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Master's Thesis
Academic Year 2017

Meta Pot: Changing Group Work Behaviour through Visualization of Mental Effort

Keio University Graduate School of Media Design

Daisuke Yukita

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
MASTER of Media Design

Daisuke Yukita

Thesis Committee:

Professor Keiko Okawa	(Supervisor)
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Abstract of Master's Thesis of Academic Year 2017

Meta Pot: Changing Group Work Behaviour through Visualization of Mental Effort

Category: Design

Summary

With the growing trend of Active Learning, and with "Collaborating" and "Communicating" listed as two of the key elements of 21st century skills, group work is becoming increasingly common among education of all ages. Although prior studies show that group intelligence and team work quality positively correlates with equal conversational turn taking, we have witnessed many cases where one or few students dominate the discussion in classroom setting group work. This paper presents Meta Pot, a plant-like device that collects group work participants' physiological responses, and visualizes their mental effort in real time through the movement and color change of artificial leaves. By placing the Meta Pots within group work, this research proposes a novel method to change group work behaviour and to encourage more equal engagement through the monitoring of one self's and group members' mental activities. The results of the user studies show that Meta Pots created significant behaviour change in group work participants both quantitatively and qualitatively, mainly motivating those who were talking more than others to offer team members the chance to speak, while motivating those who were talking less speak out and engage more in the discussion.

Keywords:

Group Work, Collaboration, Visualization, Education, Learning Analytics, Heart Rate

Keio University Graduate School of Media Design

Daisuke Yukita

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Chapter 1
Introduction

1.1 Background

As the world becomes ever more global and connected, collaboration with others are becoming a necessity everywhere. When people work together, it is possible to accomplish things that they never would have dreamed of alone, and come up with innovative ideas that they otherwise never would have thought of. Even as one looks into any story, there is always teamwork in play when saving the world; Frodo would never have been able to destroy the ring without the fellowship in *Lord of the Rings*, Harry would never have been able to defeat Voldemort without the help of his friends in *Harry Potter* and Monkey D. Luffy would never have been able to (although he still has not) become pirate king without the gang of Straw Hat Pirates in *One Piece*. When it comes to humans, however, working in teams become something very complicated. Diverse elements, including age, experience, emotions and politics withhold teamwork from functioning properly. What I am about to propose in this thesis is just the first step towards creating an ideal world where anyone can give every last bit of what they have to give through collaboration and do awesome things that the world has yet to see.

1.2 Group Work in Classrooms

Group work has become an indispensable working style, not only in business but also in education. The importance of learning with others started to become noticed in the 90's, when Vygotsky's theory of Zone of Proximal Development [59] became reacknowledged, creating the shift from Piaget's individual constructivism to social constructivism. At the time, Lave and Wenger [27] proposed their concept on community of practice, which refers to the group of people who share a common goal or passion and learn how to do it better through regular interactions, stating that learning happens through interacting with communities. Recenlty it is seen even more frequently in classrooms due to the global movement in education to adopt Active Learning, the processes where students engage in activities other than passively listening, such as discussion or problem solving. In addition, “ Collaboration ” and “ Communication ” are now listed as two of key elements of 21st Century Skills [56], making group work an ideal style of learning in modern education. Through facilitating creative workshops to students of all ages in Japan, however, we have also come to notice the various problems that lie in current group work style education. Firstly, we have witnessed how conversation share and overall engagement in group work can be unequally distributed, especially for those who are less experienced in group work, despite the fact that prior researches show group work functions best when all members are contributing. This is an issue that we also came across through the pre-study in this research, and is what this project will be mainly tackling. Secondly, it has become apparent how difficult it is for teachers to take care of each group in a classroom due to the number of groups against the single teacher. In other words, although group work is being adopted in many schools, the students' processes in group work remain a black box for teachers. Thirdly, because how we evaluate group work is still an often debated issue, many group work style lessons are difficult to analyze and its assessment measures are left ambiguous. As a result, teachers are struggling to evaluate the effectiveness of their group work usage, and students are left with no choice but to learn only through experience.

1.3 Proposal

In order to propose a solution for such situation, this paper presents Meta Pot, a plant-like device that visualizes group work participants' mental efforts in real time through movements and color change of leaves (Figure1.3.1). By placing the Meta Pot within group work, this research looks at how monitoring of oneself's and group members's mental activities changes group work behaviour and conversation share, ultimately leading to the improvement of overall group work quality. In a user study of 20 students in classroom setting where participants were asked to conduct problem solving through group discussion, Meta Pot created significant behaviour change in group work , mainly motivating those who were talking more to ask opinions of others, while motivating those who were talking less to try harder to engage in the discussion. The Meta Pots also functioned as an avatar of their mental efforts, becoming a platform where everyone can be equally open. The main contributions of this work can be summarized as follows.

- Novel and ambient way of promoting behaviour change in group work
- Providing a physical platform in group work where everyone can be equally open, enhancing socialization
- Potential post analysis of group work to examine what aspects of the group work stimulated participants

Figure 1.3.1: Meta Pot

1.4 Research Questions

The aim of this study is to to create change in group work behaviour, ultimately to improve its quality. For this we pose three research questions that we aim to answer through the research:

Research Question 1 Does visualization of team members' mental efforts make the participants talk more equally?

Research Question 2 Does visualization of team members's memtal efforts make participants to be more aware of oneself's and team members's thoughts? That is, will participants who talk relatively less than others be motivated to speak out what they have to say, and will students who talk relatively more than others realize that those who talk less have something to say and offer them a chance to speak out?

Research Question 3 By analyzing mental efforts of group work participants, can teachers or facilitators examine what stimulated students and use it to improve their instructional design?

1.5 Thesis Structure

This thesis is divided into 5 chapters. This chapter is an introduction to this project. Chapter 2 discusses related works, chapter 3 describes in depth about the design of Meta Pot, chapter 4 explains the proof of concept of the design and its results, and chapter 5 concludes with the findings, limitation and future work.

Chapter 2
Related Works

2.1 Group Work in Education

Many related researches collectively show that group work and its learning function best when all members are engaged and contributing. Woolley et al. [60] proposed that "collective intelligence" (CI), the general intelligence (often known as the g factor) factor as a group, does exist, and that it correlates with the equal distribution of conversational turn-taking, as well as the social sensitivity of group members and the proportion of female participants. It has become known that CI can predict the team's future performance [16], and that diversity in cognitive style and the team's ability to engage in tacit coordination is associated with CI [1]. In terms of learning quality, Cohen [9] explains that learning gains are also linked to group work participation, with low interaction leading to lower learning gains. According to Rogat et al. [40], socially shared regulation, the process that groups use to regulate group collaboration on a task as a pose to self regulation, functions well when each group member effectively regulates each other to sustain on-task behaviour. Vauras et al. [58] explains that such shared regulation can be enhanced with "openness" of oneself's and the team members' thoughts. Members in successful teams were more ready to "confess" their opinions. Barron [3] also states that, to be successful in group work, members must be "highly attuned to one another". Salomon [42] has stated that when some members in a group do not contribute as much as the others, it gives negative effects to the group dynamics, calling it the "Free Rider" effect.

2.2 Enhancing Group Work

The act of supporting group work to help them accomplish their goal is called "facilitation". Usually, facilitation is conducted by facilitators, who would be present throughout group work or workshops. Their role is enable groups to work more effectively from a neutral standpoint [44].

Recently there has been many attempts to support group work collaboration through technology. In an online game environment, Kelly et al. [25] explains that visualizing individual contribution can let users reflect on their performance and identify underperformers, but also reports that it was not able to provide information on peripheral contribution or the quality of work. In a virtual environment where group work is conducted through avatars, Ratan et al. [39] found that avatar design plays an important role in group collaboration, with avatars expressing individual identity leading to higher satisfaction in collaboration. With a more specific focus on brainstorming, Shi et al. [46] proposed IdeaWall, which displays images of keywords mentioned in group discussions as visual stimuli in real time. Research using interactive table-tops are also common. Martinez-Maldonado et al. [29] proposed MTClassroom, a multi-touch tabletop to analyze the strategies of student groups, and have also created a real time feedback system for teachers for them to provide feedback just at the right time [28]. Evans et al. [17] also proposed to identify touch patterns of students on an interactive tabletop to analyze the quality of collaboration. These systems, however, rely heavily on each custom hardware and are difficult to implement into other schools due to its cost.

In face to face environments, there are many research on "mirroring" displays that try to enhance group work through the visualization of specific elements in group work [21]. Commonly these displays visualize the speaking times of each participant. For example, Kim et al. [26] proposed Meeting Mediator, which visualizes data captured by Sociometric badges [32] on mobile phones in real time to promote group work behaviour, reporting that it was able to increase total speaking time and interaction between participants. Sturm et al. [52] projected participants' speaking times onto the table along with their eye gaze behaviour, explaining that visualization of speaking times affected over and under participators to become less extreme. DiMicco et al. [13] proposed *Second Messenger*, which visualied elements such as speaking time and conversational turn taking into standard data formats, enabling outside observers to make accurate reviews of the group. They also used their work to balance participation [14], where they found that it had a stronger effect for over participators to reduce their participation than for underparticipators to increase their participation. Bachour et al. [2] who proposed *Reflect*, also explain that they got similar results. Although the work introduced so far visualized participation with standard graph formats, Streng et al. [51] found that metaphorical visualizations were not only more popular but had stronger effect on participants. Tausch et al. have done several work on such metaphorical visualizations using the blossom of flowers and trees or the size of balloons as their motif, explaining that having the visualizations on the tables enhanced collaboration more than having them on the walls [54], and that visualizations presenting the group's state both in a cooperative and competitive way was more effective than presenting them in one of either way [55].

2.3 Measuring Participation and Mental Effort

How to measure group work participation and contriution is another often studied issue. Here we introduce studies from two approaches, one using traditional human assessment, and the other using digital methods.

Czekanski and Wolf [11] explain that, in addition to attendance and responce to faculty questions, rubrics describing performance expectations and rating scales are a common and useful method to measure participation. While rubrics provide a clear guideline for teachers on how to evaluate student participation, [15], it becomes difficult to use when the teacher must look over more than one group at once. An evaluation system called *Performance Assessment*, which became popular in the United States in the 1980s and 1990s, has also been gaining attention again [57]. The International Baccalaureate Diploma Program is one good example of that uses this type of evaluation. Performance assessment, however, requires the commitment of the entire school, and creating a school wide assessment rubric or benchmark requires much time. Another common method is self evaluation or peer review, but Ryan et al. [41] found that self evaluation marks were higher than faculty scores, while peer review marks were lower than faculty scores, and that students did not favour peer evaluation.

With the advance of sensing technology, many recent researches are also aiming to analyse learning from a more physiological approach with biosensors. Such researches are mainly categorized as Educational Data Mining (EDM) or Learning Analytics (LA), with EDM focusing more on automated discovery while LA focuses more on levaraging human judgement [47]. Pijeira-Daz [35] et al. explains how certain physiological coupling indices based on electrodermal activity can be used to predict collaborative learning features. Di Mitri et al. [12] explored how multimodal data such as heart rate, step count, weather condition and learning activity can be used to predict learning performance in self-regulated learning settings using machine learning. Chikersal et al. [8] found that collective intelligence was associated to synchrony in facial expressions, while synchrony in electrodermal activity was associated to group satisfaction.

Focusing more on mental effort, there are many research on the relation of physiological data and mental effort. To clarify, Kahneman explains that mental effort can be said to be a form of arousal, and that arousal is a dimension that can be measured [22]. According to Posner et al. [36]'s circumplex model of affect, basic emotions can be mapped along an axis of valence dimension and an axis of arousal dimension. Out of the various types of physiological data, heart rate has especially been focused on as an indication of such arousal and mental effort. Peterson et al. [34] explain that heart rate has shown to be an indicator of arousal. Heart rate can also be an indication of stress and emotion intensity, for arousal can be said to be short term stress [43]. Taelman et al.'s study [53] shows that heart rate increases significantly during a mental task compared to a relaxed state. Kahneman [24] stated that the increase of heart rate, pupil diameter and skin resistance correlates with task difficulty. As used in this study, pupil dilation is another often used physiological measurement of mental effort [33]. Based on such researches, Crosby and Ikehara [10] reported on the types of physiological data that are being used in classroom settings to measure mental activity, listing eye position, pupil size, skin conductivity, peripheral temperature and heart rate as effective measures. There are some work that has measured such physiological data not from students but from teachers, such as the work by Prieto et al. [38] where they used several eye tracking measures to observe the cognitive load of teachers during group work facilitation.

2.4 Ambient Displays

Heiner et al. [19] explains Ambient Displays as artifacts that are designed to work mainly in the "periphery of a user's awareness", drawing the user's attention "only when appropriate and desirable". In this sense, it can be said that the Meta Pot is an ambient display, designed to draw attention and cause behaviour change in the users when appropriate or needed. Snyder et al. [49] proposed Moodlight, an ambient lighting system that responds to the user's physiological response to enhance mindfulness. Jafarinaimi et al. [20] proposed Breakaway, a device placed on a desk that silently communicates how long the user has been sitting through its movement. Their research showed that such subtle interventions were enough to create behaviour change in the user's working style. Borner et al. [5] explains that although such ambient displays have been started to be used in learning contexts, much research simply supports awareness, and that more focus must be put into areas such as "persuasion, motivation, feedback, and behaviour change".

