skill bars, or via the chat tool. The fixed domain support provides tutors with the problem's answers, while the adaptive version has additional features, including i) providing tutors with hints if tutees ask for them, and ii) highlighting the correct answer if tutors mark their tutees incorrectly (e.g., marking a wrong step as correct). While no significant differences were found between the two types of support, they found that tutors benefited from tutees' impasses, which were negatively correlated with the tutees' learning gains [87]. Support systems could also support tutors in their ability to provide timely (i.e., providing help when tutees make errors or request for help) and appropriate (i.e., prompt tutees to self-explain and provide appropriate feedback for errors) help [88].

Interestingly, benefits can be gained from interacting with human students and with teachable agents. Systems like Betty's Brain and SimStudent contains agents that provide feedback to users either via conversations or examples (e.g., similar mathematical algorithms) [11, 52]. Processes like administering quizzes for the purpose of gauging learning progress have also been simulated using agents [11, 49]. Ravari, on the other hand, used an adaptive teachable agent to encourage equal participation within student teacher dyads and found it to be effective [65].

2.3.4 Support for Self-reflection.

Self-reflection can be supported with reflexivity tools in VLEs that allow for reflections on users' own learning processes [16]. Moreover, teachable agent systems, like Betty's Brain, can be used to support "the development of reflection or meta-cognitive skills" by using a mentor agent that directs users to reflect on specific parts of the materials based on their concept map [11].

Another aspect of self-reflection for peer tutors is to reflect not just on the content, but also their teaching approach. Walker et al. added support for tutor reflection in CTA by asking three questions after their tutoring session (e.g., "What was the best question asked by the tutee? If the tutee didn't ask any questions, what was a good question he/she could have asked") [89]. They found that the reflection questions made tutors skip less difficult questions and spend more time solving each question, even though no additional learning gains were observed. Moreover, researchers have found the use of sentence classifiers, for labeling the content of peer interactions, to be beneficial in encouraging peers to reflect on what collaborative activities are most suitable [91], and have implemented them in peer tutoring support systems [88].

In summary, prior work has shown that the various stages of LbT unfamiliar material can be supported through computer systems. However, there exists a lack of support tools built specifically for LbT in a peer-to-peer context without any required instructor involvement; which our work explores for contents at the university level.

Chapter 3

LbT Sessions and Interview Study

We conducted a study to gain a new understanding of how university students approach teaching unfamiliar material, what the individual differences are in their processes and their struggles, and how to support this process and mitigate these challenges using web based tools. The study involves two LbT sessions, where the participants teach to someone and to themselves, followed by a semi-structured interview. The tasks that participants were asked to perform in this study are explained below.

3.1 Procedure

Prior to the study session, each participant was asked to prepare to teach two assignment or quiz questions or problems that should each take about 5 minutes to teach, each from different courses that they didn't understand or fully grasp. The only requirement was that each question should not come from the same course. Participants were told that they could teach in whichever way they want, could use whichever tools they would like (e.g., whiteboard, Miro, paper and pencil, images, diagrams, and extra devices or webcams are allowed in the video call), and the use of tools is not required and is optional. They were also informed that their teaching does not need to be perfect, as we are only interested in what they naturally do. The participants then engaged in the following three stages of the study.

I. Pre-Study Questionnaire. First, a pre-study questionnaire was digitally administered to assess the students' demographic information, their prior experience with teaching, their perceived confidence and comfort level to teach each piece of material they

Table 3.1: The sequence of questions used to guide the conversation during the interview.

#	Question
1	How satisfied were you with the teaching?
2	How difficult was the teaching task?
3	How would you compare your experience teaching someone vs teaching alone?
4	Why did you choose those particular two pieces of materials to teach?
5	Did you do any preparations, why or why not? What kind of preparations did you do? How much time did you spend preparing?
6	Have you heard of "learning by teaching" and what does it mean to you? Have you tried to teach someone in order to better learn something for yourself?
7	Do you feel more comfortable teaching while interacting with a partner or alone? Why?
8	Do you feel you learn more during the process of teaching someone, or do you feel you learn more while teaching alone, why?
9	If we were to design a tool to support learning by teaching, would you prefer that this tool would let you teach alone and reflect on the materials, or connect you with a partner so that you can teach/interact with them?
10	If you want to have a partner when teaching, who would you want that partner to be, who are you most comfortable with when you are teaching? Would you choose to teach a student who already understands the content or not? Why?
11	What support would you like to have when you are learning by teaching? If there was a tool that supported learning by teaching, would you use it?
12	Imagine now you have a tablet, phone or web app for learning by teaching, would you feel comfortable with using [feature in list of features], why or why not? Would you use [feature in list of features], why or why not?
13	If there is a feature that allows different configuration for learning by teaching, which version would you prefer? Rank in order of preference: a) Synchronous and asynchronous b) teaching to a group, an individual, with a group (students in a group taking turns teaching others), alone (teaching to yourself), and to a virtual agent (e.g., chatbot).
14	If there was a feature that enabled you to upload your teaching video with other students who are learning the same content, would you be comfortable with that, why or why not? What do you think the advantages and disadvantages are of having this kind of community of students sharing videos? How would you feel about uploading a PDF file, text or images?
15	If you do another learning by teaching session again (like repeat what we have done here), would you do something differently? What would it be? How would you explain it more effectively?

prepared for the study, and a brief overview of the topic or subject they plan to teach for each session. The section on prior experience in teaching captured data about their self-perceived experience level in teaching, selecting which types of teaching they have done (e.g., marking, holding tutorials, creating course material, giving lectures, holding offices hours, tutoring, teaching outside of school, etc.) to gain a better understanding of their experience, and their confidence level in teaching in general.

II. Explanations. At the time of the study session, the student joined a conference call and was given up to fifteen minutes to teach each piece of material. For one explanation, they were allowed to interact with the investigator by asking questions, assessing visual and auditory feedback, or in whichever form they chose. For the other explanation, the student also taught their prepared material except this time, they could not interact with the investigator. For the explanation where the investigator was not present in the video call, the investigator's camera was left on, they left the study room, and returned in fifteen minutes, to show that deception was not used. The first 12 participants taught with the investigator present and then taught alone, and the rest of the participants were instructed to teach following the reverse order to reduce bias and carryover effect. The explanations were done over Zoom where they had the ability to draw, import documents, screen share, or use other features if they chose to.

III. Interview and Post-Study Questionnaire. Once the participant finished teaching both explanations, the student participated in a semi-structured interview (Table 3.1) to assess their experience in teaching to someone versus teaching alone, their previous understanding and experiences of LbT, and various feature design questions about what they would like to see in a teaching-to-learn platform to gain a better understanding of the requirements the platform would have to meet. Since the study was done over video call, the post-study questionnaire was integrated into the interview and screen sharing was used to answer feature configuration ranking questions.

3.2 Participants

In total, 24 University of Waterloo undergraduate and graduate students participated (Table 3.2). The participants who had some experience with teaching (72%) indicated gaining this experience from marking (n=5), holding tutorials (n=2), creating course material (n=4), giving lectures (n=1), holding office hours (n=3), answering questions on Piazza (n=7), and tutoring (n=14). The participants were recruited using snowball sampling through emails, the HCI Lab SONA system (Appendix A displays the study information published on the system), an internal recruitment system, and social media networks (e.g.,

Facebook). In exchange for their participation, they were remunerated with a $25 CAD Amazon gift card.

Table 3.2: Participant demographic information (i.e., gender, age, undergraduate (U) or graduate (G) level of studies, faculty, and major) and their teaching experience level (on a scale from lots of experience to some experience to no experience) and teaching confidence level (on a scale of 1 to 5, where 1 is low).

	Demographics				**Teaching**	
P#	**Gen.**	**Age**	**U or G**	**Faculty**	**Experience**	**Confidence**
P2	F	20-21	U	Engineering	Some Experience	2
P3	M	20-21	U	Engineering	Some Experience	4
P4	M	24-25	G	Engineering	Some Experience	2
P5	M	24-25	U	Engineering	Some Experience	3
P6	F	18-19	U	Mathematics	Some Experience	3
P7	F	18-19	U	Arts	Some Experience	3
P8	F	22-23	U	Science	No Experience	2
P9	F	22-23	G	Applied Health Sciences	Some Experience	3
P10	F	18-19	U	Arts	Some Experience	4
P11	F	22-23	U	Arts	No Experience	2
P12	F	18-19	U	Mathematics	Some Experience	2
P13	F	20-21	U	Science	Some Experience	2
P14	M	20-21	U	Arts	No Experience	3
P15	M	20-21	U	Mathematics	Some Experience	3
P16	F	22-23	G	Arts	No Experience	1
P17	M	22-23	U	Mathematics	Some Experience	3
P18	F	20-21	U	Mathematics and Arts	No Experience	2
P19	F	22-23	U	Science	Some Experience	2
P20	F	22-23	U	Science	No Experience	3
P21	F	22-23	U	Engineering	Some Experience	3
P22	M	18-19	U	Engineering	Some Experience	3
P23	M	18-19	U	Mathematics	No Experience	2
P24	M	18-19	U	Arts and Mathematics	Some Experience	5
P25	F	20-21	U	Science	Some Experience	4

Chapter 4

Analysis and Findings

4.1 Analysis

The learning-by-teaching and interviews sessions were screen captured and transcribed to facilitate the analysis. The data was thematically analyzed [12] by three researchers. Two researchers created an initial coding scheme to categorize the teaching sessions and interview responses. Once a consensus was reached, all data was independently coded by one researcher and a third researcher, who reviewed 25% of the participants interview and teaching sessions LbT by random selection. With the result, we aim to provide a breakdown of what happened during the LbT sessions when university students taught unfamiliar material without guidance. Some of the key primary and secondary codes included:

- **Teaching Task** (i.e., properties of the teaching-to-learn task): domain, length and type (of question)
- **Teaching Approach** (i.e., properties of the teaching method): introduction, conclusion, past errors, current hesitations, tips, key points, reiteration, definition, importance, examples, analogies and similes
- **Tools** (i.e., tools chosen by participants to aid the teaching): screen share, notes, references and visuals
- **Interaction** (i.e., types of exchanges between the participant as the teacher and the listener): check-ins and assumptions

More detailed charts with all the codes can be found in Appendix B. Codes that ultimately did not provide further insight to our research questions were omitted from the results.

To address the research questions, these results were synthesized into the following themes: psychological challenges relating to self, psychological challenges relating to others, and know-how challenges.

4.2 Findings

4.2.1 Psychological Barriers Relating to Self

Below, we explore how psychological barriers relating to self can impact the way university students select what they will be teaching, their teaching approach, as well as the amount of time and effort spent in teaching preparations.

Selection of Teaching Materials & Approach.

We observed two psychological barriers relating to self, cognitive dissonance and zero risk bias, that can both impact the kind of materials and teaching approach university students may select when using LbT. Below we outline what barriers these are, how they come into play when LbT, and the way they can negatively impact potential learning gains when using LbT.

