Designing Tangible Tools to Engage Silent Students in Group Discussion

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***Abstract*—Students being silent during group work is a typical issue. Tangible user interfaces can bring learners together and orchestrate an active environment. Thus, they can mediate discussing conflicts among group members and facilitate as an equalizer allowing everyone to join the conversation. In this work, we used an iterative design approach to develop *TalkinGlass*, a tangible user interface, to help silent learners better engage in group work. In total, 28 university students took part in designing and evaluating *TalkinGlass*. The results show that when using *TalkinGlass*, silent students had a higher general and behavioral engagement than general students. In detail, we highlight three key findings: (1) The design mapping between engagement and tangible interaction could help us design a better interface for learning; (2) Increasing silent students' cognitive engagement was critical; and (3) *TalkinGlass* was suitable to orchestrate the group discussion when having clear activity scripts. From the human-computer interaction perspective, we provide a practical and feasible solution to help silent students in collaborative group work.**

***Index Terms*—tangible learning; collaborative learning; group discussion; human-computer interaction**

I. Introduction

In the classroom, silent students tend to be identified as low achieving students. However, this is a misconception and prejudice. It is vital to consider low-participant silent students [1], [2], even when their utterances are not intentional. Previous studies have explored personal factors for students keeping silent, e.g., shyness [3], gender [4], and culture [5]. Most solutions were focused on changing teachers' behavior, e.g., attention [6] and awareness [7], to give silent students more opportunities to talk in class. An active environment or context supported with technology might be more helpful [8], where it is easier to implement active learning strategies. Tangible user interface (TUI) is such an innovative technology. It communicates by interacting with physical manipulatives and embodied metaphors [9]. TUI has broadly been used for collaborative learning [9]. However, as far as we know, there was no study explicitly aimed to help silent students in collaborative group work.

We conjecture TUI can help silent students increase their participation and engagement. Because TUI has three advantages for silent students in collaborative work. First, it is a calm technology that makes the face to face (F2F) discussion embodied, personalized, and non-aggressive. As we know, F2F discussion is more dominated by speaking (i.e., oral communication). This situation puts silent students naturally in an isolated situation because they do not like or are not good at talking. TUI gives them an embodied means to either show their thoughts or arouse attention. Second, TUI brings an *individual-with-context* perspective [6] to help students immerse themselves in the group discussion context. This is particularly beneficial for silent students, reducing their pressure from an inactive talking atmosphere. Finally, it reduces interference from non-related internet information, such as social media and news. When all the participants are present and engaged in the activity, it will help silent students share their ideas or opinions.

Therefore, our research question is *How can TUIs make silent students emotional, behavioral, and cognitive more engaged in collaborative group work?* In this study, we developed a TUI named *TalkinGlass* to scaffold collaborative learning activities. *TalkinGlass* facilitates students' learning and communication but allows them to develop naturally. In other words, we designed TUI as an orchestrating tool, task-independent, allowing it to adapt to various contexts. In total, 28 university students took part in designing and evaluating *TalkinGlass*. The results showed that when using *TalkinGlass*, silent students had a higher general and behavioral engagement. We highlight three key findings: (1) Increasing silent students' cognitive engagement was critical for excellent group work; (2) The design mapping between engagement and tangible interaction is essential for designing functions of group orchestration tools; and (3) *TalkinGlass* was suitable to orchestrate group discussions but need a clear activity design.

Our study took an individual-with-context perspective [6] rather than individual student characteristics. We were interested in the interplay between the silent student and their peers,

all situated within the collaborative learning context. Our main contributions are to (1) provide a practical and feasible solution from the human-computer interaction (HCI) perspective to help silent students participate in collaborative group work; (2) explore the benefits of tangibles for collaborative learning; (3) discuss the tangible interaction design for learning engagement. Our findings can help find an effective solution to improve the silent student engagements in group discussion.

II. Related Work

In the following, we will review tangibles for collaborative learning and how tangibles can foster learning engagement.