2.5 Plant Devices

Nieuwenhuis et al. [31] states that placing green plants in workspaces can not only make it more enjoyable but also more productive. Utilising such effect of plants, there are some studies that uses plants in human computer interaction. SEGA Toys released Pekoppa [45] in 2008, a plant shaped toy that moves according to the user ' s voice input, making the plant look like it is nodding to what the user has to say, providing relaxation to the users through the "entrainment" effect, the autonomic mechanism in our body that synchs with external rhythm or movement. Haller et al. [18] used this device to create a plant avatar that moves according to the user ' s posture, creating an ambient and less disruptive way to feedback correct sitting postures. Recently there are also some research that uses plants themselves as an interface. Poupyrev et al. [37] proposed *Botanicus Interacticus*, where they used plants as input devices to make interactions happen in living or working spaces. Steer et al. [50] builds on to this approach, focusing more on the affordances and properties that plants have as an interface. Their research showed that plants "triggered emotive connections, making interactions more enjoyable". Botros et al. [6] presented *Go and Grow*, a plant that gets watered proportionally to the user's healthy activities. Although their study is limited only to the user of live plants, their study showed that by using living visualizations it created emotional connections, sentiments and responsibility in the user.

Chapter 3
Design

3.1 Pre-study

In order to explore the problem space around current group work classes at school, and to examine what kinds of data in group work can be beneficial for teachers and students, a design research was conducted at a college in Japan as a pre-study. For this pre-study, a device called "Whitebox" [61] was used to collect several data during group work and to visualize it for the teacher and student to reference later.

3.1.1 Method

The pre-study was conducted through discreet data collection using Whitebox and thorough observation of each workshop. After all workshops were finished, an interview with students and teachers were also conducted separately.

3.1.2 Apparatus

The pre-study was conducted with 2 Whitebox devices. Whitebox is Microsoft's Kinect V2 sensors boxed inside an MDF white case and covered with artificial leaves to make it look like a table top plant, as shown in Figure3.1.1.

Using Kinect's mic arrays, Whitebox determines which direction the audio is coming from, thereby distinguishing who is currently speaking. The obtained audio is also processed to obtain the volume. Using Kinect's depth camera, Whitebox also obtains the body skeletons of the participants, allowing it to track their hand coordinates as well as their posture angles. These data were selected by referencing related work [7] [4]. Due to the way the current system is designed, Whitebox can only track the participants' data when they are sitting down and are not moving around nor switching positions. For this reason, audio recording

Figure 3.1.1: Whitebox

was also done with separate pin microphones attached to the students' clothing so that students can move around freely during the discussion. To examine the benefits of physiological data, one student was also asked to wear JINS MEME[1], a wearable eyewear device that tracks eye blinks using three-point electrooculography sensors. The setup of the pre-study is shown in Figure3.1.2. Each Whitebox was operated through Microsoft's Surface Pro 3. The collected data were analysed after each session and visualized into a one sheet inforgraphic poster per session.

3.1.3 Participants

The pre-study was conducted at Tokyo Metropolitan College of Industrial Technology, during a 4 day design thinking workshop. The sessions that took place per day were 3 hours long, and the participants were approximately 40 students, all 17 - 18 years old. All participants were fluent Japanese speakers, with little experience in group work and mostly no experience in design thinking. All participants were engineering students from the Electrical and Electronic Engineering department. Due to the lack of sensors, the Whitebox analysis was applied only to one group of 4 male students.

Figure 3.1.2: Pre-study Setup

3.1.4 Procedure

Each session began at 12:45, starting with a 10 - 15 minute ice break. The Whitebox sensors were activated after the ice break time ended and the students returned to their seats, and were stopped after the end of the workshop at 16:00 - 16:20. Every session was observed in detail, along with the data collection, analysis and visualization using Whitebox. The entire group work was also recorded, and when the group work is finished the audio data was converted into text using Google Cloud Speech API. Like all other speech-to-text services, the Google Cloud Speech API is not perfect. It skips significant parts of the conversation, and for those which it did catch, it does not convert all the words perfectly. The converted text does, however, provide a rough idea of how the discussion proceeded. One out of the 4 observed students was also asked to wear JINS MEME as shown in figure3.1.3, but due to the uncomfortableness that it caused to him, he was free to take it off anytime. After each session, the collected data were analysed and visualized in inforgraphic format so that the data can be interpreted intuitively, as shown in figure3.1.4. The 4 visualizations and speech-to-texts were later shown to both teachers and students separately, followed by an hour long discussion each on what those data meant to them. All 5 teachers who participated in the interview were those who facilitated the 4 day design thinking workshop, all teaching either electrical and electronic engineering or computer science, and all 4 students who participated in the interview were the members of the group which was recorded with Whitebox. For the interview with students, a questionnaire was also provided on a 5-likert scale, with questions intended to examine how the Whitebox visualizations will affect their future group work behaviour.

Figure 3.1.3: Student wearing JINS MEME

3.1.5 Results

The infographic visualizations of all 4 workshops are shown in figure3.1.4. On the left side is the conversation share in pie chart and bar graph format, and on the top right is the average volume of each students, both calculated from the recordings of the pin microphones. On the middle right is the average posture of each student throughout the entire session, and on the bottom right is the the

Figure 3.1.4: Visualizations of group work analysis

standard deviation of each students' hand positions, which were both calculated from the Kinect data. The JINS MEME results were shown separately through additional visualization that we provided for a more fine grained analysis of each session, as shown in figure3.1.5. Here the students' audio data, posture data and hand position data are plotted along the timeline of the workshop.

The feedback from the students and teachers after the 4 day workshops through the interviews and quesionnaires are summarized as follows.

Feedback From Teachers

- The visualizations can be used to intuitively assess who showed leadership in the group work
- Teachers are mainly interested in knowing what stimulated and engaged the students, as well as what made them bored
- By using physiological responses such as pupil dilation, they can see which

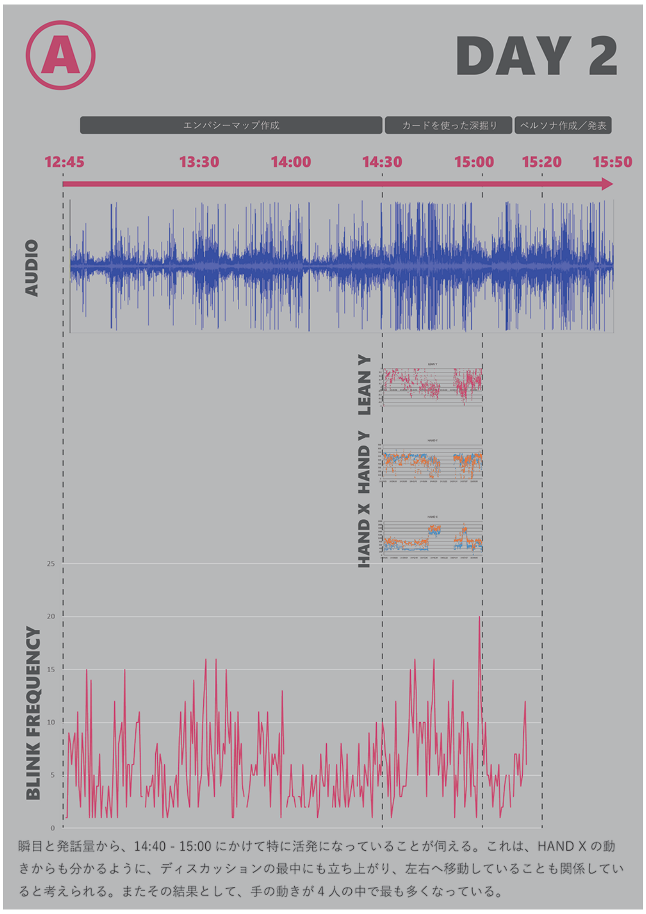


Figure 3.1.5: Additional visualization of Student A, including JINS MEME data

students made valuable contribution regardless of how much they talked

- Interventions in group work must be something that can be intuitively understood because students will be busy focusing on their group work

Feedback From Students

- The visualizations seem to be accurate and match their own thoughts
- The quantity of their talking amounts do not represent the quality of what they said, for they were dependant on the least talking student in the final phase of design thinking

- The student who talked the least was seemed slightly shocked about the result and was motivated to talk more in the next group work, whereas the student who talked the most was skeptical whether the visualizations would change his group work behaviour
- They showed most interest in the JINS MEME data, and were curious about what makes themselves engaged
- They had diffulty in regulating the group, but mentioned that by knowing who is engaged or not they can do something about members who are not concentrating

3.1.6 Insights

From the results, the following 4 insights were drawn from this group work analysis.

- Conversation share of students are unevenly distributed
- The student who talked the least and the student who talked the most perceived the visualization differently
- The student who talked the least was the key person in the group, suggesting that how much they talk do not accurately represent their mental efforts
- Monitoring each other's mental effort or engagement may help students to regulate themselves in improving group work quality
- Teachers were interested in knowing what stimulated and engaged students in group work

3.2 Design Process

3.2.1 Concept

With the insights gained from the initial design research, the concept of this project was formed. The most important takeaway from the initial research was that talking amount does not correlate with their mental effort(i.e. what they have to contribute), because the key person in the group talked significantly less than others. At the same time, that student who talked the least was highly motivated to talk more in the next workshop, suggesting that some students refrain from speaking out, regardless of the importance of their contributions or their mental effort. This is not a healthy state for group work, for in an ideal group work, each group member is equally open to one another. One possible solution for this situation is to share their mental state, which students not only found purely interesting in the pre-study but also helpful for group regulation. Although the students only mentioned about regulating members who were not concentrating, sharing their mental state may also help to shed light and put attention on those who are thinking hard but are refraining from speaking out. Therefore, this project aims to improve the quality of group work by designing an intervention that would allow every group work participants to be open through disclosure of their mental effort. The data collected from such design would also enable teachers to later examine when students were most engaged and when students were most bored during class, leading to the improvement of group work style lessons. As such, the initial prototyping began to design an object that visualizes the mental activities of group work participants. To summarize, by giving form to group work participants' mental activities, it is expected that

- students who talk relatively less can be motivated to speak out what they have to say
- students who talk relatively more can realize that those who talk less do in fact have something to say and can offer them a chance to speak out
- teachers can examine when students were stimulated or bored after the group work

3.2.2 Initial Prototyping

Unity Simulation

As a first prototype, the inputs of Whitebox, along with heart rate, were used to move a computer graphic model of a tree in Unity, as shown in Figure3.2.1. The volume and share of the user's ' conversations, their posture and their heart rate accounted for the height, thickness and twist of the tree, respectively.

This simulation was then presented to two people having a conversation as shown in figure3.2.2, which seemed to have an interesting effect of stimulating the

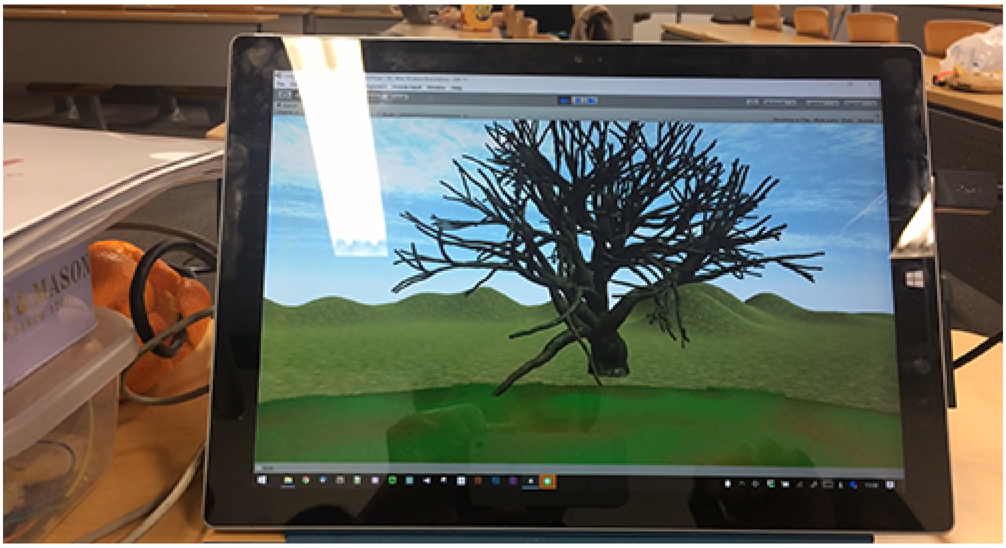


Figure 3.2.1: Unity simulation

conversation. As the tree grew, shortened and twisted during the conversation, it almost seemed to be dancing along with the pace of the conversation, suggesting the potentials of visualizing group work dynamics in real time.

Motif

Meta Pot visualizes mental effort with the color change and movement of a leaf that grows from a pot, as shown in Figure3.2.3.

Since the intervention needed to be something that does not distract students, the object had to sit naturally inside a classroom setting. For this reason, plants, which are common interiors in households, were chosen as the motif in initial prototyping, such as trees in Figure3.2.4 and flowers in Figure3.2.5. Furthermore, the intervention should be a symbolic object that represents the mental activity of users who are deep in thought. Kahneman explains that there are two states to mental activity [23]: System 1, which operates automatically and quickly, and system 2, which is the effortful and concentrated mental state most easily caused by complex computations. Such Sysem 2 is explained to be activated by cognitive strain. Out of plants, leaves, which change color to yellow under stressful environments such as lack of or the excess lighting or water, matched with the symbolic meaning of Meta Pots in the sense that Meta Pots are activated when someone is lacking the attention that is needed. Hence, leaves were chosen as an ideal motif.