When LbT, the goal of the student is to learn by preparing and teaching material. During this process, they have to select materials to teach—either materials they already were mostly comfortable with (which is less intimidating but also less useful) or materials they are unfamiliar with (intimidating but useful). Many of our participants seem to be attached to the idea that the lessons need to be accurate. There is an inherent and perhaps deeply ingrained concept of need to be correct and performing well in comparison with others that makes learning by teaching (i.e. the idea of being wrong, then using feedback to improve) foreign and counter-intuitive to students. In particular, when we asked participants if they have heard of or used LbT before, several participants mentioned that they tended to teach things that they are either familiar with or confident about (P4-5, P11-13), and ask for help on the parts that they do not know well (P2, P4-5). P13 explained, "I feel like when you learn by teaching, it tends to be content that you're more comfortable with, which kind of defeats the purpose." P4 also mentioned having used this method for courses they know well because they believed that they would otherwise

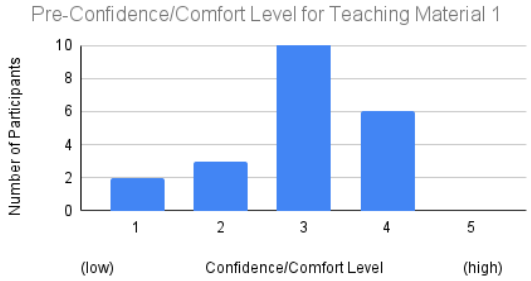

Figure 4.1: Material 1 Pre-Confidence/Comfort Levels

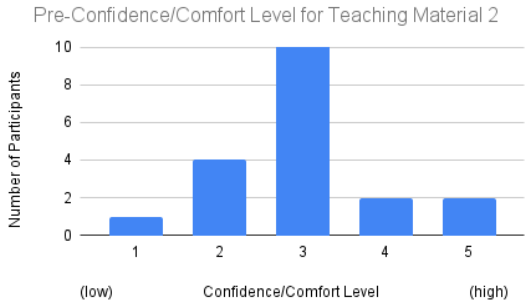

Figure 4.2: Material 2 Pre-Confidence/Comfort Levels

"confuse" themselves when teaching someone else without "really [yielding] anything" and would rather ask for help. In other words, there is a cognitive dissonance (the psychological bias that occurs when people aim to preserve cognitive consistency with their actions, values, feelings, or beliefs [26]) between what participants think they should do and what they are asked to do, and this bias becomes a barrier to learning by teaching.

To investigate further whether students avoided selecting more unfamiliar material, we analyzed participants' choices of what to teach during the LbT session. For this study, participants were required to select two problems from any of their university coursework; however, they were encouraged to choose material which they received either partial marks or none at all. Prior to the study, participants were asked to rank their confidence/comfort level in teaching each material, to better understand if there were any hesitations to choose unfamiliar materials, which may be harder to teach but where more learning gains can be expected. Figures 4.1 and 4.2 display the survey results.

In general, most participants selected material that they were neither not confident/comfortable with nor very confident/comfortable, as indicated by a score of 3 (10 participants for their first material, 10 participants for their second material). To gain a better understanding of these results, we asked participants why they selected each piece of material in the interviews. Of the participants who selected material with higher confidence/comfort levels of 4 or 5 (total = 10), P11 explained they picked topics that they became more confident about after realizing their mistakes and did not want "to teach these things that [they] know nothing about". Additionally, they thought it was suitable for teaching since teaching is "the translation of knowledge" and it was "relatively easy for [them] to explain". P18 also felt that they needed to "[know] the material well enough to explain it to someone else". P22 even mentioned that they would "have to be confident in

1.5 times the material of what [they'll] be teaching ... so that they will be able to answer 1.5 times the questions and understand where [the material] will expand to" as well as be able to "articulate the material in different ways in case someone does not understand".

Participants were also asked why they chose to teach each piece of material during their interview. A few participants admitted that they chose topics they already partially understood (P22, P25) and considered the complexity of the problem as a factor of their choice (P4, P8, P10, P17, P23). P8 thought that "both of [their materials] had really straightforward answers" and were not "high level difficultly questions". Interestingly, P3 and P15 said that they would have chosen "more difficult" (P15) questions with "more depth" (P3) instead. P18 explained that "after going through all of that time learning [the material] myself, I felt I knew the material well enough to explain it to someone else". This is in alignment with the preconception that when teaching, the listener should be able to also understand the material being taught, which is not always necessary or desired for LbT.

If the student should arrive to teach something they have not fully grasped, a grand challenge for LbT as a pedagogical method would be to get people to be comfortable teaching something that they are uncomfortable or not confident about. This requires a drastic shift in mindset to counteract the existing cognitive dissonance.

Another reason why we may have observed the results above could be due to zero risk bias, which occurs when people select options where they can have (near) absolute certainty over options that may have fewer drawbacks [4, 40, 86]. During LbT, we believe that participants exhibited this by opting for choices (e.g., teaching materials, teaching strategies) that require less effort and uncertainty. For example, for some participants, even when they realize the benefit of selecting material that is more challenging, they may be inclined to select material they know they can teach well. P3, who only spent 10 minutes preparing for each teaching session by selecting questions that are easier to teach, specifically those that "wouldn't take too long to explain" and "doesn't require prerequisite knowledge". However, when interviewed, P3 admitted that they would have chosen questions with "more depth" if they were to do another LbT session. Similarly, P15 would have chosen questions that are "more difficult" for any future sessions, instead of the questions they had chosen, which, despite being confusing, have "solutions [that are] really easy". Other participants reported selecting questions that they "fully understood" to teach (P19).

Another example of this bias is observed when participants explained why they opted for audio-only explanations without using visual representations, even if having drawings may add value to their explanation. This was due to their lack in ability to draw legibly

(P9) or success with using the drawing software (P17). P9 said "I've tried to draw and it has thus far never worked out for me because I just can't do it" and "my writing is very bad". This risk that the potential use of visuals might be ineffective becomes, in this case, a perceived risk. This risk and the anxiety due to "a fear of the unknown" [73] (that comes with making risky decisions [51]) are completely mitigated by not attempting to create and use them during the teaching sessions, resulting in a zero-risk situation. Similar to cognitive dissonance, when zero risk bias is present, the students who select material or teaching methods that present lower risks of producing incorrectly, are subject to not make the best use of LbT.

Time & Effort Spent in Teaching Preparations

During the semi-structured interviews, participants expressed having spent minimal time and effort preparing to teach. While time constraints can be an obvious reason for not spending enough time as they may have liked in preparation, another reason could be due to overconfidence in their ability to articulate the concept at hand. As a result, the teaching session may not go as planned, and they may not get as much out of the feedback. A psychological obstacle that could explain this phenomenon is optimism bias, which refers to our tendency to underestimate the likelihood of experiencing negative events, making us overoptimistic [92, 75]. For example, P19 ranked their pre-confidence/comfort level with teaching both their selected materials as 4 (where 1 = no confidence/comfort and 5 = high confidence/comfort) explaining that they "have a clear idea and structure of how to explain ... the topic". However, after their teaching sessions, they ranked their post-satisfaction score in their ability to teach the material a 2 (where 1 = not satisfied and 5 = very satisfied), since they "felt like it didn't go as planned" because they were "stumbling on [their] words" and were "not sure if [they] got [their] definitions across properly". When asked if they would do anything differently, P19 said that they would have liked to have prepared an "outline of how [they are] going to go about teaching." Similarly, several other participants mentioned wanting to have been more prepared (14/24 participants) by spending more time explaining background knowledge (P6, P8, P14, P25), having a better understanding of the content (P3, P10), or "[painting] a clear concept for the topic" (P24), by doing more research of relevant terms (P3), writing down keywords (P10), and by adding some analogies (P3) or examples (P7) to make the lesson easier to understand. While at first, optimism bias can seem to have a positive impact on learning gains in LbT, because stumbling during teaching would reveal gaps in knowledge, it can also have a negative one. This can occur when the gaps in the knowledge are gaps such as not understanding a question at all or gaps that are less complex than they could have been due to a lack of

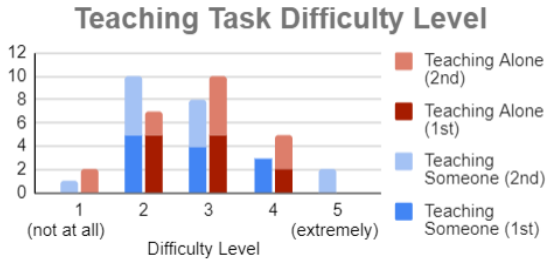

Figure 4.3: Difficulty Levels

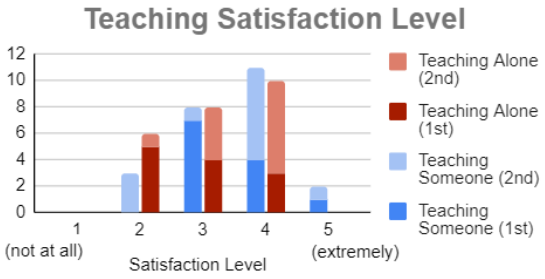

Figure 4.4: Satisfaction Levels

understanding in fundamental knowledge. For example, in P24's LbT session, they began to read the question they expected that they would teach then said "I don't know how to... I'm gonna move on to the next question" and did not try to approach the initial question at all.

4.2.2 Psychological Barriers Relating to Others

Impression Management.

Impression management in LbT can take up unnecessary cognitive effort when students devote their attention to think about how their peers will perceive potential mistakes, rather than to reflect on their teaching. For example, another reason why P11 picked topics that they became more confident in was because they did not want to appear "dumb" while explaining something they did not understand or stumbled through. Here, we can observe that the participant aimed to "maintain a desired situational identity" [55] (i.e. a desired flow of conduct in a given context) by explaining material clearly. Hence, failure (i.e. a loss of situational self-esteem) is perceived to result in embarrassment reflecting an undesired self-presentation to others [55].

Similarly, other participants reported being "afraid of judgement" (P2). An example is P19, who did not want to "seem like [they're] reading every single line" while teaching someone. This is especially the case if their sessions are recorded and accessible by others at a later time, since it could feel like having "a lot more eyes on [them]" (P3) and an "awful [experience due to having] multiple people judging [them]" (P2), or if they were teaching someone they were unfamiliar with, due to the fear of making the session "awkward" (P16). These factors might lead to a lost opportunity to learn and self-reflect during teaching, as the fear of failure drains the student's cognitive and emotional resources [22].

We also observed this phenomenon when asking participants to rank the difficulty of the teaching task (where 1 = not at all difficult and 5 = extremely difficult, Fig. 4.3) and their satisfaction level with their teaching (where 1 = not at all satisfied and 5 = extremely satisfied, Fig. 4.4) with each of their teaching materials as shown in Figures 4.3 and 4.4. When explaining their reasons for their ratings regarding the level of teaching task difficulty and satisfaction for both sessions, participants made comparisons between teaching someone (the investigator) and teaching alone (to themselves or to a pretend audience). For example, P19 explained that not wanting to "seem like [they are] reading every single line" while teaching someone resulted in a lower satisfaction. Interestingly, some participants struggled due to not being used to, or comfortable with, using a virtual teaching setup. Even when teaching alone, P13 felt uncomfortable due to a feeling like "someone's watching", which may be due to the whole study being recorded (P3). However, P13 did rank their satisfaction score higher in their teaching alone session (satisfaction = 4) than the first, explaining that there was the removed "pressure of having someone there" but they might feel differently about this in a non-virtual context.

Bandwagon Effect.

One of the ways that LbT can be organized is in a small group session, where a student is tasked with teaching unfamiliar material to several peers. This configuration could present other challenges, such as the bandwagon effect. The bandwagon effect refers to when an opinion gains more support for superficial reasons, like if an opinion is more popular than other alternatives [68, 57]. It can result in people's tendency to "remain silent if they feel—rightly or otherwise—that they are in the minority" [68]. When participants were asked about their perceptions of LbT in group settings with peers, they raised concerns of the bandwagon effect, either when learning by teaching a group, or learning by teaching with a group (where group members take turns teaching). Particularly, in these settings, if it seems like "everyone understands what one person does not", then that person would be more afraid and less likely to ask questions or provide feedback that could be useful for everyone's learning (P25). Similarly, P3 felt that when teaching in a group, they could be "the only one who's technically going to be speaking and relaying information" if the peers choose to listen passively. To avoid the potential bandwagon effect of group passive listening, some participants pointed out that they'd expect to have more meaningful and engaging one-on-one interactions when they can focus their teaching to one peer. P11 explained they "would appreciate the intimacy... [of] one-to-one interactions" because they may be "more focused" and P10 said they would be more comfortable interacting in those sessions. Other students noted that active participation of group-based learning by

teaching sessions can work—students would be able "to get more out of [LbT]" through "better conversation" and by receiving "all types of questions" (P4). P7 added that you can learn from "different [peers'] perspectives".

Ambiguity Effect.