A. Tangible Collaborative Learning

Collaborative learning is an educational approach to teaching and learning with students working together to solve a problem or complete a task. It has social, psychological, academic, and assessment benefits [10]. However, keeping quiet or silent is an issue for group work because we lose their voices. Practical group work requires contribution and engagement from all the group members. However, many factors, e.g., student personality, discussing atmosphere, and group organization [11], could influence collaborative learning. Technology-enhanced learning tools allow for the adoption of active, student-driven pedagogy, which could create a significantly enhanced environment in which to learn. TUI is an excellent technology-enhanced learning tool. Previous studies have used TUIs for concept exploration, problem-solving, and skill development in collaborative activities [9]. TUI can build a collaborative interactive space for communication, and it is suitable to increase interaction equity in groups.

More specifically, TUI has three advantages for silent students in collaborative work. First, it is a calm technology that makes the F2F discussion embodied, personalized, and non-aggressive. As we know, F2F discussion is more dominated by speaking (i.e., oral communication). This situation puts silent students naturally in an isolated situation because they do not like or are not good at talking. TUI gives them an embodied means to either show their thoughts or arouse attention. Second, TUI brings an *individual-with-context* perspective [6], [12] to help students immerse themselves in the group discussion context. This is particularly beneficial for silent students, reducing their pressure from an inactive talking atmosphere. Finally, it reduces interference from non-related internet information, such as social media and news. When all the participants are present and engaged in the activity, it will help silent students share their ideas or opinions.

B. Engagement for Tangible Learning

Engagement refers to students interact with the learning material and its context. It is an inherent aspect of the learning process [13]. Understanding students' motivational, emotional, and cognitive engagement was one of the most crucial goals of educational psychology [13] because it is associated with positive academic outcomes [14]. Engagement has three interrelated dimensions [15]: (1) *Behavioral engagement* defines in terms of participation, effort, attention, persistence, positive conduct, and absence of disruptive conduct; (2) *Emotional engagement* refers to the extent of positive and negative reactions to teacher and classmates, academics, and school, but also to a sense of belonging and identification with school and subject domains; (3) *Cognitive engagement* denotes a level of investment in learning, being thoughtful, strategic and willing to exert effort for understanding complex ideas and mastering challenging tasks.

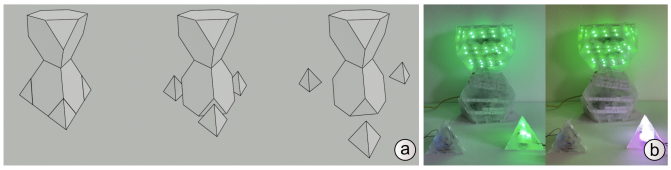

Figure 1: *TalkinGlass* diagram (a. Remove Tokens from the Hourglass; b. Light on to indicate exercise and timer).

Learning with TUI has shown many advantages, especially for collaborative learning [9]. [16] investigated the extent to which a tangible tabletop interface can enhance student engagement in a serious mathematics game compared to regular classroom interaction. However, it is still unclear how to design tangible interaction to improve students' behavioral, emotional, and cognitive engagement. In order to have an effective TUI, it is crucial to understand the design rationale to improve learning. This study designed and evaluated the effects of tangible collaborative learning on students' behavioral, emotional, and cognitive engagement. Moreover, we proposed some design principles from our practice to explain why and how to design tangibles to engage students' learning.

III. Tangible Tool: *TalkinGlass*

A. Design Challenge

Silence is a complex issue [17] because students may have diverse reasons for not speaking in the discussion. For instance, they are shy and do not have prior knowledge of the talking topic; Someone dominates the discussion and does not find an opportunity to talk; They do not like the talking atmosphere and have no motivation to speak. Therefore, it is essential to know: (1) one solution could not solve all the problems, (2) we need to focus on a specific issue. In order to find this specific issue, we did interviews with ten university students. Together with related work, we decided to design a TUI to help silent students who were shy or had no opportunity to talk. Furthermore, we came up with three concept ideas. The first idea was to improve their engagements, more specifically, emotional, behavioral, and cognitive engagement from the learning perspective. The second idea was to think about how to encourage silent students to join the discussion by themselves. Because only when interactive motivation and desire come from silent students themselves, it will help to improve their engagements, especially emotional engagement. The final idea was that silent learners should have their interactive device because it prevented them from feeling