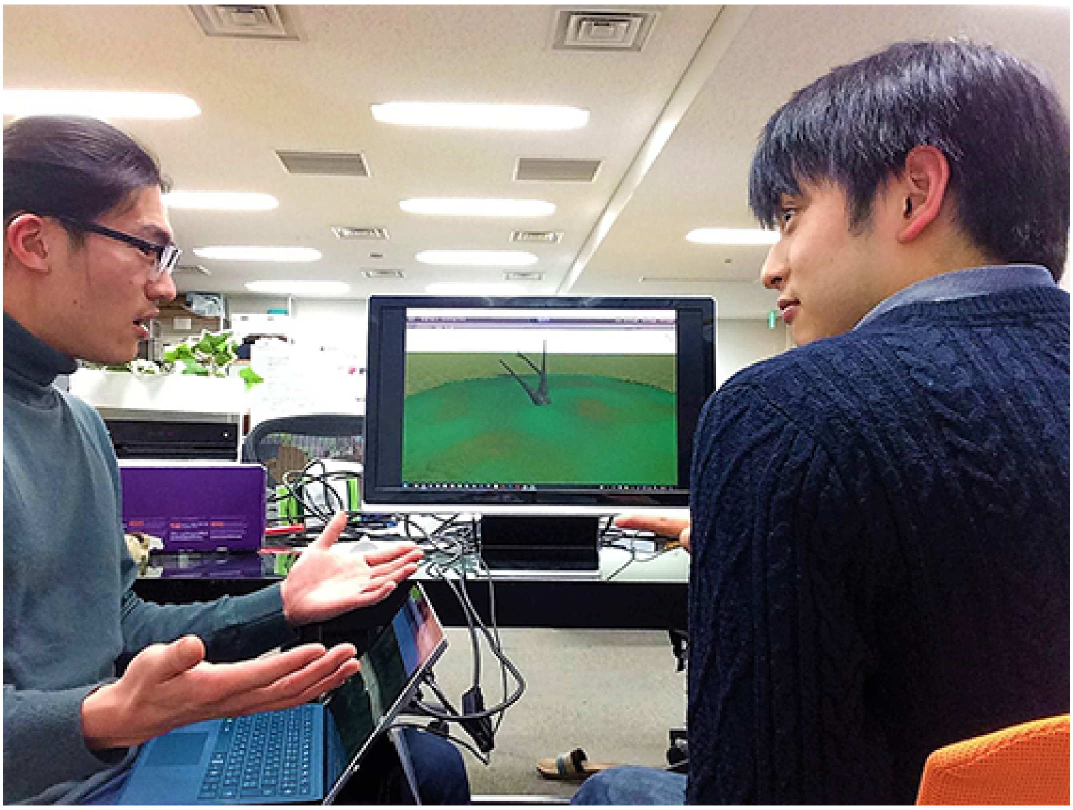


Figure 3.2.2: Unity simulation test

Bio Metal Fiber

The movement of the leaves are controled with Bio Metal Fibers (BMF), a type of shape memory alloy that shrinks when an electric current flows through, as shown in Figure3.2.6. The BMFs were successfully controlled with an Arduino by applying 0.6 - 2.0 V currents with Pulse Width Modulation (PWM), depending on its length. BMFs are extremely silent when they move, making it an ideal actuator for something that should not disturb students from their group work.

When using BMFs, it is important to regulate the voltage, for they can easily become hot enough to burn fingers or paper. In the case of Meta Pot, when they were applied the maximum 5 volts that Arduinos can manage, it became too hot that the BMFs burned themselves in an instant. To ensure the safety of the device, the cables connecting the BMFs were wrapped with heat shrink tubes.

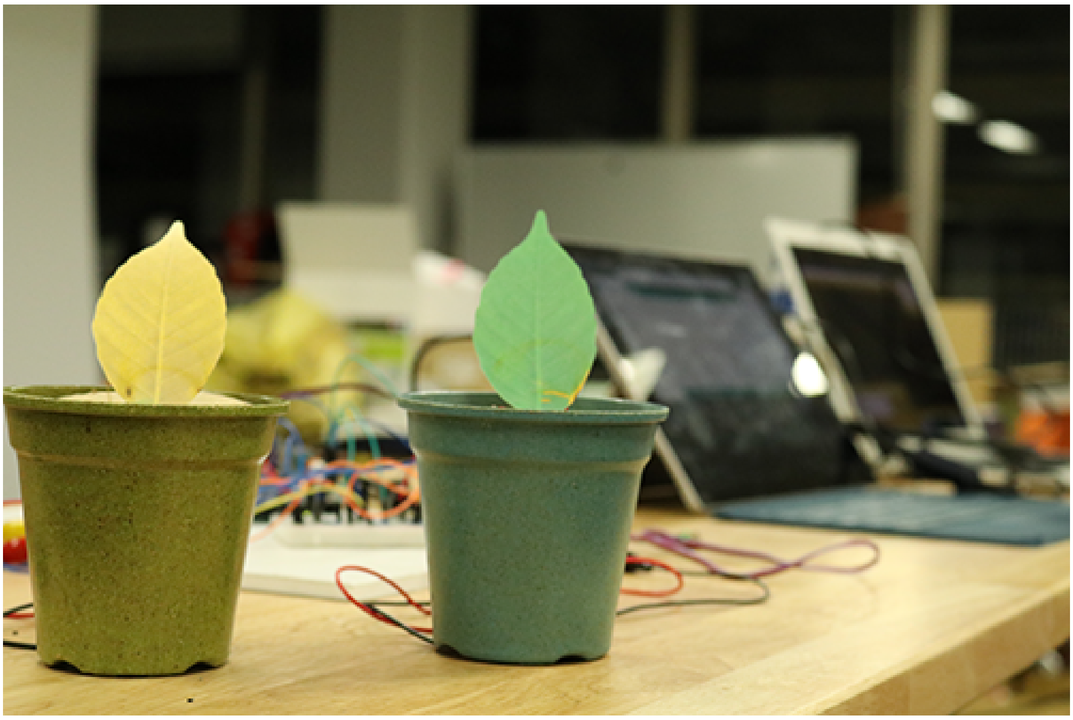


Figure 3.2.3: Leaf motif

Thermochromic Ink

To indicate the activation of the leaves more clearly, thermochromic inks were also included in the design to change the color of the leaves. When BMFs are activated, they become as hot as 50 - 60 degrees Celsius, which are more than enough to cause color change in thermochromic inks. For the final prototype, a product called *Leaf Thermometer* [2], a thermometer in the form of a leaf that utilizes thermochromic ink, was used. By letting the BMFs touch the back of the leaf when they are activitated, the BMFs gradually lift up and warm up the leaf, creating obvious color change from green to yellow within seconds, turning it mostly yellow in approximately 30 - 40 seconds. In order to prevent the BMFs from burning the Leaf Thermometers, polyimide tape was used to cover the area of the leaves where the BMFs touch.

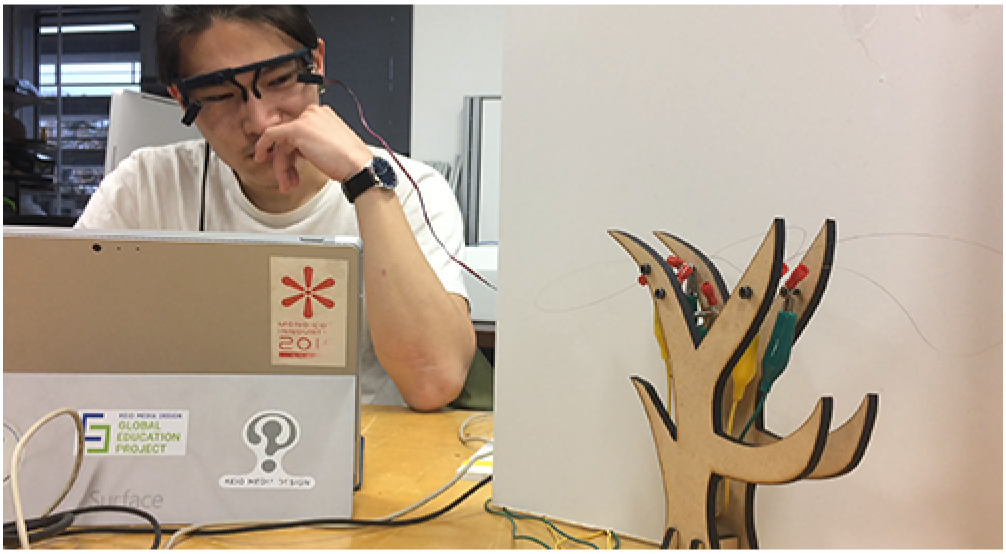


Figure 3.2.4: Tree prototype

Sensors

In order to visualize group work participants' mental efforts, Meta Pot collects heart rate and pupil dilation from the participants, based on previous research as explained in 2.3. Heart rate is measured using the "Pulse Sensor" by World Famous Electronics llc[3]. This sensor is attached to the user's ear lobes or the first joint of the index finger. As an additional input to reduce the noise of physiological responses, the "Pupil" sensor from pupil labs[4]was also included in the system to measure pupil dilation. This pupil sensor is a wearable eyewear device. Figure3.2.7 shows a user wearing both sensors.

3.2.3 System Description

Figure3.2.8 shows the system diagram of Meta Pot.

The movement of the leaves are decided with how much the heart rate of each participant changed. That is, an individual minimum threshold for each participant is set using the average heart rate of each participant calculated before the discussions, and a maximum threshold is set as the value 10 BPMs more than the minimum threshold. Equation3.1 explains how the acquired heart rate (HR) is mapped between 0.0 to 0.6 as voltage to be applied to the BMFs using the individual minimum threshold ($minThresh$).

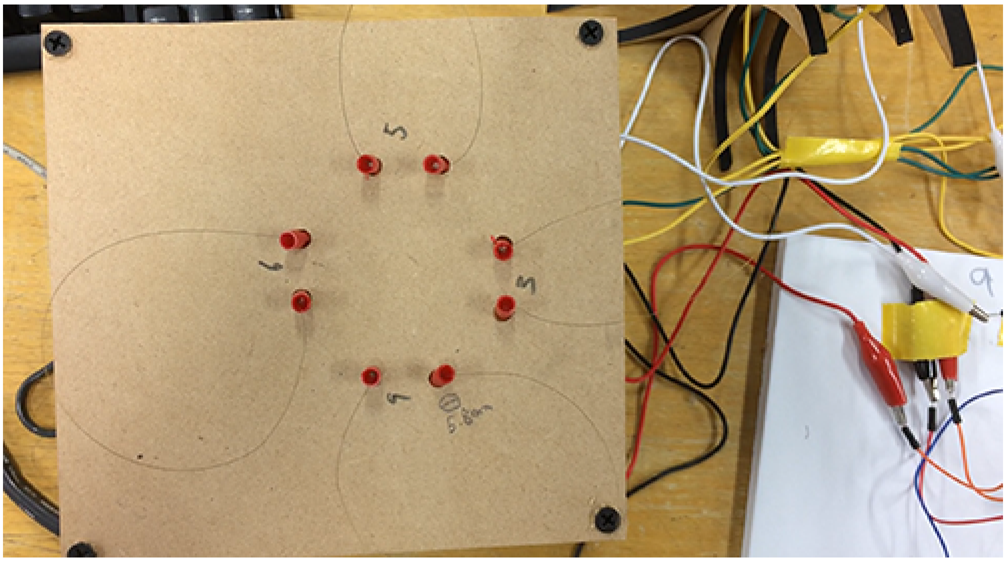


Figure 3.2.5: Flower prototype

$$voltage = \begin{cases} 0 & (HR < minThresh) \\ 0.6 & (HR > (minThresh + 20)) \\ 0.6(HR - minThresh)/20 & (otherwise) \end{cases} \tag{3.1}$$

The reason for using this method instead of using the adaptive thresholding method is to create a linear relation between users' physiological responses and the movement of the leaf, so that the leaves will show their level of mental effor instead of simply being an ON/OFF indication. The optimal method, however, is still under consideration.

The leaves lift up to 70 degrees from the initial position, as shown in figure3.2.9.

As for the latency of the leaf movement, the leaf starts its movement within 1 second of the current input, but because the BMFs are actuated by heat, the latency does vary slightly depending on the temperature of the BMF and how fast the temperature changes.

3.2.4 Pilot Study

A pilot study was conducted to explore the basic effects of mental effort visualization using Meta Pot. The pilot study was conducted with 8 Master's students

Figure 3.2.6: Bio Metal Fibers actuation

at Keio University Graduate School of Media Design (KMD) aged 23 to 32, with 3 females and 5 males. The participants were grouped into 2 groups of 4 students each. All participants were fluent Japanese speakers, and were highly experienced in brainstorming, discussing and problem solving in groups. During the pilot study, the two groups were asked to do two group discussions, one with the Meta Pots and one without the Meta Pots. The first group was asked to do each discussion for 15 minutes, and the second group for 10 minutes.For each test, the participants were asked to ideate and discuss on the solution for the following two topics, respectively.

- How to motivate students at KMD to make sure they put trash in the appropriate bins
- How to make KMD more creative for students from all backgrounds, which vary from economics to architecture

The goal was to come to a mutual agreement on one solution for the topic of discussion. During the experimental condition, all 4 students were asked to wear the pulse sensor on their right ear lobe. Due to the lack of sensors, pupil dilation was not considered in this user test. In addition, each participant had their own Meta Pot placed in front of them on the table, which were activated in real time

Figure 3.2.7: User wearing heart rate sensor and pupil sensor

according to their heart rate increase. The feedback from the pilot study was as follows:

- All participants felt it was easier to discuss with the Meta Pot for they could confirm whether the members were concentrating before asking for their opinion. "*I felt more comfortable than usual group work because I was able to check the leaves to make sure other members were participating properly*".

- Participants who talked relatively more than others during the user tests mentioned "*I was motivated to ask for opinions of group members whose leaf was green to have them engaged in the discussion more. I also talked in a less aggressive manner than usual to those whose leaf was green*", and "*Before making eye contact with other members, I took one glance at the leaves just to check if they are ready to say something*".

- One participant mentioned "*I was able to see that I was doing well because my leaf stayed yellow, so I was assured that I should just keep doing what I was doing*".

- The participants of the second group, which failed to come up with a conclusion in the discussion without the Meta Pot, agreed that they "*felt like they could be lazier when there was no Meta Pot*".