We asked participants whom they would prefer to be matched with. Several participants said they would like to be paired with a peer who is in the same program (P2, P6, P8, P11, P13, P18, P20-21) and would prefer that they were a friend (P2, P5, P17-P19). P19 explained "I would definitely prefer a friend just because we would be used to how we explain questions or talk to each other. With the other [people] ...I'm kind of shy and I feel intimidated. There's also the possibility of the other person being terrible."

In LbT scenarios where the student can select who they want their peer to be and only select peers they know or are friends with can be a result of the ambiguity effect. This effect is a cognitive bias that compromises decision making when ambiguous options are presented amongst less ambiguous ones. The options where people feel well-informed about are generally preferred [29]. It can potentially impact negatively students' experience when only selecting peers they know instead of unfamiliar peers for various reasons, including and not limited to having less availability to practice LbT with peers, which could reduce their opportunities to use the LbT method and reduce the variety in the perspectives and feedback that a student may receive. By overcoming the ambiguity effect in the LbT peer matching context, students can gain access to people they wouldn't have otherwise been able to teach or have a more authentic audience with a wider variety of knowledge and opinions. In line with this, participants noted that it could be beneficial to be paired with a classmate and not a friend, so that while there is some "familiarity", there is not enough to lose focus or "goof around" (P11, P13). Being matched with strangers could also reduce the consequences of "mess[ing] up" (e.g. saying "something embarrassing") (P16). A few participants preferred to be paired with people who have the same background knowledge (P4, P12-13) or people who already understand the content since they might be able to point out the teacher's mistakes (P6, P13), share better insights (P3, P7), and reduce the amount of time spent on explanation (P6). Sessions with these people might provide larger return-on-investment (P4), potentially result in better questions being asked (P12), and increase the teacher's motivation to help them (P13). However, several students (P7, P9, P13, P19, P21-22) did mention that they would have to know about their partner's background and expertise before agreeing to pair with them.

4.2.3 Know-How Barriers

Missed Opportunities to Learn from Content Incomprehension.

During the LbT sessions, various participants encountered the problem of content incomprehension, which could in fact deepen their understanding of the material if they had attempted to understand the content. However, participants who moved on without trying to correct or improve their understanding missed these knowledge-building opportunities. Participants' struggles with content comprehension included skipping steps (P24), hesitations about correct terminology (P2, P5, P7, P16, P19-20, P22, P25), wording/phrasing (P9), spelling and pronunciation (P11, P20), and their overall approach to answering the question (P11, P19) [1]. These incomprehensions were not resolved during their LbT sessions. On the other hand, a few students did pause to review notes to correct a potential error or forgotten content (P6, P9, P12, P18, P24) without being prompted to do so. To further illustrate the contrast between both situations where knowledge-building opportunities were missed versus taken, we outline P2's approach in both their teaching sessions and how they responded to these hesitations.

LbT Session 1: Learning from Content Incomprehension. In P2's LbT Session 1, they taught the investigator how to create a go-to-market launch strategy plan.

> P2 started with a brief introduction explaining that they would screen share and opened a blank document to write down key points on the topic they chose to teach. They proceeded to outline key steps by naming them and providing various definitions and real world examples that most people would understand (e.g., the distribution of COVID-19 vaccines). Once they finished explaining how distribution needed to be included in their plan, they forgot what the next step of the plan was and told the investigator that they were going to take some time to check their notes. Once they found the information, they provided a brief reiteration of the previous steps and proceeded to the next one. Further into their go-to-market launch strategy plan, they realized that they missed another step in creating the timeline, so they took time to explain why this is important to consider early on and what should be included. At the end, they provided extra resources of information they skimmed over, a brief conclusion, and asked if the investigator had any questions.

[1] Appendix B describes the LbT session codes for these findings

In P2's LbT Session 1, we can see how they took the time to pause, question their knowledge-gaps in the steps they wanted to provide in their launch strategy plan and filled them in by checking their notes. They also went a step further to explain why they fixed their errors and the importance of each step. By pausing after making an error, correcting it, and reiterating the steps, P2 is able to practice *reflective knowledge-building.*

LbT Session 2: Missing the Opportunity to Learn from Content Incomprehension. In P2's second LbT session, they taught how to take a mechanical model and turn it into an electrical one.

> P2 started with an introduction on how to take a mechanical model with springs and masses and turn it into an electrical model with circuits, capacitors and batteries. They also explained how they were told that this is an important skill to learn for future applications. P2 screen shared various premade hand drawn diagrams and notes and walked through them verbally as if they were solving the problem with an imaginary peer (e.g., "now we understand..."). Halfway through the explanation, P2 says "capacitances are created from springs" pauses and asks, "am I saying that right?" Then they begin to try to correct their explanation of the rules for converting specific elements from mechanical systems to electrical but say "I'm going into this assuming that these are things that you know". Then they pause and decide it's important to explain the following rule: "dampers turn into resistors with the resistance value being one over the damper, like the damping coefficient" but does not explain why this is and moves on. Later on, they concluded their explanation and provided information about additional diagrams that could be created to analyse the voltages at each node but forgot the name of these diagrams and ended their explanation.

Here, we can observe how P2 skips over key information, such as the reason behind certain rules, which could have helped them remember this rule for future applications, which they said would be important in their introduction. P2 also did not pause to check the name of the diagram that could be used for future analysis of the system. A few reasons why P2 did stop and fix an explanation but not in another could be due to thinking it wasn't a crucial part of the explanation, due to time limits, or because they were teaching alone as opposed to someone who may have not understood. Regardless of their exact reason for skipping material, if P2 had taken the time to deepen their understanding of various terminology and rules, they would be better prepared for solving future problems related to converting mechanical models to electrical ones. In order to increase the amount of

knowledge-building that occurs in LbT sessions among university students, they could be encouraged to be open to and learn how to overcome their content incomprehension.

Lack of Experience in Teaching.

Other hesitations with the LbT task were around how to approach the teaching itself. More specifically, a few participants were not sure if they should read the question they were given (P7, P9, P19), if background information should be provided (P9), and whether a practice question should be provided to apply knowledge that was taught (P11). They were also not sure about the order of the material they taught throughout the explanation (P11-12, P18, P22), how they should refer to potential listeners in the teaching-alone sessions (P14), the clarity of their explanation overall from the listeners' perspective (P25), the amount of content to include (P15, P25), and how to conclude their session (P23).

Some participants were also unsure about how to teach using visual representations of their content. For example, P2 had screen shared a static mechanical diagram but was unsure of how to explain the direction of displacement and eventually used hand motions to aid the explanation. P20, wasn't sure how to set up their laptop in such a way that the camera showed their face and they could write on it at the same time, which caused their drawings to not be legible, resulting in the use of additional verbal explanations of their visual content. Similarly, P11, P12, and P17 opted to use verbal explanations since their drawings they made on paper when showed to the camera were too difficult to see. Ultimately, P12 was left unsatisfied with their explanation, since they found it hard to visualize multiplexers in their head without visuals. Two participants, P6, P13 were successful with showing their paper drawings to the camera but were trying to point at various locations which presented the difficulty in knowing where they were pointing, so they would turn back the paper every so often to check or try to see how it was displaying on the screen by moving the paper to the side.

The various hesitations with selecting the most appropriate teaching approach or visual tools could negatively impact the amount of learning that a student can get out of a LbT session, since certain methods are more effective than others. Moreover, since several participants were unfamiliar with the idea of LbT, they were unsure about the range of possible techniques they could use for LbT sessions or what may have been expected of them.

To illustrate how the use of the effective visual tools and teaching approach in a LbT session can increase the learning outcomes for the teacher, we outline P15's teaching approach. P15 explained that they spent over 50 minutes preparing for their teaching session,

this included reviewing notes, making a slide deck, and preparing various examples. They added that they spent extra time due to a lack of confidence in "teach[ing] on the fly". Figure 4.5 displays how P15 started by sharing the question they planned to teach, followed by their initial answer including their errors, and then shared the correct answer. By doing this, they were able to clearly understand their knowledge gaps and confidently walk through a solution while still identifying more complex knowledge gaps while walking through additional examples shared later in their session.

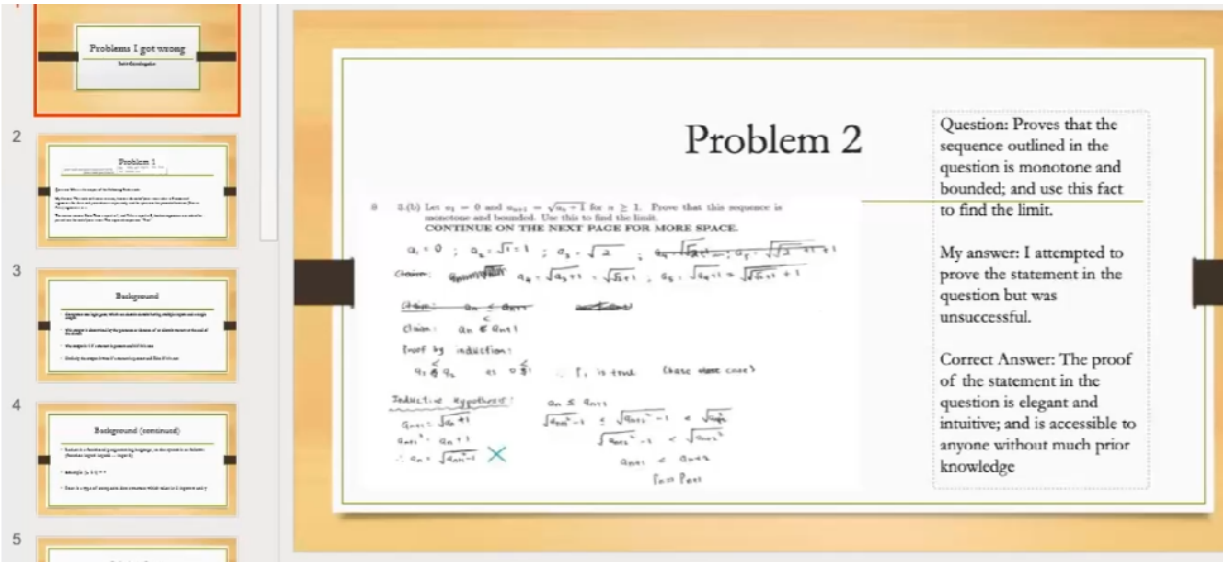

Figure 4.5: Presentation Deck for Teaching to Learn by P15.

Another barrier in LbT among university students is the lack of experience specifically when teaching alone. This was observed when participants explained their rankings in Figures 4.3 and 4.4. Some participants preferred having someone present while teaching, since teaching alone could cause nervousness because they "weren't sure if [they were] rambling" (P25). A recurring theme was the absence of feedback when teaching alone (P7, P16-17, P21-22, P25). While teaching alone, P25 could not "make sure ... if anything made sense or ... was confusing", a sentiment also expressed by P17 and P22. P21 "second-guess[ed]" themselves more, and felt less "satisfied" and "fulfillment" due to the inability to interact with the investigator. Moreover, P22 lacked "someone ... to bounce ideas off of", and P7 faced more difficulty when determining when to move on while teaching. This is reflected in Figure 4.3 and 4.4, where regardless of the order of teaching sessions (teaching along vs. someone), participants rated teaching alone as being slightly more difficult and less satisfying than teaching someone (i.e., the investigator).

On the flip side, participants also were unsure about how to approach LbT with someone without having context on their background or expertise. Some participants ranked the satisfaction level in the middle as 3. P12 explained that they did not know what the investigator's background with the material being taught was, making it "hard to judge ... where to start" but had they known a bit more they would have "been able to structure it more" appropriately. P15 provided another reason that "it [was] hard to say without like knowing if someone understood" and said that "I'm not really sure, like I put it in a way that I thought it made sense, but as for someone who is seeing it for the first time I don't know if it would." While it may be relevant to have context about peers, students can learn to tailor their LbT sessions on the fly and still identify their own knowledge gaps. For example, P21, who had some previous tutoring experience, engaged the investigator in their LbT session by asking them multiple questions to ensure they were following along. P21 also explained that they identified new knowledge gaps based on the unexpected answers the investigator followed up with in their session. Students who have less experience with tutoring may not be familiar with techniques that can be used to engage their peers in their LbT sessions to not only identify the peers' background and knowledge gaps, but their own as well.