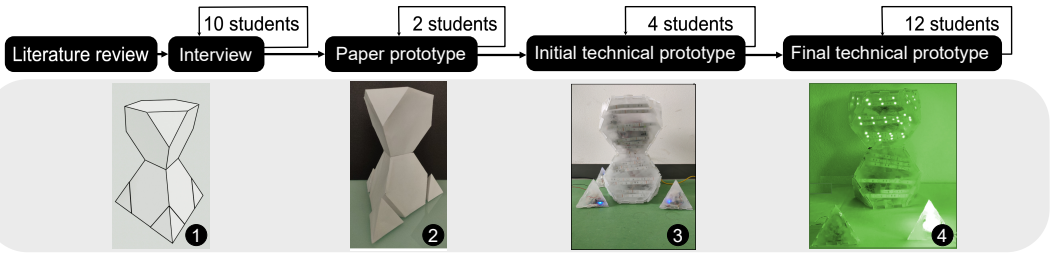

Figure 2: The iterative designs of *TalkinGlass*.

pressure or being noticed not to talk by others. The purpose of TUI was to create an environment, where the silent students in the group could feel comfortable. They could interact with the TUI and think about solving the problem. The most important thing is that they want to join the discussion.

B. Concept Idea

To develop *TalkinGlass*, we used an iterative design approach. As shown in Figure 2, we used 5 phases and 28 participants to design and evaluate our prototype. In each phase, we refined the concept idea from user feedback. In the end, we did the formal user study with 12 university students and discussed the results.

The process to concrete a concept idea has three steps: First, we conducted a literature review and found dominant and quiet participants were an issue for collaboration, for example, tutorial, which was very common in the university. Second, we conducted interviews with ten university students about their previous experience in group work during university tutorials. Problems they mentioned were: time management, an uncomfortable atmosphere (especially when group members were not familiar), or engaged group members (talk litter or not at all). Functionalities they wished for were: (1) moderation to give an equal chance to everyone in the group to participate; (2) An indication to show someone's speaking time was over, which avoided incredibly dominant people. When asked about the environment they preferred, they thought TUI was better than graphical user interface (GUI) because they were more fun and less risk of distraction. Finally, we found two previous studies that we could work on further: *Lantern* [18] and *TurnTalk* [19]. *Lantern* was an ambient lamp to display tutorial exercises with different colors. *TurnTalk* was a TUI to teach turn-taking norms, which had a visualized device and mobile application to check group conversation. Built on them, our concept idea was to have an object for the group and several individual devices for group members. The general functionalities were to: (1) record exercise and talking time, (2) make an individual device randomly light up to show the turn to moderate or talk, (3) script and orchestrate tutorial processes.

C. Prototype Development

After settling down the concept idea, we built a paper prototype and asked two participants for their opinions. It showed that they could understand the interaction and purpose. In addition, they gave us some suggestions, e.g., enable the *Hourglass* (i.e., group device) to guide us through the exercises itself, make the time frame longer for each exercise, and orchestrate activity with an "ice breaker" at the beginning and feedback in the end. We implemented these two functionalities to improve behavioral, emotional, and cognitive engagement. For behavioral engagement, students should first remove the tokens from the hourglass to start with the group work (as seen in Figure 1). They also can interact with the token to join the sequence for talking. Then, to switch between different exercises, they need to rotate the *Hourglass* to start the timer. Fe made the group device behave like an hourglass with digital sand running through it for emotional engagement. The same was for individual devices (*Tokens*). After an exercise, the *Hourglass* starts to blink. For cognitive engagement, we had a moderator and randomly talking order function.