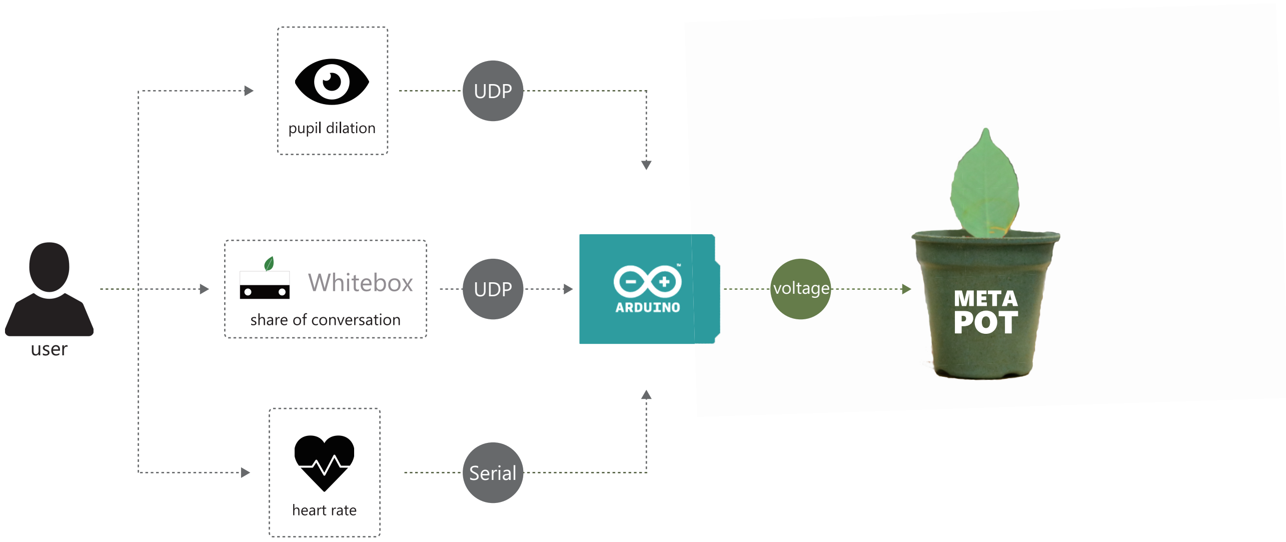


Figure 3.2.8: Meta Pot System Diagram

- Participants whose leaf stayed green for the majority of the discussion, mentioned that they were"*motivated to try harder, but was also frustrated and depressed that the leaf would not turn yellow despite my effort to engage in the discussion more*".
- As for whether Meta Pots were distracting or not, all 8 participants agreed that it was not distracting in any way. One participant mentioned " *I was unconcsiously catching the movements of the leaf with the corner of my eye*", while another mentioned "*I was too focused on the discussion that I hardly looked at the leaf intentionally*".
- One participant mentioned that although he was usually bad at having eye contact during a conversation, staring at Meta Pots were close to having eye contact except "*being much easier*". Another participant mentioned that they would glance at the Meta Pot before looking at them, just to make sure that they were engaged in the discussion.

The pilot study did confirm that the Meta Pots had an effect on group work behaviour, especially for those who tend to speak more than others. That is, the Meta Pots motivated them to ask opinions of the group members, and to withold from saying too much when their leaves were not activated. For those who tend to speak less, the Meta Pots did motivate them to engage more in the discussion,

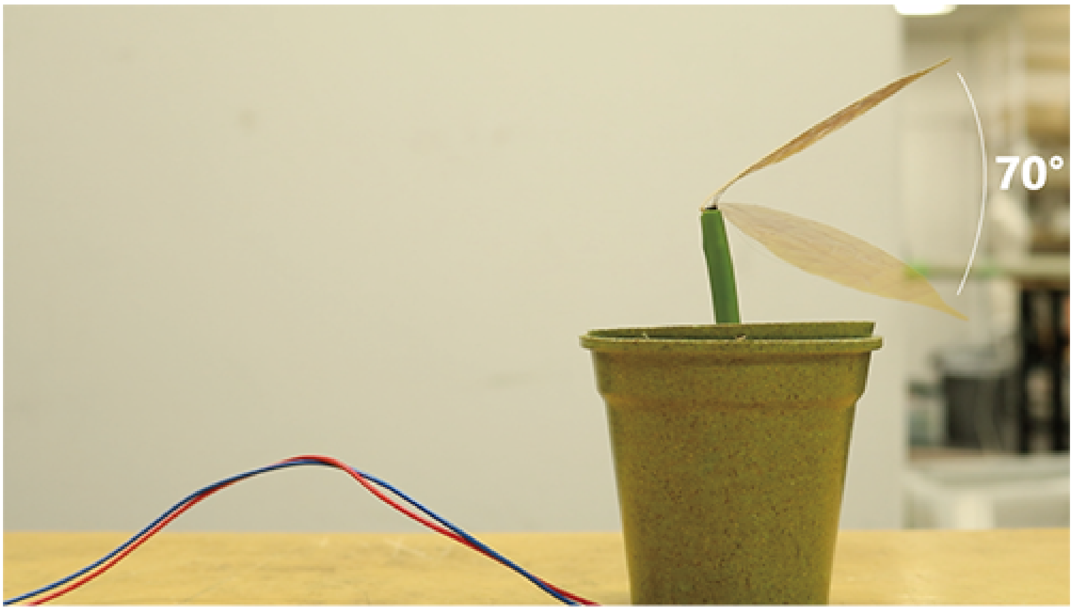


Figure 3.2.9: Movement angle

but at the same time frustrated them and caused negative feelings when the leaf did not change color despite their effort. Furthermore the feedback suggests that Meta Pot had strong effect on the participants gaze, mainly directing their gaze to Meta Pots that were active but also acting as a place to rest their gaze on. The Meta Pots did not seem to become a distraction for group work, and for some participants the ambient movements of Meta Pots may have even been a little too subtle. There were also some unexpected negative effects that Meta Pots had. For example, P5 mentioned that he thought he could "*stay out of the conversation when the Meta Pot was in active state*", and P4 mentioned that "*Meta Pots should not be something that makes participants feel negatively when they do not activate, it should be something more fun*".

These negative feedback were mainly due to the fact that many of the Meta Pots were activated regularly, decreasing the value of its activation. For the effect of the color change to function properly, the Meta Pots should stay green longer, and the users should understand that it is okay for them to stay green. Based on the observation and feedback of the pilot study, we decided to increase the level of intervention of Meta Pots, taking into account not just the participants' heart rate but also the conversational share in real time. In the new design, Meta Pots will not only visualize the mental efforts of group work participants, but also take into account the distribution of conversational share in real time, activating the leaves only when that participant showed heart rate increase and was talking significantly less than others. In other words, Meta Pot will be detecting those who may have something to say but seem to have not been a to say it. In addition, because the first group seemed to show signs of fatigue during the discussions, we decided that the discussion time should be 10 minutes each. The maximum threshold of the volatage calculation was also modified to the value 20 BPMs more than the minimum threshold instead of 10 BPMS, using the average standard deviations of the participants' heart rate in the pilot test, which was 19.78.

Notes

1 https://jins-meme.com/ja/

2 https://www.amazon.co.jp/Leaf-Thermometer-%E3%83%AA%E3%83%BC%E3%83%95-%E6%B8%A9%E5%BA%A6%E8%A8%88-HD1011/dp/B008I0Y8VQ

3 https://pulsesensor.com/

4 https://pupil-labs.com/pupil/

Chapter 4
Evaluation

4.1 Proof of Concept 1

A user study was conducted as a proof of concept to both quantitatively and qualitatively evaluate how the visualization of mental effort through Meta Pot affects group work behaviour.

4.1.1 Participants

The user study was conducted with 16 Master's students at Keio University Graduate School of Media Design (KMD) aged 22 to 26, with 7 females and 9 males. The participants were grouped into 4 groups of 4 students each. All participants were either fluent Japanese speakers or fluent English speakers, and were highly experienced in brainstorming, discussing and problem solving in groups. Participants were from various backgrounds, including material science, psychology and engineering, and also from various countries.

4.1.2 Method

The user study was conducted as a within-subject study in latin square condition. The first group was asked to do the first group discussion for 10 minutes without Meta Pot (control condition) and the second discussion for 10 minutes with Meta Pot (experimental condition), while the second group was asked to do the first group discussion with the Meta Pot (experimental condition)and the second discussion without (control condition). Each group consisted of 4 students. For each test, the participants were asked to ideate and discuss on the solution for two topics. The goal was to come to a mutual agreement on one solution for the topic of discussion. After each session, a 30 minute group interview was conducted with each group to ask about their behavour change with and without the Meta Pot.

4.1.3 Apparatus

During the experimental condition, all 4 students were asked to wear the pulse sensor on their right ear lobe. Due to the lack of sensors, pupil dilation was not considered in this user study, but one participant was asked to wear the pupil sensor purely for data collection. Each participant had their own Meta Pot placed in front of them on the table, which were activated in real time according to their heart rate increase. Their conversation share was also analyzed in real time with the audio data collection function of the Whitebox system explained earlier. During the control condition, the pulse sensors were removed from the participants' ears, and only the Whitebox system was used to analyse their conversation share. Because the Whitebox system is designed to collect data from 2 group work participants, 2 Whitebox systems were used, each operated through Microsoft's Surface Pro 3.

Figure4.1.1 shows the setup of this study.

Figure 4.1.1: User Study Setup

4.1.4 Procedure

After the participants were brought to the study room, they were first asked to wear the pulse sensors on their right ear lobe. They were then given a brief explanation about the procedure of the user study, while their average heart rate was also being accumulated. They were then instructed about the task and goal as follows: *"The topic for today is about Hiyoshi, the beloved town where our campus is situated. The goal for today is to come up with ideas on how to turn Hiyoshi in to a city like Portland, which is ranked not only as one of the best cities to live in, but is also ranked as one of the most green cities and also the cities with the best coffee. First, you will be asked to discuss for 10 minutes on how to make Hiyoshi cleaner and greener. You will be then asked to discuss for 10 minutes on how to make Hiyoshi more creative, especially by providing the resources of KMD. Please come up with one or more solutions within the 10 minutes, and be prepared to explain your solutions at the end. "* For the experimental condition, the users were then explained as follows: *"The Meta Pots in front of you can detect people who seems to have something to say but haven't been able to say it. When the Meta Pots detect such people, the leaves on the Meta Pot will rise up and change color to yellow, and will go back down and back to green when it thinks that that person has been able to say it."*. After confirming that their average heart rate has been calculated (table4.1 shows the accumulated average heart rate), the values were set into the system to be used as minimum threshold, and then the participants were asked to begin the group discussion. During the interview, the data collection of heart rate and conversation share was monitored on the computers to check that the system was functioning properly. For the control condition, the users were asked to begin the group discussion without any other explanation. Each group discussion was timed, and after 10 minutes, the participants were asked to stop their discussions and present the solution that they came up with. After the 2 group discussions in both conditions, the participants were interviewed in a group about the following topics:

- How they felt when the group members' Meta Pots were in active state
- How they felt when the group members' Meta Pots were not in active state
- How they felt when their own Meta Pot was in active state
- How they felt when their own Meta Pot was not in active state

- Whether Meta Pot was distracting to the discussion

Table 4.1: Minimum heart rate threshold in proof of concept 2

Participant	Average Heart Rate
P1	95
P2	100
P3	95
P4	100
P5	100
P6	100
P7	75
P8	90
P9	90
P10	70
P11	90
P12	80

4.1.5 Results

Since the first group ran out of time during the user study and failed to complete the tasks, only the results from the second to fourth gorups are cosidered. Figure4.1.2 shows the total speaking time of each participants from the second group (P1, P2, P3, P4), third group (P5, P6, P7, P8) and fourth group (P9, P10, P11, P12), with and without the Meta Pots. These speaking time are the number of times Whitebox detected significant audio input from the directions of each participants.

Figure4.1.3a, figure4.1.3b and figure4.1.3c show the individual conversation share of group 2, 3 and 4 with and without the Meta Pots, respectively.

Figure4.1.4 shows the average standard deviation of the conversational share per condition in this study. In other words, it shows how spread out the conversation share was, with and without the Meta Pots.

Figure4.1.5 shows the total number of times conversatinal turn taking took place during the group work in each group.

Figure4.1.6 shows the average heart rate of each participants, along with its standard deviation.