Chapter 5

Design Implications

To support the previously outlined challenges that university students face—psychological barriers relating to self, psychological barriers relating to others, and know-how barriers—we present potential design solutions drawing from our own analysis and existing work in related educational support methods and tools. More specifically, this section outlines two main solutions first a "crash and learn" approach aimed at helping students become comfortable with learning from their mistakes, and methods for supporting online peer collaboration for LbT at the university level.

5.1 Crash and Learn

The participants in this study were unfamiliar with the idea of teaching material to peers without having mastered it first. This cognitive dissonance could in part stem from students' education system since a "classroom climate is likely to convey a performance-goal structure and may prompt fears of failure and avoidance motives among many students" [38]. However, in order for LbT to be useful, students must overcome the fear of being wrong or the idea that they must do things correctly as previously noted in Sections 4.1 and 4.2. Below we outline two possible design solutions that could encourage students to become comfortable with making mistakes ("crashing") and learning from them in their LbT sessions.

I. Incorporating Productive Failure. Productive Failure (PF) outlines the design of conditions for learners to persist in generating and exploring representations and solution methods (RSMs) for solving complex, novel problems [42, 44]. Contrary to traditional

ordering of instruction, PF starts with a problem-solving phase where learners explore and generate RSMs to complex problems based on material they have not learned yet (similar to LbT), followed by an instruction phase by an expert or teacher who builds on the learners' solutions [79]. While students typically fail to produce correct solutions, they benefit more from subsequent instruction (i.e. guidance) [43, 74] since PF primarily impacts conceptual understanding and transfer and maximizes learning in the longer term [42]. This sequence follows a similar approach to LbT where a student may fail to teach material correctly to a peer, but the peer may be able to provide guidance by asking questions or providing feedback. In order to promote PF in LbT the core mechanisms of PF ("(a) activation and differentiation of prior knowledge, (b) attention to critical features, (c) explanation and elaboration of these features, and (d) organization and assembly into canonical RSM" [44]) can be integrated using a modification of Kupar's two phases of PF. The first phase (Phase 1) encourages the generation and exploration of multiple RSMs (where failure typically occurs) during the preparation and explanation phases of LbT. The second phase (Phase 2) provides opportunities for consolidation (e.g., reviewing notes, asking peers questions, etc.) and knowledge assembly (e.g. comparing and contrasting failed or suboptimal RSMs) into canonical RSMs. In addition to incorporating these two phases, there are three design layers that can be applied to embody the PF principles including a) the task the students take part in which should be adequately complex and engaging, b) the participation structures used to engage with the task where student collaboration is enabled, and c) the social surround framing the task which should be a safe space for students with affective support for persistence [44]. By designing computer-supported LbT that prompts PF to occur could help set expectations among university students where they know that failure or imperfect teaching is common place in Phase 1.

II. Incorporating Micro Learning. Once students who are learning by teaching have clearer expectations of potentially failing when teaching unfamiliar content, they can also minimize their own perceived burden of these failures by making mistakes with smaller sections of content. This can be done by integrating micro learning techniques, which is a holistic approach that involves conveying information through short instructional segments known as *micro content*. Micro learning focuses on small content units and narrow topics that can be accessed as part of an informal learning process that fosters active collaboration [37]. Research has shown that using shorter content may increase information retention by 20% compared to longer instructional content (i.e. macro content) [33]. The length of each instructional segment in a LbT session can affect the quality of the content and knowledge retention. In a system designed by Joshi et al. [39], help sessions between an expert and novice are time-limited to three minutes per answer. This creates short explanations that

are coherent on their own and also easier to link with other snippets to create a more complex series of tutorials. Micro learning has also been integrated into MOOCs (Massive Open Online Courses) to motivate learners to make incremental learning progress in online modules [41] and has been found to make learned subjects more memorable for a longer period [56].

Deconstructing complex tasks into simpler parts that can be mastered individually is a memory-sensitive strategy that improves learning while reducing mental load on learners [94]. Teaching tasks in smaller parts can also give tutors a sense of accomplishment and motivation to continue [94]. Micro teaching has also been shown to reduce teaching anxiety in mathematics teachers [59]. By giving teachers the ability to teach in small units, they were able to solicit feedback on the sections to improve and not worry about small mistakes undermining an entire lesson. Since the creation of micro content in collaborative online teaching environments can relieve nervousness, boost confidence levels, and increase knowledge retention in tutors. Therefore, it would be beneficial to incorporate this method into the LbT web based scaffolding for university level students. Furthermore, micro learning could be designed into the PF phases. Where this has been done by structuring the exploration in PF into shorter iterative cycles of 2-3 minutes and the task involved learning a series of steps [99].

5.2 Online Peer Collaboration for LbT

As previously discussed in Section 4.2 Psychological Barriers Relating to Others, university students can take up unnecessary cognitive effort to impression management when teaching to peers, may be hesitant to pair with unfamiliar students who can still act as beneficial peers in a LbT session, and can fall into the trap of the bandwagon effect making LbT feedback potentially less useful. These challenges can be overcome by designing the appropriate peer matching and feedback configurations that enable positive collaboration among university level peers during LbT listed below.

I. Supporting Peer Matching. It is important to begin by understanding how the ambiguity effect can influence students' decision making when deciding to pair with a particular peer for LbT. It can actually lead to students seeking out more information about the ambiguous pairing (i.e. working with a stranger) through the web based tool in order to be informed about a decision [29]. Therefore, it is important to understand which information students would like to know about their peers in order to feel familiar enough with them to comfortably engage in LbT.

Participants said they would like to be paired with a peer who is in the same course or program (P2, P6, P8, P11, P13, P18, P20-21), has the same level of understanding as them (P3, P5-7, P9, P11-12, P17, P21, P24), or the required prerequisites (P2, P6, P14-16, P18, P20-22, P24) to avoid teaching redundant material (P18). Interestingly, participants also cautioned against pairing with friends since that might lead to a loss in focus and "goofing around" (P11, P13) instead of providing feedback. Moreover, students should be given the option to be paired with those who are familiar with the specific content being taught, since they would be better able to point out mistakes by the student teachers (P6, P13) and share better insights (P3, P7). In summary, information that would help students make an informed decision about which peer they would most benefit from pairing with in a LbT session would include the peer's expertise, educational background, and disclosing their name (so as to know if they already know them).

Designing for this type of peer matching gives students access to a larger pool of potential peers they would want to work with due to feeling more familiar with their options, thus increasing the amount of perspectives and type of feedback they could receive in a LbT session.

II. Supporting Collaborative Feedback It is also important to consider how collaboration in the LbT sessions can be supported through web based tools to get the most out of feedback, and question and answer phases in LbT to avoid negative impacts of the bandwagon effect and impression management.

Given the benefits of feedback for knowledge-building, tools can be built to support teaching *to* a group (an audience larger than one), since it might lead to "better conversations" (P4), and allow the teacher to get "more on-the-spot feedback" (P16) because having more people involved would culminate "different amounts of knowledge" and might encourage "different types of questions", which could lead to the discovery of "different gaps in [the teacher's] knowledge" (P22). Support for teaching *with* a group (where students in a group take turns LbT each other) could also yield better feedback, since everyone is also "expecting good feedback" for themselves (P9).

Regarding group sizes, allowing students to be in smaller groups can allow them to "get to know each person's deficits" and be more comfortable to provide critical "follow-up[s]" and "feedback" (P8). This could also mitigate students' fear of asking questions in groups, as mentioned by P25. Although LbT in a larger group setting might reduce the amount of attention given to self-reflection due to a sense of "insecurity" (P11), these settings also have their own benefits (as reported above). As such, a possible middle ground is to allow the organization of group-based LbT with "small groups [of] people [whom] I know will reciprocate the same level of attention to what I am doing" (P9).

Another possible feature is to encourage self-reflection by allowing a community of students who are learning the same content to upload their own teaching videos and share amongst the community. By having a community, participants mentioned that they can become both better teachers and better learners. As P12 said, "Having people practice teaching other people and making tutorial videos ... will help them ... instill the concepts better for themselves." P10 said, "You can learn something from somebody else's lesson, whether you're ... learning how to be a better teacher or whether you're just like another learner... trying to pick up the concepts that were talked about." The key reason for these learning benefits, as the participants see it, is the exposure to different forms of teaching approaches, questions, explanations and perspectives of the same topic (P2, P6, P19, P24), and the ability to reinforce knowledge, identify knowledge gaps, and get feedback (P18-19, P7).

Chapter 6

Students' Feature Recommendations & Opinions for Web-Based LbT Platform Tooling

We are interested in discovering features that would be necessary or desirable for supporting LbT activities (e.g. content preparation, finding peers, teaching, receiving and giving feedback, etc.). During the interview, we attempted to gauge whether participants would be comfortable with the features and if they could see themselves actually using them. We also asked participants whether they would adopt specific features (e.g., lesson templates, peer matching) for a LbT platform if it exists. Towards the end of this chapter, we also present an early stage prototype that incorporates design solutions outlined in Chapter 5 to begin exploring LbT platform designs for university students.

Web-based Tools Supporting LbT	
Tools for Teaching Preparation	
Number of participants who are comfortable with using this tool:	23 participants
Precieved Benefits:	document preparation for planning the structure (P3), organization (P8, P18, P20, P24), timing (P12), lesson material standardization (P4, P17), expectation setting (P11, P17), improving content (P5) or notes (P19) (e.g. by making them more "consolidated and cohesive" (P7)), and template ideation (P24) design by teaching experts (P14)
Concerns:	such tools could be an "overhead" (P2), be potentially restraining (P21), and not necessary for their own learning since it might encourage a specific pace (P15)
Tools for Teaching during the LbT Sessions	
Screen Sharing	
***Participants who are comfortable with using this tool and would use it:**	21 of 21 (P2-4, P6-8, P10-14, P16-25)
Precieved Benefits:	for math sessions (P6-7, P19, P23) that has "a lot of notations" or is "very computational" (P23), or when trying to code and show various programs (P12), drawing 2D coordinates (P17)
Concerns:	"security risks" (P12), "academic dishonesty" (P12), teachnical issues (P13)
Whiteboards and Concept Maps	
***Participants who are comfortable with using this tool and would use it:**	13 or 21 (P2-4, P6-7, P10, P12-13, P15, P18-20, P23)
Precieved Benefits:	enables collaboration (P7, P15, P20) with locking functionality to give open up the board only if wanted (P7), provides the ability to restrict what is visible until prepared material is intended to be revealed (e.g. stepping through graph theory (P15)),
Concerns:	time constraints (p25), the overal experience may be good or bad depending on the functionality (P17), needing to learn how to use another tool when they could screenshare and use one they are familiar with (e.g. Google Drawing, Paint) unless the proposed tooling is well designed and integrated (P16), and having poor digital drawing and writing abilities (P9)
Digital screen pointers	
***Participants who are comfortable with using this tool and would use it:**	19 of 21 (P2-5, P7, P9, P10, P12, P14-20, P22-25)
Precieved Benefits:	ability to draw attention to specific areas of a busy screen (P3), point out important parts of the diagrams (P10, P11), allow peers to give specific live feedback (P4, P10, P19) in combination with the screen sharing feature (P17, P22) or whiteboard feature (P23), pointing to messages in a chat window (P5), and when indicating a specific location in a peer's code especially when there were no line numbers (P12)
Concerns:	the pointer blends with the colours on the screen (P14)

* of the 21 participants who were asked if they would feel comfortable with using the tool and if they would use the tool

Figure 6.1: Students' perceived benefits and concerns when using web-based tools supporting LbT

6.1 Tools for Teaching Preparation

Figure 6.1 displays a summary of participants opinions on various features. The first section of this chart, breaks down their views on using tools for teaching preparation. Most participants said that they would be comfortable using a web based support tool to help prepare for their LbT session through a guide or template aimed to help students generate content or lesson plans (P2-8, P10-25). The table also provides a list of participant's perceived benefits of such tools (e.g. content organization). P4 also mentioned such tools would make the process of preparing "easier" for "someone who hasn't done it before". In addition to the concerns listed in the table, other participants' preference to use preparation tools depends on a few considerations. P6 would use preparation tools if they "knew the material" and were going to teach someone who did not (i.e. regular teaching), but would not use them to teach material that the they themselves do not understand. This is a recurring theme, with P10, P13, and P22 expressing similar opinions that they would not use them if the purpose was to learn the material for themselves through teaching, instead of ensuring the audience learns something. While many participants commented on the benefits of using preparation tools, the design should avoid solutions that might discourage their use (e.g. lacking flexibility) and carefully consider the balance between the amount of effort and time needed to use these tools.