D. Pilot Study

We conducted a pilot study with four participants (2 females, 2 males, ages 21-25) for about 30 minutes. First, we gave them a short task to simulate the group work with *TalkinGlass*. Then, we did a survey with System Usability Scale (SUS) [20] and questionnaires about the interactive experience. Finally, we conducted a group interview. For SUS, we got an evaluation of 88.75, which was very good. Regarding their interactive experience, we asked about the user experience on Hourglass and Tokens separately. It showed that both devices had an excellent interactive experience. We asked them about the suggestions to improve *TalkinGlass* for the actual tutorial in the interview. Their feedback was to: (1) add audio to give an extra hint (except for the fading light) for the next person to talk; (2) Extend it to include more people for group work. We adopted the first suggestion and made the second one for future work. We can redesign the shape quickly to have more group members.

IV. User Study

A. Participants and Context

Twelve university students (7 females, 5 males), 21 or 22 years old, participated in the user study. Three students worked on three mathematical problems together for around 30 minutes during the study. We arranged a silent student in each study group for our study purpose, which we got from convenient sampling. The second and third authors recruited

them because they attended the same tutorial lectures and found they tended to be intrinsically silent learners. Therefore, there were four quiet students and eight other students. We conducted the studies in a large meeting room. In order to improve student engagement, as shown in Table I, we designed a mapping (i.e., correspondence) between behavioral, emotional, and cognitive engagement and tangible interaction.

B. Learning Activity Design

During the group work, the participants were supposed to work together on three mathematical exercises with the help of the *TalkinGlass*. There was an introduction round with a starting question to break the ice in the beginning. During this time, the *Tokens* light up one after the other to allow everyone to talk equally. Afterward, the three exercise rounds started. They were given three mathematical tasks with increasing difficulty. To guide through solving a task, the group chose one moderator for each round who then started the discussion mode. During the discussion mode, everyone could join in by pressing a button and was again given enough time to talk without being interrupted. Meanwhile, the *Hourglass* displays how much time was left for the current exercise and starts to blink when the time is up. After they finished the exercises, there was a feedback round where everyone could give each other feedback about their participation.

C. Data Resource

After the exercise, we did a survey (around 10 minutes) and an interview (7 questions, around 30 minutes which we audio recorded). The engagement survey [21] contained ten 5-point Likert items (*1 = strongly disagree*, *5 = strongly agree*), with one item for general engagement, three for behavioral, emotional, and cognitive engagement, respectively. In addition, we collected the worksheet they worked on during the study and evaluated their performances. Finally, the system recorded the talking time tracked with *Token*. Overall, as shown in Table II, engagement was evaluated from system data, performance in exercise, engagement survey, and after study interview.

D. Findings

We analyzed the participants exercises. In addition, we calculated their talking time, which is recorded by the system. The data showed that four quiet students and the other eight students had a similar performance, 59.5 and 59.8, respectively. However, the quiet students talked less than others, 40.4%, and 59.6%. In the survey, we asked all the participants to rate their engagements. As shown in Figure 3, quiet students had a higher general and behavioral engagement but lowered emotional engagement than other students. For cognitive engagement, both were similar, which was around 3.20.

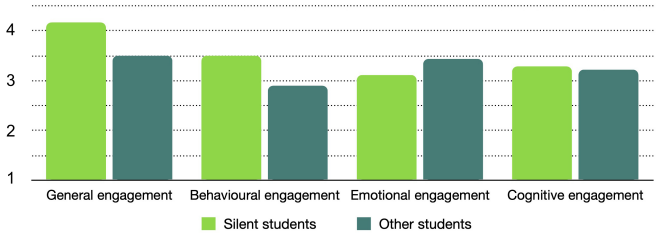

Figure 3: Engagement of silent and other students.

As shown in Table III, we transcribed all the interviews and coded them into four themes: general engagement, behavioral engagement, emotional engagement, and cognitive engagement. For general engagement, quiet students had a higher engagement and balanced collaboration with *TalkinGlass* than quiet students but still felt less comfortable asking for help and participating. In addition, quiet students expressed higher emotional engagement but less behavioral and cognitive engagement with *TalkinGlass* than other students.