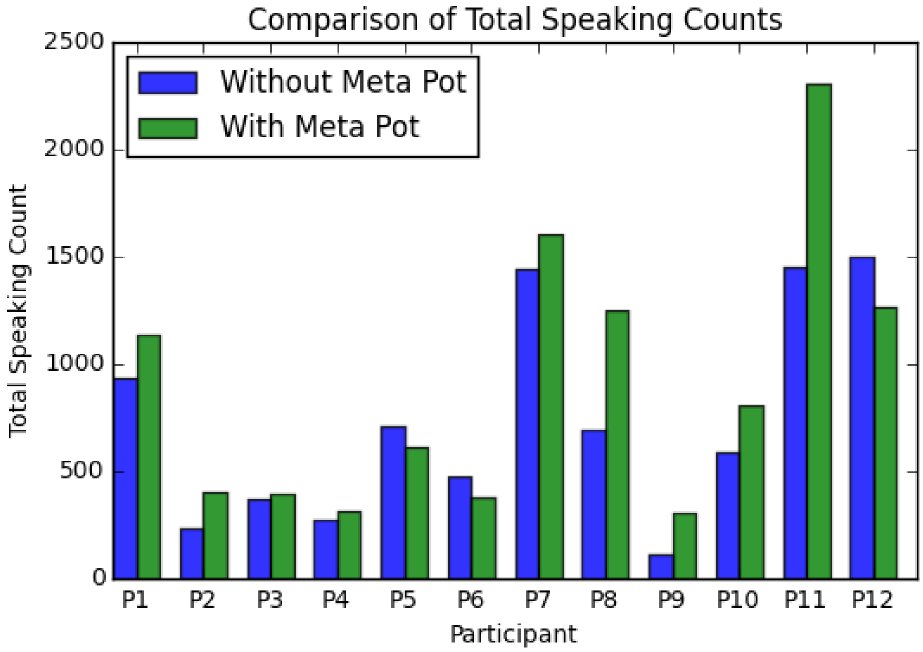


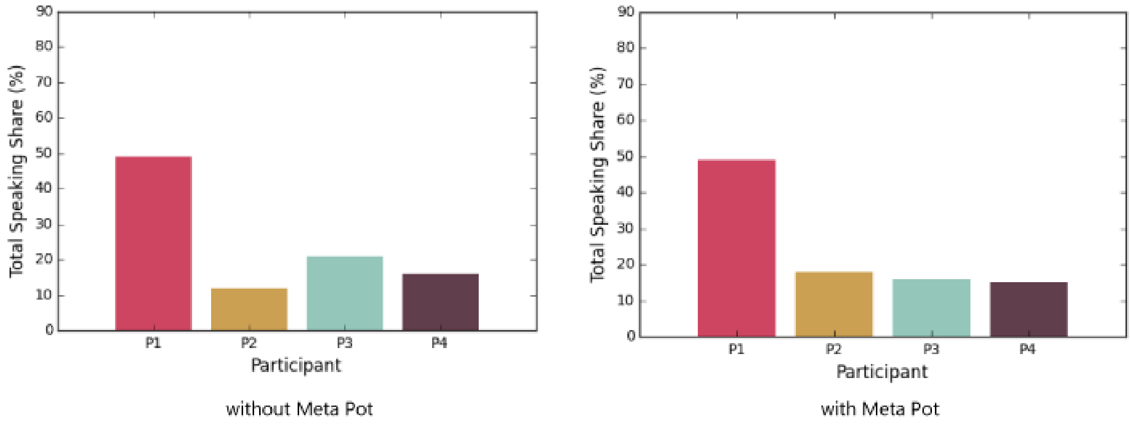
Figure 4.1.2: Comparison of speaking time of each participant in proof of concept 1

4.2 Proof of Concept 2

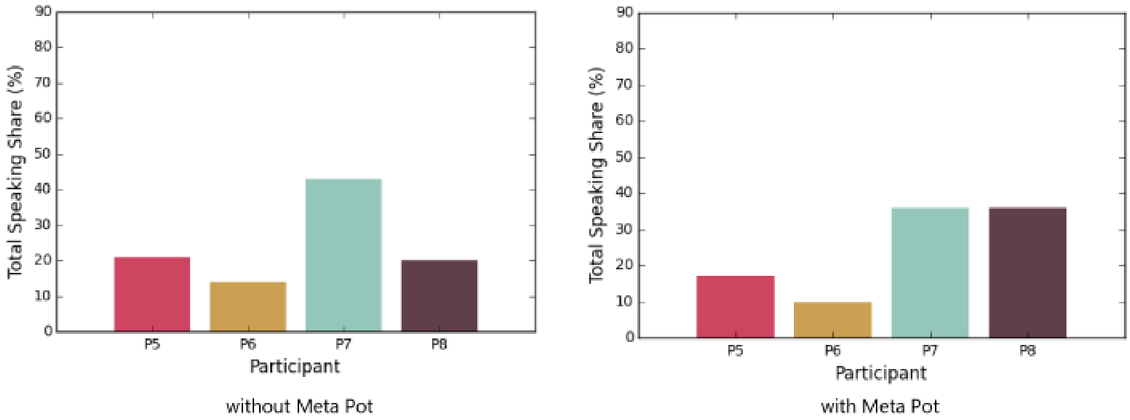
Another user study was conducted as a proof of concept with 2 students from Tokyo Metropolitan College of Industrial Technology. These 2 students were the same students participants from the pre-study, who provided the initial insights for this project. This proof of concept had to be separated from proof of concept 1 because of the various differences in the study setup, due to user demographics and technical troubles.

4.2.1 Participants

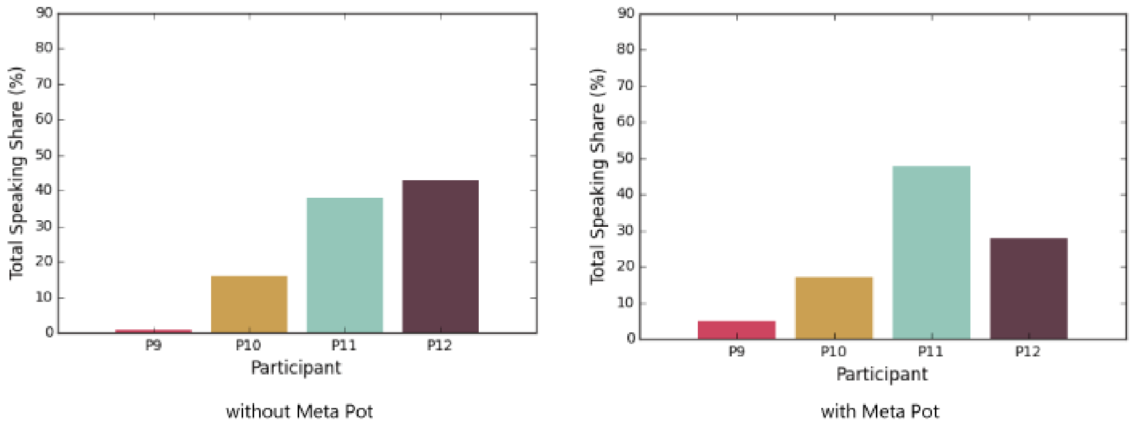
The user study was conducted with 2 students from Tokyo Metropolitan College of Industrial Technology aged 18 and 2 Master's students at Keio University Graduate School of Media Design (KMD) aged 23 to 24. The 2 Master's students were invited so that the group work can be done with 4 people, and they did not participate in proof of concept 1. 3 participants were male and 1 was



(a) Group 2



(b) Group 3



(c) Group 4

Figure 4.1.3: Comparison of conversation share

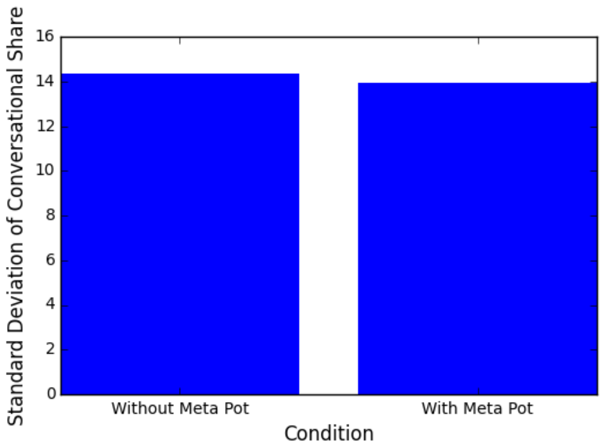


Figure 4.1.4: Standard deviation of total conversational share in proof of concept 1

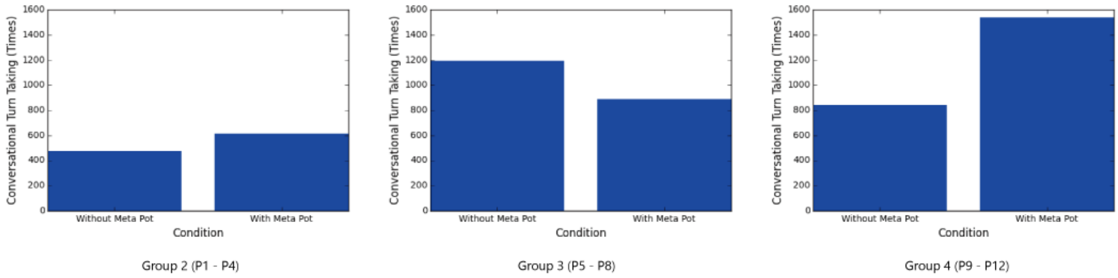


Figure 4.1.5: Number of total conversational turn takings in each group

female. All participants were fluent Japanese speakers, and were experienced in brainstorming, discussing and problem solving in groups.

4.2.2 Method

The methods were mainly the same as proof of concept 1. Due to technical issues, however, the Meta Pot system did not take into account the distribution of conversational share this time. That is, instead of activating the leaves when that participant showed heart rate increase as well as talking significantly less than others like in proof of concept 1, the Meta Pots were activated simply when the participants showed heart rate increase in proof of concept 2 (i.e. the same

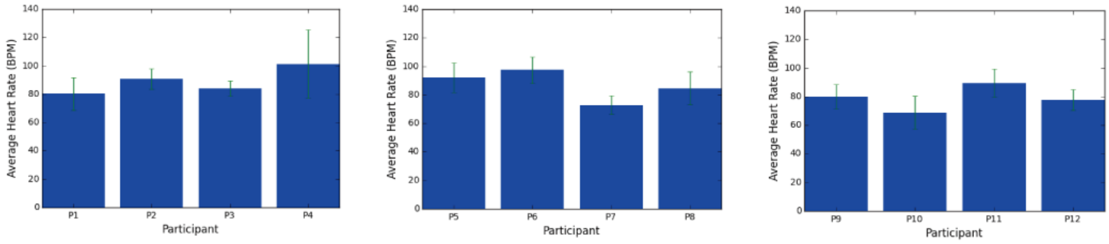


Figure 4.1.6: Average heart rate in proof of concept 1

method as the pilot test).

4.2.3 Apparatus

The apparatus was the same as proof of concept 1, except all four students wore the pupil trackers in this study. Again, the retrieved pupil data was not used as the input for the Meta Pots, but was extracted for data collection purpose.

Figure4.1.1 shows the setup of this study.

4.2.4 Procedure

Again, the procedure was generally the same as proof of concept 1, but the topic of group discussions were modified considering the participants' demographics. The discussion time was also shortened to 8 minutes due to time constraints. They were instructed about the task and goal as follows: *"You will be asked to conduct a group discussion on 2 topics for 8 minutes each. The first topic is to think of what university students today need to know and to come up with a new university course for them. The second topic is to think of how we can reduce packaging in Japansese products. Please come up with one or more solutions within the 8 minutes, and be prepared to explain your solutions at the end. "* For the experimental condition, the users were then explained as follows: *"The Meta Pots in front of you will be a representation of how hard you are thinking. When the Meta Pots think that you are thinking hard, the leaves on the Meta Pot will rise up and change color to yellow"*. Same as in proof of concept 1, after confirming that their average heart rate has been calculated, the values were set into the system to be used as minimum threshold. Table4.2 shows the accumulated average heart rate. After each group discussion, they were also asked to answer a questionnaire in likert

Figure 4.2.1: Second User Study Setup

scale this time, to evaluate the group discussion and their contribution.

Table 4.2: Minimum heart rate threshold in proof of concept 2

Participant	Average Heart Rate
P13	130
P14	82
P15	86
P16	82

4.2.5 Results

Figure4.2.2 shows the total speaking counts of each participants(P13, P14, P15, P16) with and without the Meta Pots, with P13 and P14 being the 2 students from Tokyo Metropolitan College of Industrial Technology.

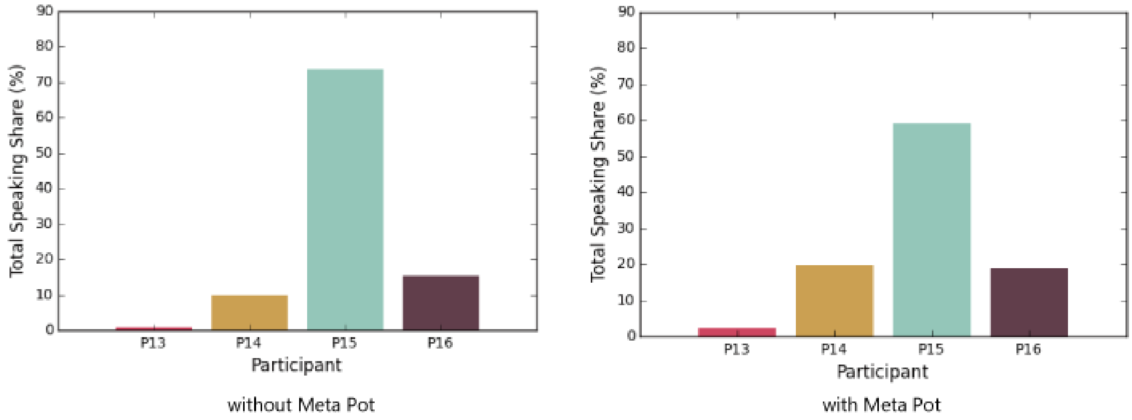


Figure 4.2.2: Comparison of conversational share of each participant in proof of concept 2

Figure4.2.3 shows the standard deviation of the conversational share per condition in this study. In other words, it shows how spread out the conversation share was, with and without the Meta Pots.

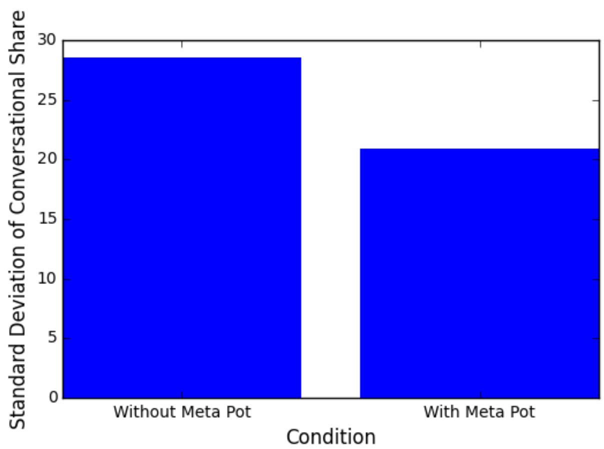


Figure 4.2.3: Standard deviation of conversational share in proof of concept 2

Figure4.2.4 shows the average heart rate of each participants, along with its standard deviation. It must be noted, however, that from figure4.3.3d it is clear that we failed to collect P13's heart rate correctly, meaning that P13's heart rate data and Meta Pot activation was not accurate in this proof of concept.