6.2 Tools for LbT in Various Configurations

6.2.1 Preferences & Perceptions of Various LbT Configurations

Participants were asked about their thoughts on various ways of setting up a web-based LbT platform including the following: teaching synchronously, teaching asynchronously, teaching to a group of student, teaching to an individual student, teaching with a group of students (where students in a group take turns teaching each other), teaching alone (or to oneself), and teaching to a virtual agent (e.g., chatbot). Figure 6.2 summarize the participant's order of preference.

Teaching an Individual. Teaching someone is most frequently ranked as the most preferred configuration by participants (Fig. 6.2). Familiarity with this configuration due to prior experience with one-to-one tutoring might be a reason behind a high rank (P10). Aligned to analyses presented previously, the presence of feedback is a common reason for participants' favourable opinions of teaching a person. Feedback could take the form of visual cues (P2) like the peer's facial expressions (P6, P12), and peer's questions

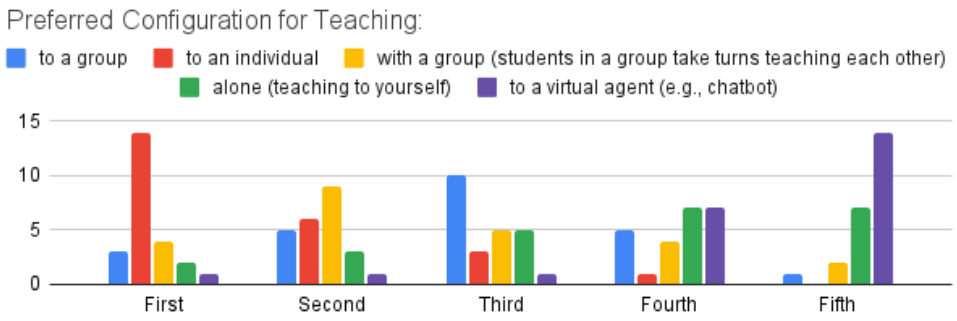

Figure 6.2: Preferred Configuration Types for LbT Sessions

(P13). Feedback can improve the teaching experience by letting the teacher know what the peer understands (P9-10) and the peer's level of engagement (P10), and by allowing adjustments (e.g., adjusting pace, teaching style, content, structure) while teaching (P3, P12). However, some participants disagree, since feedback "is not necessarily a confidence booster" (P7); for instance, it could be rude to keep asking the peer if they understand the content taught (P9). Instead, the teacher should make better preparations before teaching "to make [their] thoughts more eloquent" (P9).

Peers' feedback and questions could benefit teachers by identifying gaps in understanding (P11), gaining alternative perspectives (P11, P13, P14, P19) and a deeper understanding (P4, P7), and encouraging "more critical thought" (P11), especially for "certain parts [concepts] that are more difficult" (P13). These learning benefits, however, might only be possible if the audience has "a certain level of understanding", enough to "challenge the teacher" (P25), with other participants expressing similar sentiments (P8, P11). Teachers, however, might also prefer teaching someone just because they "get to interact with them", making the session "more interactive" and "fun" (P21). These interactions are also a way to "bounce ideas off" of each other (P16). In contrast to bigger groups, teaching a single person is "more personal", and the teacher can be "more focused on just that person" (P11), with similar sentiments also expressed by P7, P18 and P21. There might also be less fear to ask questions in a one-to-one setting (P25).

Moreover, several participants prefer teaching someone because it provides a source of motivation and purpose for their teaching; for instance, via reassuring comments for the teacher (e.g., "it's all good"(P12)). Teaching someone might make the teacher more accountable (P2, P4) due to a fear of "wasting [others'] time" (P2), a feeling of being relied on (P2), and feeling more pressure to "get it right" (P7). This motivation and common engagement could lead to increased interest (P21) and focus (P4), and encourage

self-reflection (P14). Furthermore, a few participants also reported more nuances to their preferences. For instance, although P17 would prefer to interact with someone when trying to solve questions, they would prefer learning the content by themselves to stay "100% focused". There is also a possibility that teaching only a single person would make the person "less likely to give feedback" due to the "fear of asking stupid questions" or making it "awkward" (P16).

Teaching with a Group. Teaching with a group (where students in a group take turns teaching each other) is most commonly ranked as the second most preferred configuration (Fig. 6.2). Teaching with a group is beneficial since everyone could "teach and learn in the same session" (P13). This removes "the pressure of ... being the sole teacher" (P13) and the sole focus of the group (P6). Moreover, teaching with a group might encourage more social interaction and better feedback, since everyone is also "expecting good feedback" for themselves (P9). However, teaching with a group might be "really confusing" because "everyone has a different teaching style" and there is a need to "keep adapting" to each person's teaching (P15).

Teaching to a Group. This configuration is most commonly ranked as the third most preferred configuration (Fig. 6.2). Teaching an audience of more than one might lead to "better conversations" (P4), and would allow the teacher to "teach more people at the same time" (P4). Moreover, the teacher can get "more ... on-the-spot feedback" (P16) because having more people involved would culminate "different amounts of knowledge" and might encourage "different types of questions", which could lead to the discovery of "different gaps in [the teacher's] knowledge" (P22). That said, this configuration might need the teacher to be an "expert" who is capable of "handling all types of questions" (P4). On the flip side, however, having "multiple people judging you" could be an "awful" experience (P2).

Teaching Alone. Opinions on teaching alone were not unified, but participants generally ranked them in the bottom three (Fig. 6.2). Participants reported reasons for not preferring to teach alone, including that teaching alone might evoke "a greater sense of apathy" and a lack of purpose (P11), which might lead to a feeling that the teacher "doesn't feel like [they are] really doing anything" (P24). Moreover, teaching alone only requires the teacher to "regurgitate information because you're not actually trying to make someone learn the content" (P13). However, in the case that the teach-alone session is recorded and viewable by others later, teaching alone might encourage more concentration (P5), thorough preparation work and hence a better understanding since the teacher "can't rely on someone else to fill in the gaps of where [the teacher's] knowledge is lacking" (P8). Not teaching anyone also gives the teacher more control, as having someone else might result in comments and questions that "throw [the teacher] off" (P16). In contrast, other

participants felt that if they were just teaching themselves and no one else, their thought process could be less refined and as such, the process is "less difficult" due to a lack of confidence to teach others (P19) or a feeling of incompetency as a teacher (P19). In this sense, "having a person listening or not actually doesn't change very much" (P5). For a few participants, preferring to not teach anyone else is a matter of personal preference, as they might be "shy" (P19), "don't want to have to meet with somebody" (P11) and "more comfortable" with teaching alone (P18). Moreover, not having to teach someone else might be "a lot more efficient" logistically, since there is no need to "set up times or things with other people". Interestingly, P21 suggested using teach-alone sessions as a form of "full-dress rehearsal" for teaching others. This might be useful for participants who are not confident about their understanding of the material (P11, P19, P21).

Teaching a Virtual Agent. Teaching a virtual agent is most commonly rated as the least preferred configuration (Fig. 6.2). Reasons for this rating include the perception that virtual agents are "dumb" (P2), "feels fake" (P2) and "not very interactive" (P5). Moreover, virtual agents do "not [provide] actual feedback" (P2), since they must be "really well-developed ... [to] give you proper feedback" (P4). Teaching a virtual agent might also be seen as distracting and pointless (P4), and participants would rather teach alone (P2). However, a few participants thought teaching virtual agents would be "cool" (P4), "interesting and different" (P12), which make participants "genuinely curious" about them (P18). Virtual agents would act as "another entity" during teaching sessions, which might be analogous to "talk[ing] your ideas out to a rubber duck", and as such could be superior to teaching alone (P12). Teaching virtual agents could also "help the algorithm", and could be beneficial due to the agents' suggestions (P5). That said, a lack of understanding of virtual agents might result in hesitations towards using them (P14).

Synchronous vs Asynchronous Participation While many responses by participants for teaching an individual, with and to a group assume a synchronous nature, participants were also asked about their preference for synchronous vs. asynchronous LbT. Three participants preferred asynchronous (P14, P16, P19), with the rest preferring synchronous (P2-13, P15-18, P20-15). Most participants preferred to participate synchronously because teachers could receive immediate feedback or questions (P2, P8-10, P15, P18, P20-22, P24-25), see facial cues (P22, P24), adapt quickly (P2, P8, P10, P12, P15, P20, P22), and have direct interactions (P3, P13). Moreover, participating asynchronously would require repeated checks for feedback, instead of just focusing on a single block of synchronous activity (P13, P23). As such, participants might not have the motivation to perform the repeated follow-ups required from asynchronous sessions (P25). Further, feedback received not during teaching, but after the teaching is completed, might be less helpful for learning (P8). The advantage of increased accountability when teaching others might also

be dampened (P23). On the other hand, working asynchronous allows for more flexible scheduling (P3, P14, P19) and the teacher can record their teaching at any time (P6). Participants watching recorded asynchronous sessions could also focus only on things they need help with, and "skip through" other parts, potentially saving time (P16).

6.2.2 Tool Design Implications for LbT in Various Configurations

Having presented participants' perceptions and preferences for various LbT configurations, we now present implications for designing tools for these configurations that are either directly suggested by participants, or derived from previously presented comments.

Encouraging and allowing informed decisions. Each configuration has their own strengths, weaknesses, and varying degree of suitability depending on many factors (e.g., content (P11), level of expertise (P4), relationship between users (P8), amount of free time available (P4)), as discussed above. As such, for a platform supporting multiple configurations, it is essential to educate users of differences between the configurations and guide them towards choosing the best configuration for their unique context. Specifically, if teaching a virtual agent is an option, designers should make clear the capabilities of the agent, since most users might be especially unfamiliar with this configuration. On the other hand, for users who might lack the confidence to use configurations that involve other people, additional tools for boosting users' confidence or guiding users to make it less difficult to use those configurations might be useful. Otherwise, they might be inclined to only teach alone or a virtual agent, and miss out on the unique benefits from teaching someone, a group, or with a group. Furthermore, other features could be added to provide more flexible support for users, for example, a scheduling workflow that mitigates scheduling difficulties between users, a possible issue commonly reported by participants.

Encouraging self-reflection. A few participants reported preferring to teach alone or a virtual agent due to having more opportunities to perform self-reflection. However, tools could be designed to encourage self-reflection regardless of configuration. These tools could "reintroduce concepts throughout the day and re-solidify them ... similar to Duolingo" (P12).

Encouraging productive group interactions. Participants suggested a need for some way to practice teaching in group settings as a way of increasing their confidence and preparedness (P19). Moreover, to mitigate the increase in communication difficulty within larger groups (when teaching to or with a group), tools could be designed to facilitate teaching a larger group, and make it easier to direct questions to a specific person and speak without interrupting others. Furthermore, the ideal group size in teaching to or with a

group configurations might change depending on various factors (e.g., material complexity). As such, these configurations should support varying group sizes, and allow users the flexibility of changing the size. Even though most participants preferred synchronous sessions, tools should support both synchronous and asynchronous sessions to accommodate more users.