V. Discussion

A. Designing Tangible Interaction for Engagement

TUI for silent students is a good research topic for tangible learning. The main contribution of our study was to systematically explain the rationale and provide a practical solution to design tangible interactions for engagement. As we have known from the findings, silent students showed a higher general engagement than other students. To some extent, this supported our hypothesis that TUI had an advantage for silent students in the group. The other two interesting findings were: (1) Silent students have a higher behavioral engagement but a lower emotional engagement than other students. It is hard to make any concrete conclusion, but we speculate it might be because the interaction with *TalkinGlass* was practical but not fun for silent students. Emotional engagement is a complicated factor that affects learners' involvement with learning and their sustained effort. In this study, we have only measured students' positive emotions. However, negative emotions might significantly influence learning, which we should know and try

Engagement	Meaning	Tangible design
Behavioral	Participation, effort, attention, and persistence	Move, touch or rotate *Tokens* or *Hourglass*
Emotional	Interest, happiness, and other positive states	Digital sand animation in the *Tokens/Hourglass*
Cognitive	Invest in learning, being thoughtful, strategic and willing to exert effort	Moderate the exercise, choose a person to speak randomly

Table I: Mapping of engagement and tangible interaction.

Engagement	Data Resources
General	System data (participants' talking time), math exercise performance, questionnaire, and interview
Behavioral	System data (participants' talking time), questionnaire results, interviews, and observation
Emotional	Questionnaire and interview
Cognitive	Math exercise performance, questionnaire, and interview

Table II: Data resource of engagement.

Engagement	Themes	Quiets		Others
General	**Engagement of quiet students with *TalkinGlass***	83.3%	↑	66.7%
	- Feeling obligated to engage (moderator role, discussion mode)	33.3%		50.%
	- More engagement than without *TalkinGlass*	50.%		16.7%
	- Easier to participate (inhibition barrier smaller)	33.3%		33.3%
	- Nobody is passed over	33.3%		16.7%
	- Integrating (introduction round, moderator role)	16.7%		16.7%
	- Comfortable collaborative environment	33.3%		33.3%
	Help-seeking or participate	50.%	↓	83.3%
	Balanced collaboration	66.6%	↑	50.%
Behavioral	**More interaction with tools**	33.3%	↓	50.%
Emotional	**Likeness of *TalkinGlass***	100.%	↑	83.3%
	- Fun	16.7%		83.3%
	- Playful	16.7%		33.3%
	- Motivating	16.7%		16.7%
Cognitive	**Promoted cognitive engagement**	16.7%	↓	66.6%
	- Stayed more focused and thought of what to contribute	.		50.%
	- Liked everyone learned interaction together	.		16.7%
	Promoted time management and structuring exercises	33.3%	=	33.3%

Table III: Interview results of engagement.

to avoid; (2) Silent and other students had a similar cognitive engagement, which was a psychological investment students make towards learning. This finding was good evidence for effective collaborative work with *TalkinGlass*. The mapping between (behavioral, emotional, and cognitive) engagement and tangible interaction could help us make good tangible designs. However, two things need to be precise. First, we did not prove a direct or causal relationship between tangible interaction and engagement. As we explained in the design challenge section, we developed an orchestrating tool. The tool itself does not influence engagement. Its benefits show when used in the learning activity. However, the engagement framework is good guidance for us to think about the tangible interaction design. Second, we showed a specific mathematical tutorial design in this study, but it could be easy to apply to other areas. For example, we can also use *TalkinGlass* as an ambient clock in the classroom. Teachers can use *Token* to control *Hourglass*.