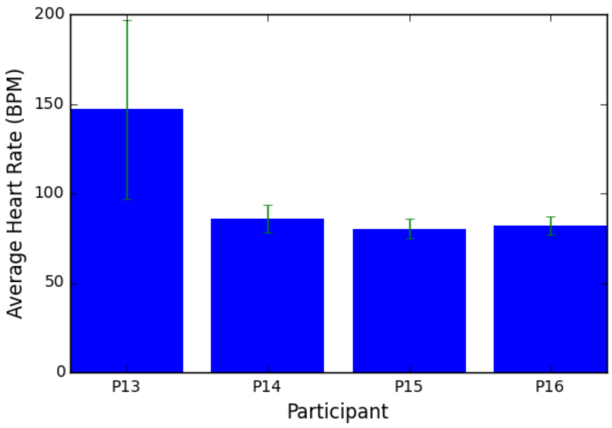


Figure 4.2.4: Average heart rate in proof of concept 2

Figure4.2.5 shows the average pupil size of each participants, along with its standard deviation.

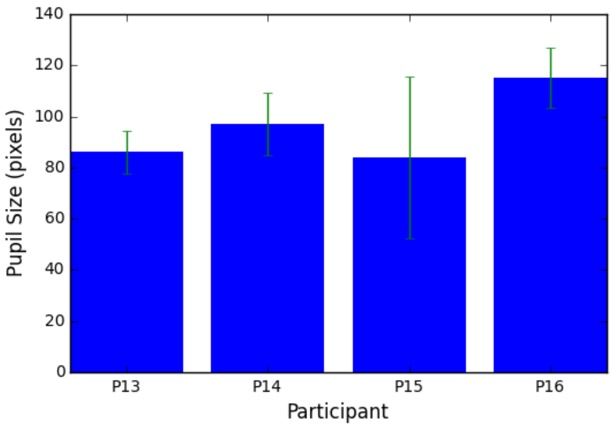


Figure 4.2.5: Average pupil size

Figure4.2.6 shows the results of the questionnaire of the two college students (P13 and P14) with and without the Meta Pots. The results were quantified by converting the 7 step Likert scale answers to numbers, with "Entirely Disagree" being 1, "Neither Agree Nor Disagree" being 4 and "Entirely Agree" being 7.

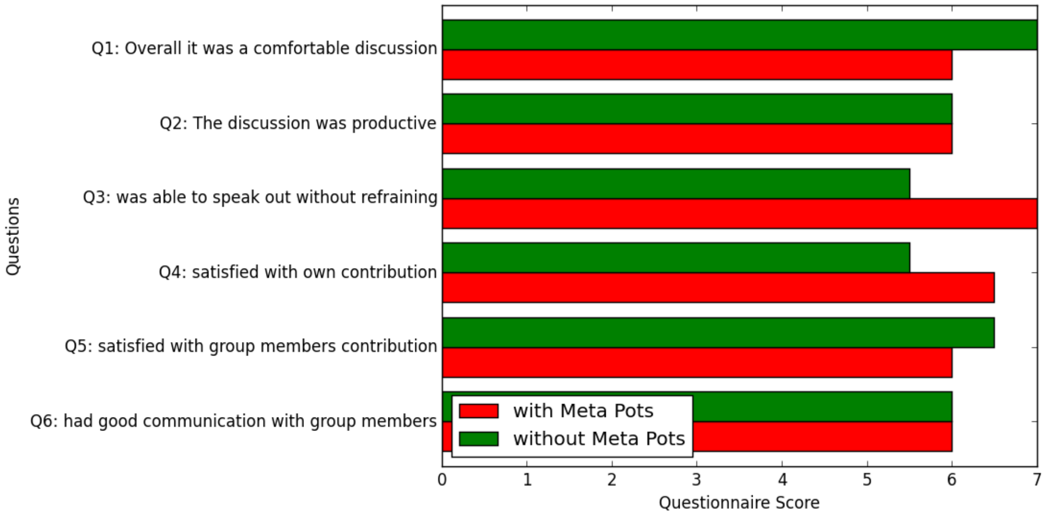


Figure 4.2.6: Average results of questionnaire results of P13 and P14

4.3 Discussion

4.3.1 Research Question 1

From figure4.1.3 and figure4.2.2 we can see that the way the Meta Pots affected conversational share differed in each group. Figure4.1.4 and figure4.2.3, show that the standard deviation of overall distribution of conversation share became smaller for both proof of concept 1 (-0.40%) and proof of concept 2 (-7.66%) when Meta Pots were used, meaning that the conversational share became closer to equal. (if conversation share was exactly equal, the standard deviation of each participants' conversational share would be 0). The equality of conversational share was also calculated using the Gini coefficient, which is a measurement for participation rates that has been used in several researches [14] [55], with 0 being perfectly equal and 1 being completely unequal. The Gini coefficient is calculated with equation4.1.

$$Ginicoefficient = \frac{2}{3}\sum_{i=1}^{n}|Participation_i - 25\%| \tag{4.1}$$

We found a decrease in the Gini coefficient for both tests when the Meta Pots were used, changing from 0.33 to 0.32 in proof of concept 1, and from 0.64 to 0.45 in proof ocf concept 2.

Figure4.1.5 shows that the number of total conversational turn taking increased in group 2 and 4, but decreased in group 3. As for conversational turn taking, it is difficult to say whether more converstional turn taking times results in better group work, because increase in total conversational turn taking means that participants did not take turns in speaking but rather jumped in on each other. Nevertheless, one interesting topic we can draw out from this is whether Meta Pots make group discussions more organized or more chaotic, but we will be needing more data to discuss this. The p-value for the T-test between the total speaking coutns of the two conditions (i.e. *with* Meta Pots and *without* the Meta Pots) in proof of concept 1 was 0.080, meaning that there was statistical difference between the two conditions. Although the system was slightly different in proof of concept 1 and 2, if we combine the 2 results and conduct a T-test the p-value was 0.011. From this it can be said that the Meta Pots did make the participants talk moderately more equally, and that Meta Pots created statistcal change in the way the participants talked.

4.3.2 Research Question 2

Participants explained the behaviour change that Meta Pots created as follows.

- "*I looked at the face of peole whose leaves were active. When my leaf was active, I could feel people's gaze on me, and I tried to speak for a little longer.*" (P3)
- "*When my leaf was active, it nudged me to speak out what I had in my mind.*"(P5)
- "*Usually I only look at people who is talking, but the Meta Pots made me more aware of the entire group, and as a result I looked more at people who wasn't speaking.*"(P16)

In particular, participants who talked significantly more than others, who ended up accounting for more than 40% of the discussions (standard deviation of conversation share was 15%), mentioned the following.

- "*When other people's Meta Pots were in active state I thought I should give them a chance to speak. Even if they looked like they don't have anything they want to say, I still offered them a chance to talk. To do this I glanced at them and tried to confirm their opinion, kind of like 'don't you think so?'.*

It's really sad when you're the only one talking and everyone else is quiet, so when the Meta Pots were active it was much easier to seek for reactions." (P1)

- "*When I saw my group member's Meta Pots being activated I tried to offer them the turn to speak. I touched on the fact that their leaf was erecting, and kind of joked on that.*" (P7).
- "*It was good to have the Meta Pots when we were in the divergent thinking phase, but not so much in the convergent thinking phase because the pots are kind of funny and it feels weird when people are trying to wrap up but their pots are active.* "(P8)
- "*I was checking the pot to see if I have something to say or not, so I tried even harder when my pot was not active.* "(P11)

Overall, the qualitative findings from the interviews did confirm that visualization of mental effort created behaviour change for those who spoke more than others. That is, the Meta Pots motivated them to ask opinions of the group members, and to withold from saying too much when their leaves were not activated. Interestingly, P1, who spoke the most out in group 2, mentioned

"*It was much easier without the Meta Pots because I was free to say what I want. For people like me who like to talk a lot, Meta Pots are something that blocks you from talking.*"

, meaning this witholding function was so effective that it caused frustration in some cases. As for a quantitative comparison, the average conversational share of these over participators decreased from 45.0% to 37.7% in proof of concept 1, and decreased from 73.7% to 59.1% in proof of concept 2, meaning that Meta Pots were able to withhold the over participators from talking. At the same time, however, it is also true that when individual speaking times are compared with and without the Meta Pots (as in figure4.1.2) instead of the overall conversational share, such participants who say that they withheld from speaking too much all ended up speaking more. The possible reason for this is that after they withheld their thoughts like they said they did, they took their turn to speak longer. Although this will also be discussed in limitations of this work, creating continuous withholding effect throught the Meta Pots is one obvious issue.

On the other hand, participants who talked significantly less than others (those who talked for less than 10%) mentioned the following.

- *"I paid more attention when there was the plant. Not just to my plant to the other's plant too. For example P10's turned completely yellow a few times so I paid attention to P10's flow of the discussion more, it triggered me to ask P10 or discuss more with P10 to dig what P10 wants to say. In an indirect way, like reacting to P10's comments and opinions, so indirectly it made me pay attention more."*(P9)
- *"I waited when others Meta Pots were in active state. I offered them a chance to speak, and I waited for them to talk."* (P2)
- *"It was easier to ask opinions and to listen to people whose leaf was standing."* (P13)

What their comments have in common is that all of them paid attention to their group member's Meta Pots and were motivated to listen and comment on the members whose pots were active. It is important to mention that P2,P9 and P13 resulted in talking more when Meta Pots were used. In other words, for those who talked significantly less, Meta Pots enabled them to be more attentive to the group member's opinions, which may have led to them talking more as a result. As for a quantitative comparison, the average conversational share of these under participators increased from 1.0% to 5.0% in proof of concept 1, and increased from 5.4% to 11.0% in proof of concept 2, meaning that the MEta Pots were also able to make the under participators speak out more.

It is important to mention that in proof of concept 2, there were several occurences of participants asking P13 for his opinion because his Meta Pot was being activated. Figure4.3.1 shows the moment when P14 asked P13 for his thoughts because his leaf was "*standing up a lot*" (P14).

Going back to the pre-study in chapter3.1, out of the 4 students of Tokyo Metropolitan College of Industrial Technology that we observed, P13 was the student who was talking the least, and P14 was the student who was talking the most. The fact that the Meta Pot made P14 ask P13 for his thoughts quite literally proved that Meta Pots can motivate students who talk more than others to offer the chance for others to speak out. This can also be said from figure4.2.6, which shows that the most significant change occured in Q3, meaning both P13 and P14 felt they were able to speak out what they had in their mind without refraining when the Meta Pots were used.

Figure 4.3.1: P13 being asked for his thoughts by P14

4.3.3 Research Question 3

By observing the heart rate data of each participant, there are several assumptions that we can draw.

From Figure4.1.6 and figure4.2.4 we can see that all participants' average heart rate ranged from 80 to 100 except for P13, who most likely had not worn the sensor properly and failed to get the correct heart rate. P4 and P6 had slightly higher heart rates than others. P4 in particular had larger standard deviation than others, showing that some participants' heart rate increase more dramatically than others. This could raise awareness for facilitators or teachers that such participants may be more susceptible to stress or tension.

When the heart rate is mapped on to the timeline of the group work, it enables more assumptions to be drawn from the data.

For example one can assume from the figure4.3.3a that something stimulated the participants during 12:21:00 - 12:21:30. From the video recordings of the discussions it became apparent that during that time, P4 was asked for her opinion due to the activation of the Meta Pot, which caused her obvious stress. It can also be assumed that something stimulated P2 during 12:23:30 - 12:24:00, and P1 around 12:24:30. Again, from the recordings of the discussion, it became apparent that P2 was laughing out loud at that time, and P1 was trying to explain to P4 how there are a lot less bins in Japan compared to other countries.

Likewise, from figure4.3.3b one can assume that something stiumulated the participants during 13:42:30 - 13:43:00. From the recordings it became apparent that during this time P7 was describing to its members about what he studies at his graduate school. It can also be assumed that something stimulated P8 around 13:54:30. During this time P8 was showing disagreement on what was being discussed. The other peek of P8's graph which occurs around 13:51:30 was most probably caused by him being surprised at P5's Meta Pot being activated.

From figure4.3.3c it can be assumed that something stimulated the participants around 14:33:30. During that time the participants were discussing about specific elements that are making Hiyoshi dirtier, especially about the vomit and excretion caused by drunk people.

The 3 graphs in figure4.3.3 from proof of concept 1 were shown to a teacher at the Electrical and Electronics Department of Tokyo Metropolitan College of Industrial Technology to inquire how the graphs can be used for group work evaluation. He was optimistic about the potential of group work analysis through biometric data, for he is always curious to know *"when studetns were engaged or not"*. In this sense he was more interested in seeing the transition of the average heart rate of all participants rather than for each participant indiviually, so as to get an idea of when they were most excited as a team. An example of such graph is shown in figure4.3.2. He also explained how they were constantly *"troubled with how to grade group work"*, and was interested in how the Meta Pot data can be used for grading. Currently they grade group work through evaluation of written documents and additional points through teacher's observation. In this method, it is not rare that those with good grades are *"not necessarily the ones with the best output"*. Meta Pot data can hence be used to fill in on the observation part of the grading and to provide information on who was constantly active. For this data to be really useful, however, he mentioned that he would like the system to provide them with what students were doing and what teachers were saying in the key points of the graph *"in text form"*, so that they do not have to go and analyze the situation themselves.