Partner matching. Another important aspect of configurations involving multiple people is partner matching, i.e., the way peers are connected with each other for LbT sessions. All 23 participants who were asked whether they would use a matching tool reported intentions of using such a tool. Participants were also asked who they would like to be matched with. Some participants said they would like to be paired with a peer who is in the same course or program (P2, P6, P8, P11, P13, P18, P20-21), has the same level of understanding as them (P3, P5-7, P9, P11-12, P17, P21, P24), or the required prerequisites (P2, P6, P14-16, P18, P20-22, P24) to avoid teaching redundant material (P18). Interestingly, it could be beneficial to be paired with a classmate and not a friend, so that while there is some "familiarity", there is not enough to lose focus or "goof around" (P11, P13).Being matched with strangers could also reduce the consequences of "mess[ing] up" (e.g. saying "something embarrassing") (P16). Furthermore, a few participants preferred to be paired with people with background knowledge, but do not already know the content itself. Sessions with these people might provide larger return-on-investment (P4), potentially result in better questions being asked (P12), and increase the teacher's motivation to help them (P13). On the other hand, people who already understand the content might be better in pointing out the teacher's mistakes (P6, P13), share better insights (P3, P7), and reduce the amount of time spent on explanation (P6).

In summary, partner matching tools should offer ways of filtering partners based on learning goals (P22), availability (P18), field of content (P21, P23), familiarity with user (P11), whether they are taking/have taken the same course (P4), their level of expertise (e.g., year of study, absence of prerequisite knowledge) (P3-4, P9, P18) and intended role (e.g., teacher, listener) (P3, P8, P12, P15, P25). Moreover, these tools should allow users to use their university email or profile and have ways of preventing fake profiles and trolls (e.g., via email verification) (P7, P9).

6.3 Tools for Teaching during the LbT Sessions

In Figure 6.1, we outline various tools that can be used to support the teaching activities during students' LbT sessions. For each of these tools, the figure outlines their perceived benefits and concerns for using this tool. For screen sharing, all participants who were

specifically asked about it (P2-4, P6-8, P10-14, P16-25) said that they would use it, however, one participant didn't use it for their LbT session. P12 explained that they didn't use this tool during their session due to concerns of "security risks" and the concern of users using this "for academic dishonesty" when matched with their peers in the same courses. Another participant also shared some concerns, P13 said "there's technical issues like when you share they don't see it or vice versa, or you don't know what you're sharing like which screen or desktop, or it slows slows down your Wi-Fi. It would be more comfortable if you knew exactly what you were screen sharing and you could double check." For whiteboard and concept mapping tools, one participant (P23) said that they would like to "be able to use [their] Apple Pencil" but a "big problem is [that they] currently don't know how to screen share [their] iPad to [their] laptop, so [they] ...don't do it... There should be an easy way for people to [do so]." A few participants imagined this tool to be collaborative (P7, P15, P20). P20 described it as a "way of illustrating ideas and it's ... very collaborative oriented—I mean—if you make it to be that way." Figure 6.1 outlines other participants perceived benefits and concerns about these tools. In general, participants would like to be able to use this collaboratively, with specific peers, and features. While a few participants said that they would be comfortable with using it, they might use it depending on the situation (P9, P16-17, P25) or on the content they are teaching (P11). For using digital screen pointers when teaching, several participants said they would feel comfortable with using this and would use it (19 of 21 participants) for the benefits listed in Figure 6.1. One participant who outlined both benefits and concerns explained that during their LbT session, when using "Photoshop, it's confusing if you don't have a mouse or a pointer because you can't just say 'this tool', 'that tool', 'oh go to the left side of your screen' because there's just so many calls to action ... and buttons all over the screen" but "a regular mouse courser could get lost just because black on dark grey—I think Photoshop's dark grey—so if ... it was a bright red dot that would be helpful like a laser pointer almost" (P14).

6.4 Tools for Receiving and Giving Feedback

Rating Feedback. Participants were asked if they would be comfortable and if they would use various forms of feedback rating systems. This covered rating systems that would be only visible to the students who were teaching, or public ratings to everyone in the platform (where the author could be identified or anonymous), and if such systems existed which rating prompts would they include. Some participants mentioned that they may be rated on depth of content (P3, P4, P20), quality of content (P4, P20), clarity of

content (P20-21), organization of content (P20), overall presentation (P4), how much help they required (P3), how responsive/adaptive they are (P22), on a numeric scale (P3, P15, P25), on a non-numeric scale from "low to high" (P23), or "drop down fields" (P7) that the student can modify (P15).

Several participants said they would feel comfortable if the ratings were only visible to the student who was teaching (P2-3, P6-18, P20-25) and one participant said that they would not be comfortable with any form of ratings (P19). P3 said "it would be a good way to figure out which improvements I can possibly do and see where I am currently at" and P10 added "I think that's the only way to improve", "if I'm participating it's because I want to help other people so I would need that feedback in order to improve." A few participants said that they would be comfortable with this because "if you're going on the platform, you should be receptive to feedback" (P7), but "it'd have to be open-ended" (P7), "allow [students] to make comments" (P6-7) and explanations (P2, P8), "rather than just having ... drop-down fields" (P7) "because a lot of misinterpretation/miscommunication [can be taken] the wrong way" (P7), "rating could vary quite a bit from one person to the next" (P8), and comments could be "clearer if this is a short amount of time that you're meeting" (P6). P18 also said that they would use this if it has "the option for anonymity because [they] think that gives people a different level of confidence ... to speak freely". Various participants were hesitant to use and feel comfortable about public ratings in the platform (P2, P3, P6-9, P16, P18, P25) since there would be more "pressure" (P3), more nervousness (P3, P8), and it would feel "like a teaching app more than a learning-by-teaching app" (P6). Additionally, there could be more "bias" ratings (P7, P25), and people "might troll you and give you like no stars at all" (P25). Some participants said that they would be comfortable with and would use public rating systems (P4-5, P12, P15, P17, P20-23) and some participants would feel slightly less comfortable but would still use it (P10-11, P13) for making informed peer matching decisions (P4, P5), for transparency (P5) and honesty (P5).

Feedback Forms. Participants were then asked how they would feel about giving and receiving feedback through a form. In terms of what feedback is most useful, P10 would expect to see feedback criteria like "organization", "time management", "friendliness", "competence in explaining the content", "how much knowledge [the teachers] have about what they are trying to teach", and a freeform field. P11 said that open-ended feedback would be more thoughtful (as compared to people "mindlessly circling" options on a form). Another participant, P21 said they would use this in combination with ratings if they could be anonymous. In general, participants who said they would feel comfortable and would use feedback forms (P2-14, P16, P18-19, P21-25) would also want to see some feedback prompts including: learning/teaching style (P14, P22-23), ability to answer questions (P16), and

visual/presentation material (P9, P16) as long as the form is not too time consuming (P24-25). Some also said that they would prefer this method over rating systems (P2, P9, P11, P14) and one explained that they would "trust" the feedback more (P11). Lastly, P12 would like both the teacher and the listener to take part in filling out the form to help with understanding what they each thought about it or what could be improved, such as how "engaged" they were.

Feedback Saved in History Tools. Participants were also asked about a history tool designed to view and access previously taught session recordings, and to save student's questions. Several participants said they would feel comfortable having their sessions saved and would use the tool (P2-8, P12, P14, P16-20, P22-24) to be able to view previously taught content, check for areas of improvement (P3, P6), re-watch clips of well explained segments (P4), and to enable asynchronous input from the listener (P5, P19), check if you would be "interested" in pairing with that peer based on past recordings (P14), and to follow up with comments (P19). Participants P2, P3, and P8 also said they would be OK with sharing this with the students and P12 agreed given that there is "consent to be recorded for both parties". Other conditions included having the choice to make it public or not (P2, P7, P16-15, P22), have the ability to "take it down" (P8) or "delete" it (P22) when they want to. P7 explained that they would not want others "to be able to like hang on to a copy of me explaining something or struggling to explain something for like forever".

Another feature that was included in this history tool was a method for saving answered or unanswered questions in the LbT sessions. Various participants said they would use this and would be comfortable with it (P2-4, P6-9, P11-23) so that they could "brush up" on areas of improvement (P2, P11), follow up with the feedback (P2, P4), and to see other peers' answers to questions (P13). P11 explained that they would find saved student questions useful because "it gives me a point of reference to refer back [to see] where the gaps in my knowledge were and [allow him to work on] a second attempt [to] close those gaps." However, P2 noted that they would not be sure if other listeners who shared questions would be comfortable having it saved and P15 would like to have consent from all parties. Other conditions included being able to make your questions anonymous or not (P16, P19), having visibility control to specific users (P22), and being able to delete questions (P22). P9 and P8 said it would be helpful and save time to quickly find specific questions, and P8 explained that "it's basically like taking notes for you" and it "keeps a log of what really stood out to the participants or what they didn't understand". Similarly, P10 thought this, and would use it if there was a way to timestamp questions by showing a symbol along a timeline. Two participants thought it would be better to turn this into an FAQ section (P4, P15) where various peers can share answers and follow up with each

other. A few participants said they were comfortable with having their questions saved, but they may or may not refer to them (P10, P24-25). One explained that they prefer addressing it in the moment (P24) and one participant (P5) said that they would not use it due to it being a "waste of time".

Post-session Annotated Feedback. Lastly, we asked participants how they would feel about using a specific tool for post-session annotated feedback. In the history tool—where users can see your saved sessions—users would be able to select a session, then click on a timestamp of that recording, then a dialogue box would appear and the user could write feedback and/or select a category describing the type of feedback they wanted to give (e.g., correct content, incorrect content, area of improvement, etc.). Once saved, the timeline would display symbols over those timestamps to be able to reveal the feedback when selected and jump to that spot. Of the 23 participants who were asked, most of them said they would be comfortable with such a tool and would use it (P3, P5-11, P13, P15-23), a few others said they might use it (P4, P12, P14, P25), and one said that while they would be comfortable with it, they would not use it (P24). P20 said that they would use it to comment on areas where content could be expanded, to indicate which sections are more important for a course, where an explanation could be slower, or where an image could have been used, and P22 would use it to identify knowledge gaps. One participant, P3, thought that this would be useful for the listener and also for the one doing the teaching. P11 can see the benefit of an annotation tool where you can provide feedback to others: "if a person seemed frustrated, I would [tell them], 'You're doing so good! Don't worry, you got this!'", "as a way to encourage people", and to provide "critiques". A few participants said that they would use it upon certain conditions. P10 said they would use just the textbox without selecting specific prompts or feedback types. P23 said that it could be "demotivating" if there is no "constructive feedback" and the annotation only indicates if a timestamp was good or bad. Another participant (P15) said that they would like to use this too if there are only a few people in the session, "like five people or less" otherwise it could "cause some confusion". The participants who said they might use it, said this due to not always seeing "the value in pairing a comment with a timestamp" (P12), preferring to make their own notes separately (P14), or due to time constraints (P25).

6.5 Tools for Supporting an Online LbT Community from the University Students' Perspective

During the interview, we asked participants the question "If there was a feature that enabled you to upload your teaching video with other students who are learning the same

content, what do you think the advantages and disadvantages are of having this kind of community of students sharing videos?"

6.5.1 Advantages

Exposure to Different Approaches. In terms of advantages, by having a community, participants mentioned that they can become both better teachers and better learners. As P12 said, "Having people practice teaching other people and making tutorial videos ... will help them ... instill the concepts better for themselves." P10 said, "You can learn something from somebody else's lesson, whether you're ... learning how to be a better teacher or whether you're just another learner... trying to pick up the concepts that were talked about." The key reason for these learning benefits, as the participants see it, is the exposure to different forms of teaching approaches, questions, explanations and perspectives of the same topic (P2, P6, P19, P24), and the ability to reinforce knowledge, identify knowledge gaps, and get feedback (P18-19, P7).