B. Increase Cognitive Engagement of Silent Students

The finding showed that quiet students had less talking time than others. However, it did not mean *TalkinGlass* was ineffective because the actual difference was not noticeable. In addition, it was more meaningful to discuss the reasons for it. We found that scaffolding might hinder a "natural" discussion during the interview. In this study, we designed a turn talking mechanism to create an equal chance for students to contribute to the discussion. It means if you want to talk, you can interact with your Token. Then you will be added to the waiting list. Some participants mentioned that it was frustrating to wait for a talk; if they only wanted to make a small comment, they would hesitate to join the waiting list. This situation is a dilemma because, for group discussion, it is impossible to have many people talking simultaneously. However, during a natural conversation with our friends, we do not feel uncomfortable even though we wait to talk. We are engaged in the conversation, where the discussion is talking and thinking (cognitive engagement). We lose the voices or contributions of quiet students in group work because they do not talk too often. However, the essential question is to improve their cognitive engagement. We can design a tool to force silent students to talk more. However, it will make them feel uncomfortable and reduce their emotional engagement. Therefore, we should know that cognitive engagement aims to help silent students engage in groups.

C. TalkinGlass for Orchestrating Group Discussion

It is critical to make tangible prototypes simple, easy, and flexible for use in the classroom. Each class or tutorial has fixed times and students with different personalities. Therefore, designing a "powerful" device with many technologies, e.g., camera, app, and speaker, is not wise. Such design contributes to research but will encounter an enormous difficulty to use it in an actual classroom. Therefore, for *TalkinGlass*, we avoided designing unnecessary functions and simplified them with actual requirements. *TalkinGlass* needs to have a context (i.e., script) to show the effects as an orchestration tool. In the study, we designed an activity with a warm-up, exercise, and feedback parts for silent students to naturally communicate with others. *TalkinGlass* played a role in communicating within a context where silent students feel equal with other students. The results showed that students desired to solve the exercises and stayed more focused with *TalkinGlass*, which is good evidence of the effectiveness of our design.

VI. Limitations and Future Work

When reflecting on the study design, tangible prototype development, and user study, we realize this study has three limitations: First, it has few tangible technological contributions. Our study aimed not to have an innovation or improvement of tangible technology. Instead, we aim to develop an orchestration tool. Second, we did not study in an actual learning environment, e.g., a classroom. We might consider more factors when using them in class. For example, how to make it more flexible for different collaborative learning scenarios. Finally, silence is a complex issue. In this study, we only targeted silent students who were shy or had no opportunity to talk in group work. Inspired by this study, we found two valuable future directions: (1) Design tangible interaction to improve silent students' cognitive engagement: The purpose of *TalkinGlass* should not be a tool for facilitating talking but for helping students engage cognitively. [22] found cognitive engagement had a significantly positive effect on students' behavioral engagement, and both predicted an excellent

learning performance. This study designed two mechanisms to improve students' cognitive engagement: moderate the exercise and choose a random speaking person. We did not focus on tangible interaction designs because the *TalkinGlass* we developed was for orchestrating activity. However, this can be an important future work; (2) Design a graphic user interface to show their behaviors in the group work captured by *TalkinGlass*, to have a self-reflective dashboard to understand and change their group behavior. For example, if we gradually improve participation in group work, we will positively feel and self-regulate our future behavior.

VII. Conclusion

Silent or non-engaged students are not advantageous for group work. TUI is an useful and innovative tool to engage silent students for group work. It brings the individuals into the context and orchestrates an active environment. Our study used an iterative design approach to develop a TUI named *TalkinGlass* to help silent students in group work. For using it in an actual class, we designed principle functions to make it simple, easy, and flexible. Twelve university students attended our study experiment. The results showed that when using the *TalkinGlass*, silent students had a higher general and behavioral engagement than general students. The three key findings are: First, the theoretical mapping between (behavioral, emotional, and cognitive) engagement and tangible interaction could make the tangible design targeted and effective. In other words, researchers should understand the interactive rationale to increase learning experience. Second, it is critical to increase the silent students' cognitive engagement. Silence is a complex problem. We can design a device to force silent students to talk more often, which increases their behavioral engagements. However, this might not be an appropriate solution because it decreases their emotional engagements, and also ignores their cognitive engagements. Finally, *TalkinGlass* was suitable to orchestrate the group discussion, but acquires a clear activity design. TUI has an visible and actual effect only when we use it in a scenario as an orchestration tool.

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