The post analysis of participants' states using physiological data can be used by as a guideline for group work facilitators or teachers which they can use to pick out scenes from the group work that caused significant stimulation to the students. By collecting data for more sessions repeatedly, these data can further assist teachers and facilitators in improving their instructional design, through knowing what excited or bored students.

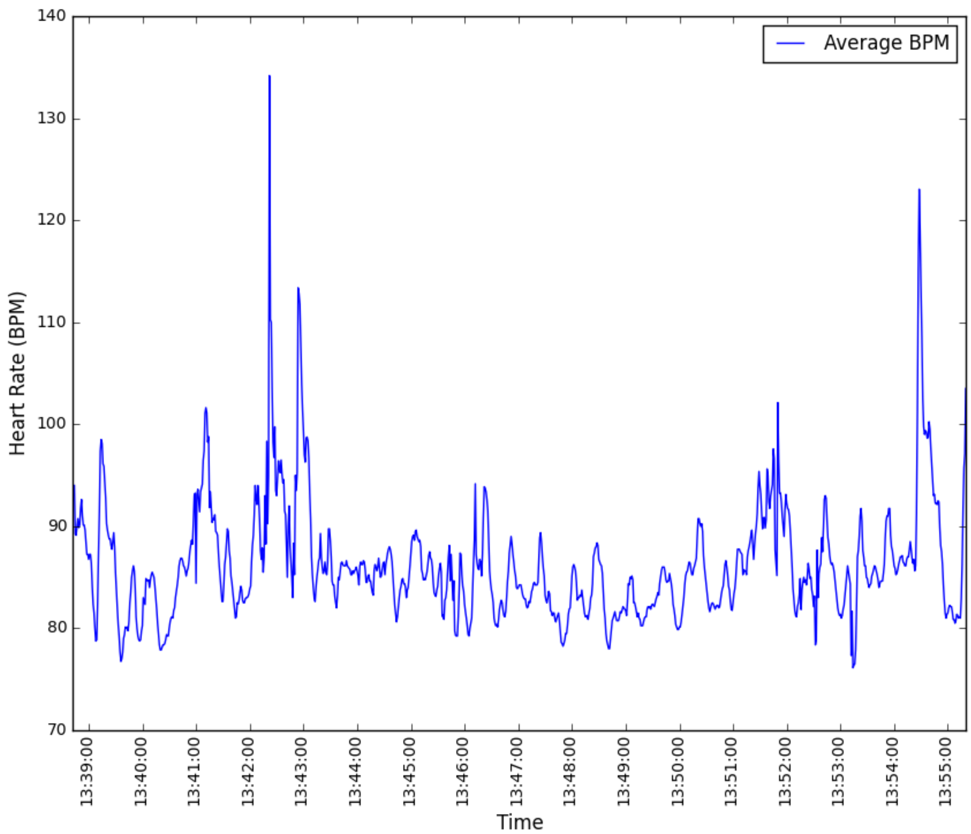
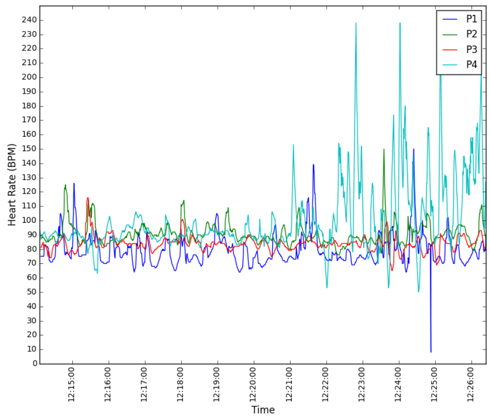


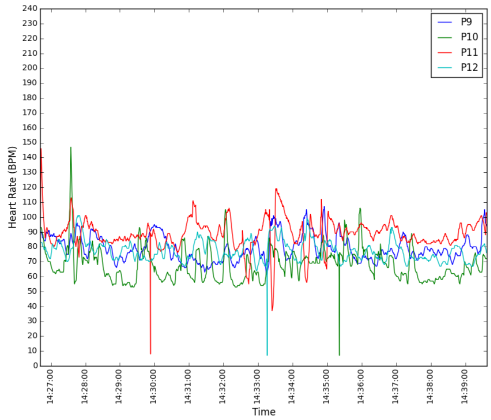
Figure 4.3.2: Transition of average heart rate of all 4 participants of group 3 in proof of concept 1

4.3.4 Effects Of Having a Common Avatar In Group Work

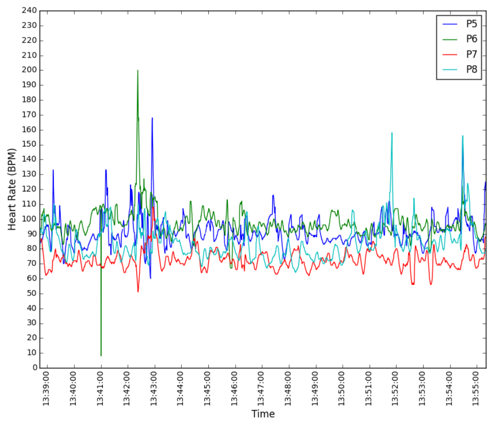
Another interesting finding from the user studies were that participants enjoyed having a common tool that all group members shared. P9 mentioned *"If there's nothing visually there my mind would go everywhere, but having something that indicates everyone's state helped. So I found it not very important, I focused on what I talked."* In particular, Meta Pot seemed to act as an ice breaking tool for group 3, which was the group where all participants met for the first time. P5 mentioned *"It felt easier to socialize when we used the Meta Pots. It was like a pet or a pal, it was an avatar of myself and I cared for it. It created this atmosphere where it was easier to talk."* P7 mentioned *" Having this visualization as an object*



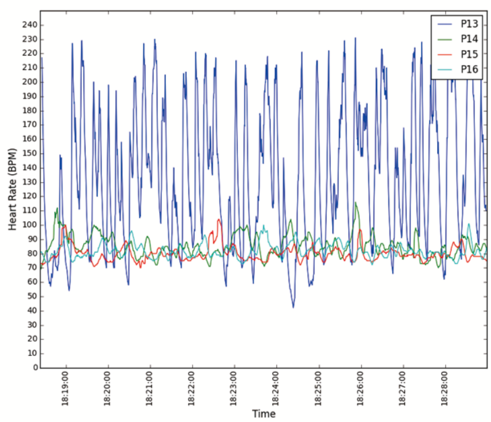
(a) Proof of Concept 1 - Group 2



(c) Proof of Concept 1 - Group 4



(b) Proof of Concept 1 - Group 3



(d) Proof of Concept 2

Figure 4.3.3: Heart Rate Transition of Participants

enabled everyone to present that they have something to say."

Another aspect that many participants agreed on was how Meta Pots affected their gaze. Many participants mentioned that, in order to offer others a chance to speak, they would look at their face, rather than to say it in words. This brings us back to the pilot test, where participants placed their gaze on the Meta Pots even when they were not in active state. These behaviours suggest that gaze play an important role in group work dynamics, and that Meta Pots have the potential to control such gaze. This leads to the discussion of why Meta Pots should be visible to all participants, instead of just to theirselves or to all others but theirself, like *nekomimi* [30]. Unlike *nekomimi*, participants can glance at Meta Pots without having to look directly at their group members' face, allowing discreet monitoring of their mental activity. This creates a strong basis for teamwork, for mental activity is usually something that is concealed within each person, and something that another person cannnot bluntly observe. When the Meta Pots are activated, it is also obvious to all, including the Meta Pot's owner, enabling them to become aware of their thoughts that they otherwise may not have. As explained in Chapter 2, it is essential in group work for all members to feel safe to say what they have to say. Thus, it is the role of Meta Pots to provide a common platform where all members are forced to be equally open.

4.3.5 Negative Effects of Meta Pots

One of the downsides of using the Meta Pots that became apparent through the user study was that some participants were frustrated about their Meta Pots not activating. In particular, in proof of concept 1, those who relatively dominated the discussions tend to feel this way because the Meta Pots were activated only when the conversation share was below 25%, which never happened for those participants. P1, whose conversation share was close to 50% with and without Meta Pots, mentioned

"I was confused with why my Meta Pots didn't activate, because there were so many things I wanted to say!"

P11, whose conversation share was also above 40% for both conditions, mentioned

"I felt empty when the pot didn't turn yellow, I didn't even understand myself any more.I felt lost. There was negative feeling when didn't activate. It felt kind of weird, so I found it distracting."

Another downside was that those whose Meta Pots were constantly activated felt it distracting, due to too much attention from the group members. P6 mentioned

"Even when we were in the middle of discussing something, everyone asked for my opinion when my leaf was active and it made the discussion go off track. It didn't make me uncomfortable when everyone was looking at me, but I did force myself to continue to talk. So it was distracting in that sense."

P4, whose Meta Pot stayed active the longest out of all participants, mentioned

"Because my Meta Pot was active all the time, everyone asked me for my thoughts throughout the discussion and I was less and less motivated. Also, it made it difficult for me to ask opinions of other group members. Having the Meta Pots worked as an obstacle to the group work."

It is likely that P4's average heart rate before the test was higher than usual, which would explain why her Meta Pot was active for so long. Due to this, however, we were also able to learn that having the Meta Pots constantly active causes excessive stress to some users. In these cases the user was being looked at from other participants and were asked for their opinion, even when they had nothing to contribute.

Interestingly, during the pilot test in which the Meta Pots simply visualized each participants' mental efforts, participants whose Meta Pots were constantly active mentioned that they felt assured that they were doing well. On the contrary, when the Meta Pot system activated the leaves only for those who were talking less than others, participants felt that having their leaves constantly active was a burden.

This implies that, when using Meta Pots, the way we describe the device has significant effect on the behaviour change it creates. When the Meta Pot activation is perceived as something that requires attention, all participant must understand that they must work as a team to distribute their conversational turn taking equally in order to keep everyone's Meta Pot green. Without this mutual understanding, the participants simply wait until the participant with the active Meta Pot speaks, thereby turning into "Free Riders" temporarily.

4.3.6 Agency and Skepticism

Whether users were able to feel they had control over the Meta Pots and gain a sense of agency varied. It seems that the conversational share thresholding used in proof of concept 1 decreased the sense of control, for a majority of participants who showed signs of skepticism in the interview were from proof of concept 1.

- *"I didn't have anything that I really wanted to say but the Meta Pot was standing up."* (P6)
- *"I didn't think that the pots were moving with real time data."* (P8)
- *"The Meta Pots activated in unexpected moments so it felt a little weird."* (P15)

This was anticipated, for in the system setup of proof of conept 1, those who were dominating the conversation were excluded from the Meta Pot activation, meaning their mental efforts were not directly visualized. Interestingly, both P8 and P15 ended up talking more when the Meta Pots were used, suggesting that sense of agency over the leaf movements is unrelated from how Meta Pots affect group work behaviour.

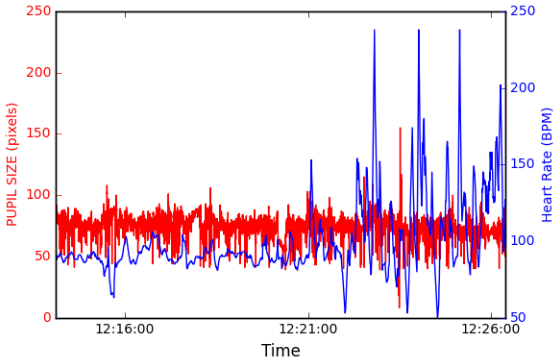
There were also some who seemed to give credit more to the Meta Pots than themselves, allowing the Meta Pots to change how they were feeling.

- *"When my pot was activated, I could feel my group members looking at me. But then it would go down fast too so I thought maybe I don't have to say it any more."* (P2)
- *"The leaves stood up after I was done with talking, so I thought I'm already done, but then I thought maybe I should talk a little longer."* (P3)

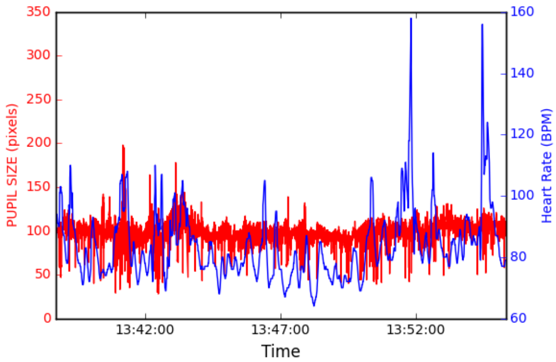
This tendency of giving credit more to the system than themselves was also explained in the user study of MoodLight [49], which used skin conductivity values of users to change the color of lighting of a room. The fact that both projects used biometric data suggests how people seem to understand how their physiological response cannnot be controled actively.

4.3.7 Using Pupil Data

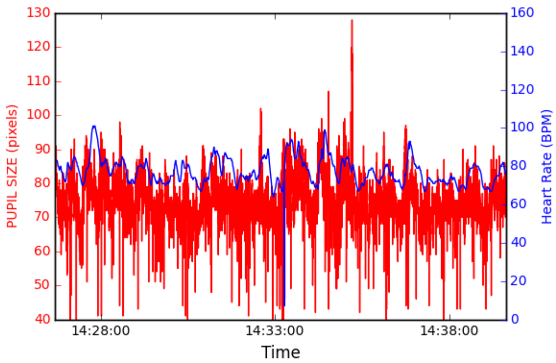
Although only the pulse data was converted into voltage as the input of Meta Pots in proof of concept 1 and 2, using pupil data as additional input should be considered if using pupil data would increase the accuracy of mental effort visualization. Figure4.3.4 shows the pupil size data and heart rate data of P4, P8 and P12 (who were wearing the pupil tracker) during proof of concept 1 plotted on a same timeline.