Familiarity with the Learners. Another benefit of having a LbT community is that students may have more familiarity with how other students learn the content, "how best [to] fill in the gaps" and how to avoid falling behind, compared to the professors themselves (P2). Moreover, it might be beneficial for peers to be "in a positive group of students who want to learn together" (P24). If LbT videos are shared in smaller groups, students can "get to know people's deficits" and be more comfortable to provide critical "follow-up[s]" and "feedback" (P8). On the flip side, P22 saw advantages with larger groups: "when you have more individuals who are viewing your content, then you have more individuals who may ask you questions, who may point out gaps in your knowledge, and who may point out gaps in their own understanding." An added bonus of understanding your peers and learning with them is having the opportunity to make friends (P9, P23).

An Opportunity to Contribute to Others. Finally, participants also think of LbT as a way to contribute to other people's learning. P11 said that "if it could help people's learning, then [students] should be able to freely use it without worrying." In line with this, P12 thought that having a LbT community would help to promote a healthier mindset amongst students "to be helping each other versus competing against each other". The listeners who are giving "feedback, can also learn from it" (P7) and if you're a user who is just listening you can "pick up concepts that were talked about in the lesson" (P10). Moreover, participants might also be motivated by the feeling of "being useful" since their contributions could be used by others "as a resource to learn materials" (P16). P16 also noted that with existing resources for "specific, nitty-gritty" details, "no one's bothered to make a YouTube video about it", making this a useful feature.

Learning on your Own Time at your Own Pace. Since content shared on such a platform "is not a set class time", students could use them "whenever" and "revisit" them, which could help "solidify" their understanding (P14, P20). In addition, P14 said that with annotating while they might not use it, they "know others would find that helpful or be able to take notes and pause it, speed it up". P20 also thinks "having that makes learning very accessible to individuals who are at different paces and individuals who perhaps didn't get to attend the session in real time but really still wanted to be able to gain insight from the content."

6.5.2 Disadvantages

Scrutiny and Fear of Judgment. Students mentioned feeling uncomfortable having their teaching being recorded, because of potential mistakes they might make (P10). There is definitely a sense that since it is a lesson, that it needs to be perfect, even though our particular study presented a LbT exercise where the student is teaching something that they are in the process of trying to learn. P2 mentioned being "afraid of judgment". P3 describes the scrutiny having "a lot more eyes on me" and a community where "everyone's going to be going over everything I say". P16 said that they feel "a bit like an imposter because I know I'm far from an expert" and "it's hard to pretend that I know this like the back of my hand when I've really only done it once." Another participant said that "as someone who's just like a nervous teacher, I definitely do a lot of planning" and they would take more time as a result.

Lengthy Preparation Process. Students of this platform may feel like they take a significant amount of time to upload content, as there is some additional overhead. For example, P23 explained "I guess it's kind of inefficient you can say for some people that you need to prepare beforehand on the teaching materials and if it's asynchronous teaching then you just you need to have a recording set up for your iPad, for your laptop, and stuff." Similarly, P19 said that "to prepare to teach something for the session ... I feel it would be time consuming as a student, especially if you have other courses and whatnot." Lastly, P21 added that "it requires so much time to prepare the material, to practice your delivery, to actually record the video because sometimes you didn't set up the video properly and then nothing recorded and you have to do it again."

Bad Intentions and Unequal Contributions. There is some sense that a LbT community requires trust and equal participation between community members. P11 mentioned that students could be "rude" and without proper monitoring, students can easily fall into "the trap of comparison" where they feel "embarrassed" that they do not know as much

about somebody else, instead of being part of a supportive community. P2 mentioned that there could be a "shortage of people wanting to help", and another problem is that "by the time students see all the materials come together, it is already midterm time, when recording a LbT video at that time may be already too late." Likewise, P6 expressed some doubts as to whether students would try to learn a concept by teaching, or just "search the video up and learn by watching". P8 said, "professors are really focusing on articulating the feedback in a really gentle and delicate way and then it doesn't come across as bluntly as it needs to; whereas other students, since you're all kind of on the same level of authority, they're totally fine sharing something with you". They added, "then, the other students are quiet because they don't want to seem like they're offending me in front of the professor." Another participant, P9, brought up the issue of "group dynamic"—you could be "shouting into a group chat void" where group members do not deliver what they promise.

P12 said, "I could see people trying to use it for academic dishonesty; and, in a worst case, trying to spread misinformation in [order to be] competitive. It's a possibility that could happen". P16 and P20 shared this thought and feared that if their own notes for LbT were taken from their professors, this could become an "academic integrity issue". P17 also thought that "ethic issues can be complicated when ... students ... upload videos." More specifically, P20 further explained that "people may begin to exploit [intellectual property] because if people find a way to go about downloading this content they would then be able to sell it and that's no fun."

Privacy Concerns. There are also privacy concerns about the video being permanent, public, and shared beyond the group without the teacher's permission (P10, P11, P13), and having personal identifiable information (P2, P7). As P2 said, "Your voice is always your voice. Even if you took out the names from it, I think it's pretty clear, especially as a girl [because there are only] so many girls anyway in my program." In general, P18 added a disadvantage is "having your video on the internet if you don't want it to necessarily be there."

Information Overload. Participants mentioned that such a LbT community can "get really cluttered when there's just too many sources of information" (P4), "too many files to keep track of" (P5), and that it would be nice to have "less amount of information but better quality" (P4).

Incorrect Content. Two participants mentioned the disadvantage of posting content with mistakes. P15 said, "if someone doesn't really know what they're talking about and they end up teaching something which is just wrong, it can cause a lot of confusion." P16 explained that "platforms like YouTube already have a lot of that similar content produced

at higher quality because people are getting money for it, and they put more thought into it, and they're also experts—generally more expert than students— so they are less likely to make mistakes whereas if students were teaching each other there's always the chance that someone says something that's wrong and no one knows any better to correct it."

6.5.3 Tool Design Implications & Recommendations for an Online LbT Community

Participants also provided a number of suggestions on how to create a LbT community.

Rating System.. P10 suggests a rating system to signal the quality of the recorded lessons, or showing the credentials of the teacher (e.g., what degree they have) and "giving those people some kind of privileged position within" as they may be a "more valid source of information".

Mitigating Insecurity by Keeping Groups Small. P11 suggested one way to mitigate the sense of "insecurity" in teaching something unfamiliar, which is, to "screen people by their averages so that really smart people cannot see my [videos]". Though they acknowledged that this solution is not realistic, they thought that "limiting the exposure" could be "more encouraging for people to actually use the platform and upload their stuff". P9 said they prefer "small groups [where there are] people I know that will reciprocate the same level of attention to what I am doing." They added, "it's kind of like a social media for teaching."

Managing Access. P14 had the idea of censoring certain peers comments in a LbT session if the learner "might not take criticism" well, however, if you "completely censor" some users "like [P14], who's trying to teach other people, [they] might get offended." P15 suggested that for giving ratings, there may need to be content regulations and users may need a verified account (e.g., using university email) before being able to participate in the rating system.

Managing Information Overload. When scrolling through many files, P21 said "I'm hesitant because like if everyone [uploads content] then we'll have a lot of files, so I would prefer a way to rank those files. For example, [having] a lot of people to give likes and dislikes on how useful it is, and then having those highly ranked [content] show up first, given a particular topic. For example, given the topic of linear regression, when I click on the topic, it will show me a bunch of files but the files will be listed based on how useful ... other people rate it". They added that otherwise when "allowing people to upload files, the quality of files may really differ, and ... seeing a lot of files could really ... waste people's time".

6.6 A LbT Platform Prototype

To begin understanding how to design a LbT Platform for university students we built a prototype that begins to incorporate design solutions presented in Chapter 5 and ran a pilot study with 12 students enrolled in the Winter 2021 graduate offering of *CS889: Masterclass in Human-Computer Interaction: Educational Technology* at the University of Waterloo.

Prototype System Design. We present *MicroLbT* (Figure 6.3), a prototype platform

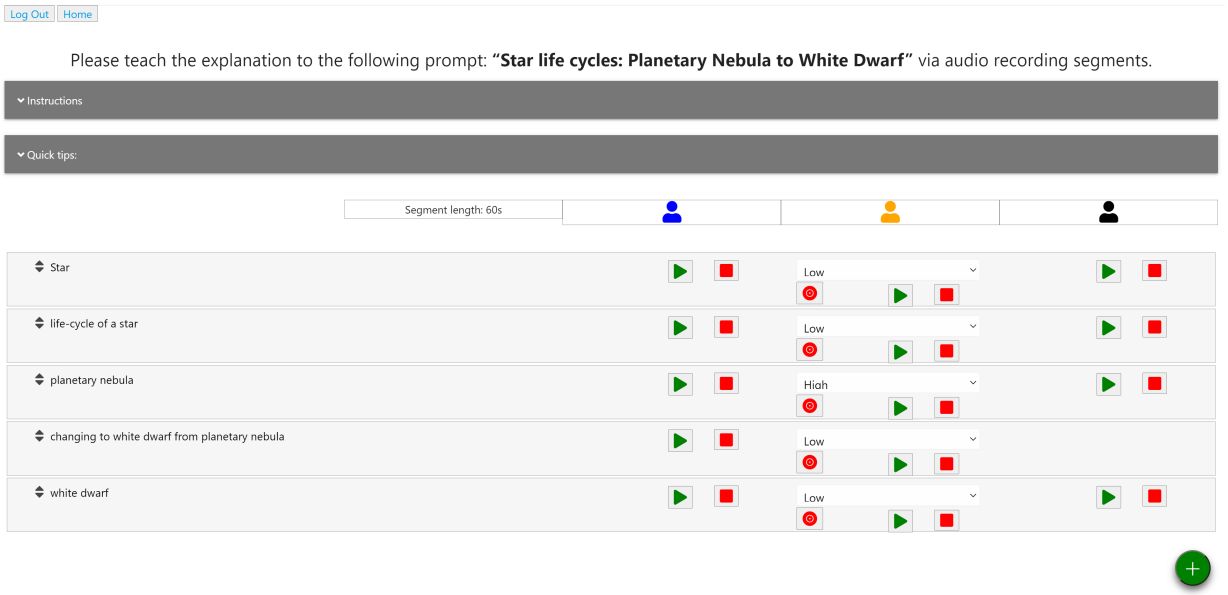

Figure 6.3: MicroLbT

that supports collaborative LbT in an online context. This platform incorporates micro learning (discussed in Chapter 5) where a group of peers simultaneously take the role of the teacher and learner in LbT to answer a shared question by collaboratively deconstructing and sequencing segments of an explanation and then recording instructional and time-limited audio for each segment. More specifically, the platform scaffolding provides the students with an audio segment creation and organization tool where each segment in a sequence holds both the micro-teaching segment name and its corresponding explanation recordings. MicroLbT segments can be easily added, rearranged, and modified to restructure the explanation as many times as group members require. Users can also rearrange the

order of segments by simply clicking and dragging a segment. This reordering is preserved so that other group members can work on the updated sequence. The ability to restructure segment orderings supports learner-teachers (i.e. students who are simultaneously in the role of the student and teacher) as they make clarifying edits to the explanation, much like in the multi-component model of micro learning [82].

Previous work further specifies how having screen-capturing and voice recording instead of videotaping reduces the Hawthorne effect and that subjects may be more shy in front of a video camera than a microphone, since the latter is less conspicuous [95]. Since audio recordings could ensure a greater degree of comfort, we chose to enable students to share teaching segments via audio recordings.

The goal of this platform is to support the LbT Crash and Learn process to become comfortable with making mistakes and learning from them. Therefore, we have designed it so that students can listen to the clips of other group members in order to learn from them and iteratively improve their own explanations. A participant can both listen to and record their own clips for a segment. To reduce nervousness and errors in recordings, we allow students to overwrite their own clips and edit the clip's label at any time, which is a technique that has been shown to reduce anxiety in language tutors in previous work [64].

Pilot Study. To understand the effects of recording time-restricted LbT audio segments to encourage micro learning, we conducted a within-subject pilot study conditioned on the segment length. One experimental condition enabled the students to create thirty-second LbT segments, while the other condition allowed the students to create one-minute LbT segments. We were interested in evaluating whether participants will feel a reduction of nervousness around teaching material incorrectly when the segments limit the length of time for which a student could potentially be incorrect, compared to the condition where they must record longer segments and could potentially be incorrect for longer lengths of time. Participants confidence levels were recorded in the platform after each recording as well as in a post-pilot-study survey.

The preliminary results suggested that deconstructing a topic into smaller subtopics could increase confidence in students and that interactions with content from group members could have positive impacts on confidence. Furthermore, it was also observed that given a fixed duration to interact with the system, shorter time limits free participants to explore peers' responses on the platform more. Future directions of this pilot study could focus on improving the prototype interface to enable the grouping of shorter audio segments into larger units, supporting the learning of various domains, and executing a more thorough experimental study to get enriched and reliable results. From the pilot study results, this platform shows promise for facilitating online collaborative LbT beginning

with incorporating micro learning methods.

Chapter 7

Future Work & Conclusion

7.1 Future Work & Going Beyond Our Limitations

A limitation is the extent to which people are comfortable with the idea of teaching something they don't know. For example, P11 said they would have preferred if the investigators presented them with new content to learn to compare "teaching styles" and "have the same sort of baseline." However, P11 said, "then I thought probably not because then I would have had to learn something for the study and at least now I could just choose things I'm already familiar with, ... I'm comfortable talking about, and would care to talk about." Even though participants knew the intent of the study and met the criteria of teaching an assignment they did not receive full marks on, many are unfamiliar with the idea of teaching to learn, so they may have come into the study with the mindset that they were tutoring, focusing less on how the teaching process makes them learn. Another limitation included self-reported time estimates on how long preparation took, this could have helped us understand how much knowledge was acquired after having completed the assignment to assess participants' expertise level in the topic and understand how much preparation is really required to use this pedagogical technique. Additionally, this information could point towards which domains, if any, may require different amounts of effort in terms of time preparation for LbT which helps determine the best use cases for this method. Future work could explore LbT in a controlled scenario where participants are given unfamiliar material, have the required background to learn it, and can interact with a peer who shares this prerequisite knowledge. This would create an environment where peers are learning by teaching to each other, and each stage of the LbT method could be observed. Furthermore, implementations of the design suggestions to promote and set expectations around failing

and learning from their mistakes as well as supporting university level peer collaboration can be investigated. Integration of generalized design principles for PF and micro learning should be carefully considered since they have been studied under specific conditions and settings respective to their study (e.g., content domain, communication modality, age group, sociocultural factors, etc).

This thesis presents findings for understanding university students' unguided process and approach to teaching unfamiliar material, the students' individual differences to their approach, their struggles, and provides an outline of design suggestions and implications for web-based tools supporting this pedagogical method. These insights can help inform future virtual LbT platform designs to best support students in a peer-to-peer context. Our results highlight three key challenges university level students face, including psychological barriers relating to self, psychological barriers relating to others, and lack of know-how. We also provide design solutions to overcome these challenges, including "crash and learn" and online peer collaboration support for LbT. In addition to this, we outlined student's perceptions on possible tools that could be implemented in a LbT platform, the various ways it could be configured, and their advantages and disadvantages.

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APPENDICES

Appendix A

Participant Recruitment Information

Study Information

Study Name	(Online) Exploratory Study for a Learning By Teaching Platform
Study Type	**Standard (lab) study** This is a standard lab study. To participate, sign up, and go to the specified location at the chosen time.
Study Status	**Not visible to participants :** Not Approved Send Request **Inactive study :** Does not appear on list of available studies
Duration	90 minutes
Pay	25 CAD
Description	The objective of this study is to understand how to design a web-based platform that facilitates the learning by teaching process of college students. The study is part of an ongoing research project, led by Dr. Edith Law, at the University of Waterloo. If you decide to participate, please bring two homework/quiz/exam questions from TWO of your courses, that you got wrong or want to have a better understanding, and teach it to us. The only requirement is the two questions should NOT come from the same course. You can teach in whatever way you want and use whatever tools you want (e.g., whiteboard, Miro, paper and pencil, images, diagrams, and extra devices or webcams are allowed in the video call), the use of tools is not required and are optional. Your teaching does not need to be perfect, we are only interested in what you naturally do. Before teaching, there will be a pre-study survey asking you for your demographic information (e.g., age, gender, major, etc.) as well as prior experience with teaching. Teaching each question should take about five minutes. After that, you will fill in a survey and the researchers will ask you a few follow-up questions. The whole study takes about 1 hour - 1 hour and 30 min. Remuneration: You will be paid 25 dollars (in Amazon.ca gift card) for participating in the whole study. If you decide to drop out before finishing the study, you will be paid prorated depending on the time you spend. Requirement: We would like to video record your teaching and interview session for accurate transcription. Your consent to being video recorded is required to participate in this study. Note: Please note that a study sign-up is a firm commitment to the researcher running the study so select time slots carefully and if you cannot attend the lab study session at the specified time [do the online survey before the specified deadline], please cancel the Sign-Up or contact the researcher in advance. Failure to appear for too many studies without providing adequate prior notice to the researcher may result in denial of access to further studies. Details are provided on the frequently asked questions (FAQs) page on your SONA account. Confidentiality: When information is transmitted over the internet privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies, hackers). University of Waterloo researchers will not collect or use internet protocol (IP) addresses or other information which could link your participation to your computer or electronic device without first informing you. Ethics Information This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. To sign up for the study, or if you have any questions about the study, please contact Dr. Edith Law at edith.law@uwaterloo.ca. To sign up, please contact [agdebban@uwaterloo.ca].

Figure A.1: The Study Information was published on the University of Waterloo's SONA system for Human-Computer Interaction

Appendix B

Thematic Codes & Descriptions

B.1 Codes for LbT Session Analysis

	Primary Code	Secondary Code	Tertiary Codes (Additional Descriptors)	Description
1	Participant			Characteristics of the participant
1.1		language fluency	fluent, mostly fluent, lacks fluency	describes the verbal language fluency in english
1.2		humour		participant uses humour during teaching sessions (e.g. makes a joke)
1.3		nervousness		participant sounds nervous when speaking (e.g. nervous giggling)
1.4		hesitation (during teaching)	moves on, corrects, checks notes	participant is hesitant about the validity of a piece of what they are teaching, they either move on, try to correct it, or verify their notes
2	Task			Properties of the learning-by-teaching task
2.1		domain	math, accounting, computer science, digital arts, psychology, biology, etc	the domain of the teaching material
2.2		length	within range, below range, above range	length of explanation was within the instructed range, below the range, above the range
2.3		type	multiple choice, short answer, long answer, project, paper	the type of question the student selected to teach
3	Method			Properties of the learning-by-teaching method
3.1		introduction	reads question, mentions course, includes purpose	participant includes an introduction to the explanation
3.2		conclusion	reiterated question, purpose, summary of answer	participant includes a conclusion to the explanation
3.3		error		participant explains why they got the question wrong or where they went wrong prior to the teaching explanation
3.4		tip	problem solving, memorization	participant shares tips to help with problem solving or memorization
3.5		key point		participant states or highlights (verbally or visually) key points
3.6		reiteration		participant reiterates a portion of the teaching explanation
3.7		definition		participant tells a definition
3.8		importance		participant shares the relevance or importance of learning a piece of the material
3.9		example	commonly known, not commonly known	participant shares an example (it could be commonly known or not)
3.a		comparison	similes, metaphors, analogies	participant shares a simile, analogy or metaphor
4	Tools			Tools used to aid the learning-by-teaching
4.1		screen share		participant screenshares
4.2		notes	handwritten, digital, pre-made, made live	participant shares their text notes to the learner either by trying to show it to the camera or screen sharing (this does not include notes they are referencing but not sharing to the learner note: that would be under references)
4.3		visuals	handwritten, digital, pre-made, made live	participant shares their visuals or graphics to the learner either by trying to show it to the camera or screen sharing (this does not include notes they are referencing but not sharing to the learner note: that would be under references)
4.4		references		participant references their sources (e.g. prof notes, lecture, textbook question)
5	Interaction			Interaction between the participant and investigator or imaginary learner
5.1		check-in		the participant checks-in with the investigator this could be like asking if the investigator understood or a question about how their teaching process is for example
5.2		validation		the investigator validates the participant either by nodding, agreeing verbally (e.g." mhm", "makes sense", "ok"), showing interest (e.g. "cool", "that's an interesting question"), or asking a question to the participant
5.3		assumption	teaches prerequisite, skips prerequisite, recalls prerequisite	participant mentions assumptions about the learner (either the investigator or imaginary/themselves)

Figure B.1: The codes above were used to analyse the participants' LbT sessions. If data from certain codes did not provide enough information to answer our research questions or were not relevant they were omitted from the analysis.

B.2 Codes for Semi-Structured Interview Analysis

ID	Primary Code	Secondary Code	Tertiary Codes	Description
1	Current			Understanding of current methods of learning by teaching
1.1		presumption		presumptions and experiences participants had about learning by teaching
1.2		selection		why participants chose each piece of material
1.3		preparation		preparations participants did to teach and how long they spent
1.4		reflection		participant reflections on learning-by-teaching sessions
1.4.1			explanation	what participants think makes a good explanation
1.4.2			self-assessment	how satisfied were participants with each material and how difficult did they found the teaching task
1.4.3			improvement	what would participants do if they were to improve and repeat their learning-by-teaching sessions
2	Features			Features, scaffolding, or system support for learning by teaching
2.1		preparation		would participants feel comfortable with using and would they use tooling for teaching preparation (e.g., lesson plans, templates)
2.2		matching		support for peer matching
2.2.1			someone, alone	comparing experience with teaching someone vs alone
2.2.1.1			motivation, purpose	how teaching someone or teaching alone impacts participant motivation or purpose
2.2.1.2			comfort	how can it impact participant comfort level
2.2.1.3			learning	how can it impact the amount participants learn as the teacher
2.2.2			matching	participants' partner preferences
2.2.3			other	participant preferences for teaching to a group, with a group, or to an individual
2.2.3.1			synchronous, asynchronous	participants' preferences for synchronous or asynchronous setup
2.2.4			individual	participants' preferences for teaching alone vs with an agent
2.3		teaching		support for teaching
2.3.1			screen share	are participants comfortable with and would they use this tool
2.3.2			drawing	are participants comfortable with and would they use this tool
2.3.3			pointers	are participants comfortable with and would they use this tool
2.4		feedback		support for receiving and giving feedback
2.4.1			annotation	are participants comfortable with and would they use this tool
2.4.2			ranking, rating	are participants comfortable with and would they use this tool
2.4.3			feedback form	are participants comfortable with and would they use this tool
2.4.4			history Tool	are participants comfortable with and would they use this tool
2.5		adoption		participant platform adoption and other features they would want before adopting a learning-by-teaching platform
3	Community			Understanding the implications of learning by teaching in an online learning community
3.1		advantages		advantages participants believe they could have from learning by teaching in an online community
3.1.1			exposure	exposure to different approaches
3.1.2			familiarity	familiarity with the learners
3.1.3			contribution	opportunities to contribute to others
3.1.4			pace	learning at your own pace and at your own time
3.2		disadvantages		disadvantages participants believe they could have from learning by teaching in an online community
3.2.1			judgment	scrutiny and fear of judgment
3.2.2			time	time constraints and spent using this method
3.2.3			inequality	bad intentions and unequal contributions
3.2.4			privacy	online data privacy concerns
3.2.5			overload	information overload
3.2.6			incorrect	incorrect content being shared to peers
3.3		recommendations		participant recommendations on building an online learning-by-teaching community
3.3.1			rating	rating system
3.3.2			size	mitigating insecurity by keeping groups small
3.3.3			access	managing user access
3.3.4			manage	managing information overload

Figure B.2: The codes above were used to analyse the participants' semi-structured interviews. If data from certain codes did not provide enough information to answer our research questions or were not relevant they were omitted from the analysis.