(a) P4



(b) P8



(c) P12

Figure 4.3.4: Comparison of pupil size and heart rate

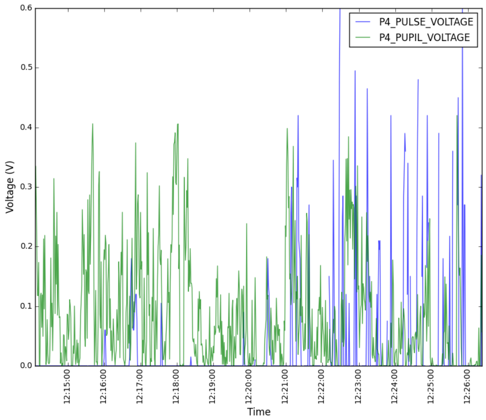
From Kahneman's study [24], it can be said that if participants were increasing their mental effort, the pupil data would peak a few seconds after the increase in heart rate. Based on this theory, we can simulate how different the Meta Pot activations would have been if we had included pupil data as well.

The average standard deviation of pupl size in figure4.2.5 was 16.03, so we will use the same calculation method (equation3.1) we used for heart rate in converting pupil data to voltage for now. Figure4.3.5 shows the comparison of voltage from heart rate data (i.e. the actual input used for Meta Pots in proof of concept 1) and voltage from pupil data.

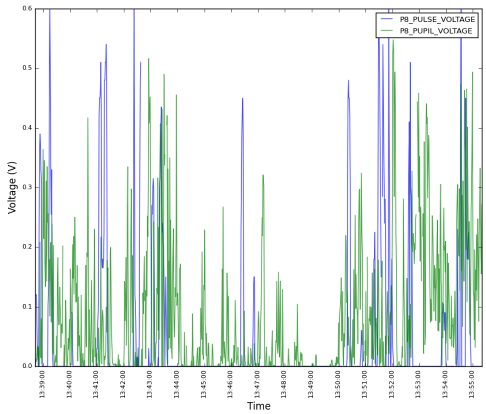
From this we can see that, while some peaks of the two graphs are overlapping, there are some that are not, suggesting that by calculating the average of the two graphs, the irrelevant noise of heart rate and pupil data can be removed. Figure4.3.6 shows such voltage data calculated by averaging the voltage from pupil data and voltage from heart rate, compared with the voltage from heart rate only (i.e. the actual input used for Meta Pots in proof of concept 1).

From figure4.3.6 it can be said that combining heart rate data and pupil data decreases the overall peak voltage applied to the Meta Pots, which in turn means that when Meta Pots are activated it is for a good cause.

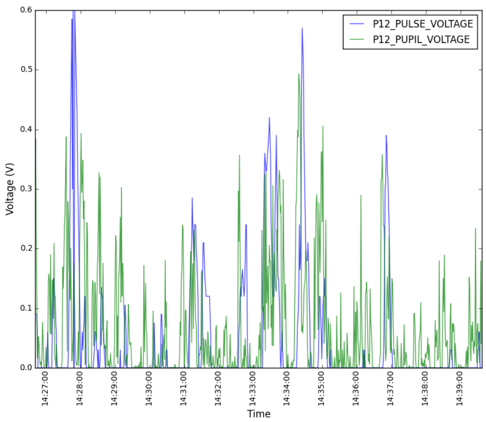
Some problems that must be tackled before including pupil data as Meta Pot input is the measurement unit and latency. Currently the unit for pupil size is in pixels, which means that only the relative increase and decrease matters, and that its absolute value has no value. Although the pupil trackers used do have the function of converting the retrieved data to milimeters, its accuracy must be confirmed. If the pixel units must be used, the conversion to voltage must be done using only the change in values instead of the current method of using minimum and maximum thresholds. As for latency, there is the physiological difference that pupil data peaks several seconds after heart rate, which is something that must also be considered when combining the two data in real time.



(a) P4

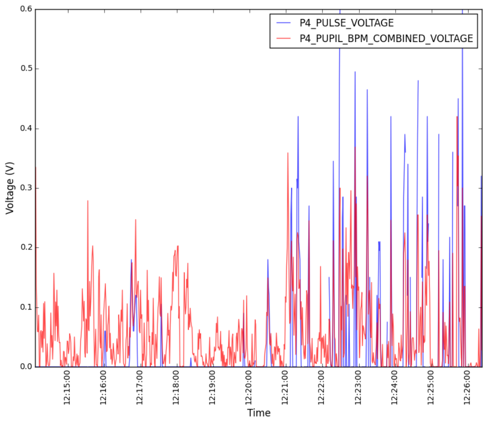


(b) P8

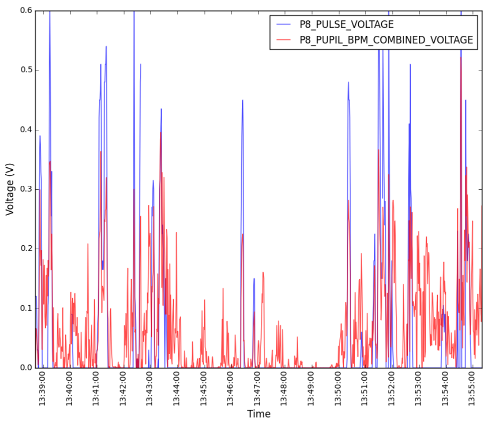


(c) P12

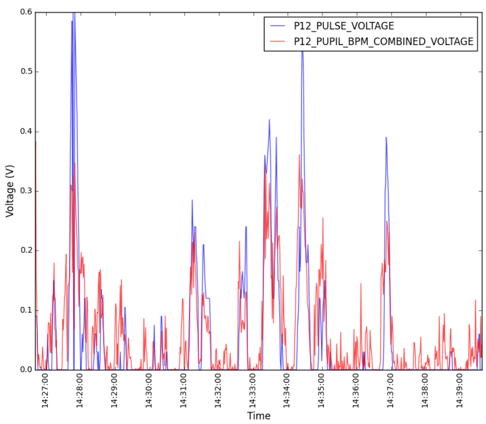
Figure 4.3.5: Comparison of voltage from pupil data and voltage from heart rate data



(a) P4



(b) P8



(c) P12

Figure 4.3.6: Combined voltage from pupil data and heart rate data

Chapter 5
Conclusion

5.1 Findings

This research presented Meta Pot, a plant-like device that collects group work participants' physiological responses and visualizes the mental efforts of group work participants in real time through the movement and color change of leaves. Through user studies in classroom settings, our work was found to create significant behaviour change in group work participants, mainly motivating those who talk more than others to listen and ask opinions of others, while motivating those who talk less than others to speak out what is in their minds and to engage more in the discussion. The Meta Pots also functioned as a common avatar of the group, providing a platform where all members can be equally open to each other by exposing their mental efforts, which is something that is usually concealed within each person, creating a strong basis for team work. Using the collected physiological data, our work also showed potential to be beneficial for teachers or facilitators of the group work, enabling them to examine what stimulated and what bored students.

5.2 Limitation

The results of the user studies showed that visualizing mental effort of group work participants who are talking more than others or less than others created the desired behaviour change and statistical difference in most participants. However, the conversation share was still far from being completely equal. One reason for this was that some participants whose Meta Pots were frequently active were demotivated by the endless shower of eye gaze and questions. Although the decision of increasing the level of intervention by limiting the activation only to those who were talking less than equally was intended to increase the value of the activations, it turned out to have the opposite effect in some cases. Another reason was that participants who talked more than others resulted in talking more when Meta Pots were used, meaning that they were not able to withhold from talking as much as they said they did. In order to maximize the effect of the Meta Pots, it is important to design the system so that all participants can cooperate to keep all leaves green. This means that those whose leaves are green must proceed the discussion in a way so that those whose leaves are yellow can contribute comfortably, and those whose leaves are yellow must accept that fact and contribute more until the leaf is green again. This way, the leaves can stay green for longer, and the team could cooperate to not let the leaves turn yellow. One future idea for such design is to create a flower that would bloom when all members' leaves are green for a consecutive amount of time. This way the participants can cooperate and aim towards the common goal of blooming the flower. The possible downside of this, however, is that it may be over-gamifying group work, losing the initial aim.

In addition, as much as the need to conduct the user test on more people, there is also the need to conduct the test on the same group multiple times to confirm if there are any learning effects. The instructions on how to use Meta Pot were left intentionally vague in the user test to observe how users would interact with it, but it is possible that users will make more use out of Meta Pots after using it several times. From the results of the user study there were cases where the participants' interview answers did not match with the quantitative results. That is, those who mentioned that the Meta Pots did not affect their behaviour much were talking more as a result when the Meta Pots were used. Such skepticism too may be wiped away after repetitive usage.

Another limitation is mobility, for both the Whitebox system and the pulse sensors stops the users from moving about freely in the room. In particular, the pulse sensors physically connect users to the table, possibly making it difficult for them to give their usual performance. Furthermore, the fact that the current system relies on User Datagram Protocol (UDP) for sending data between each device makes it highly difficult to set up the system in places with different network settings. We suggest making the pulse sensor wireless as a start by turning it into an ear cuff style wearable device with Bluetooth connection.

5.3 Future Work

Since heart rate is influenced by elements other than mental effort such as stress or fatigue, and because physiological data tends to be noisy in general, we must consider how we can improve the accuracy of mental effort visualization. The Meta Pot system already extracts pupil size data of the users, so we can begin with how pupil data can be merged with heart rate and be converted to electricity voltage. At the same time, however, we must consider how we can conceal the sensors and cables as much as possible, so that the group work participants will be able to conduct their group work as they would usually do. The design of the pots must also be updated to increase the safety and durability, mainly by concealing the BMFs entirely in a way that would still allow the BMFs to smoothly actuate the leaves. The color of the leaves before and after the actuation can be explored more as well, examining whether different colors can give different effects to the participants. It would also be interesting to explore what kinds of group work Meta Pots are most suited for. For example, brainstorming sessions require participants to be creative. Research shows that for minds to wander freely, heart rate should slow and time between beats should be more variable, which are signs that the default mode network of the brain is being activated [48]. This means that during brainstorming, it is in fact better for Meta Pots to stay green. There might even be cases where concealing mental activity is considered important, in which case Meta Pots should not be used.

If the improvements above are implemented, Meta Pots would be ready to be placed in classrooms for everyday use in schools. Perhaps there can be a Meta Pot table in a classroom which teachers can use as a place for students to go and learn to be more aware of others and to work as a team. Or perhaps there can be a Meta Pot for each student, which students can use not only in group work but also during lectures to simply be aware of their mental state. In this case, Meta Pots can also be used to detect whether students have any thoughts or questions to the lecture, for heart rate tends to shoot up when students have something they wish to say during class. In fact, although the main target of Meta Pots are students engaged in group work, Meta Pots can also be used for anyone working in teams, such as business meetings or family conversations. Regardless of who or where they are used, Meta Pots can be used to increase the individual awareness to team members' states, allowing people to no longer withhold their thoughts due to any reason.

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Appendix

A Source Codes

All source codes for Meta Pot are uploaded on my Git Hub account[1].

B Questionnaires

Notes

1 `https://github.com/daidaidais`

産業高専WS分析アンケート

デザイン思考WSのグループワークの分析結果に対する率直な感想を教えてください。

*Required

1. **分析結果で自分がA-Dのどれに当てはまるかを教えてください。（勝手にアルファベットで呼んでしまい大変申し訳ないです、個人名を出さないためにやむを得ずそうさせてもらいました。）** *

Mark only one oval.

- 生徒A
- 生徒B
- 生徒C
- 生徒D

Figure B.1: Questionnaire for college students in the pre-study, Page 1

2. **以下の質問に対しての5段階の項目の当てはまる箇所にチェックを入れてください。** *

Mark only one oval per row.

	全くそう思わない	そう思わない	どちらとも言えない	そう思う	とても思う
自分の分析結果には納得がいきましたか？					
自分の分析結果に意外だった点はありましたか？					
他のグループメンバーの分析結果には納得がいきましたか？					
他のグループメンバーの分析結果に意外だった点はありましたか？					
この分析結果を受けて、次のワークショップの取り組み方に変化があると思いますか？					
次回以降のワークショップでもこの分析結果が欲しいと思いますか？					
この分析結果を先生が見ることに抵抗はありますか？					
この分析結果が成績に加味されることに抵抗はありますか？					
この分析結果で自分の長所が分かると思いますか？					
この分析結果で自分の短所が分かると思いますか？					
ワークショップ中にデータをとられていたことが作業の妨げることはありましたか？					

3. **この分析結果を受けて次のワークショップやグループワークの取り組み方に「変化がある」と思う場合は、どのような変化があると思うかを記入してください。**

Figure B.2: Questionnaire for college students in the pre-study, Page 2

4. この分析結果を受けて次のワークショップやグループワークの取り組み方に「変化が無い」と思う場合は、何故無いと思うかを記入してください。

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Figure B.3: Questionnaire for college students in the pre-study, Page 3

Meta Pot Questionnaire

*Required

1. 以下の質問に対して7段階の項目うち最も近い番号にチェックを入れてください。 *

Mark only one oval per row.

	強く思わない / Entirely Disagree	思わない / Mostly DIsagree	やや思わない / Somewhat Disagree	どちらとも言えない / Neither Agree Nor Disagree	やや思う / Somewhat Agree	思う / Mostly Agree	とても思う / Entirely Agree
全体的にやりやすいディスカッションだったと感じた	◯	◯	◯	◯	◯	◯	◯
グループとしても生産的なディスカッションを行えた	◯	◯	◯	◯	◯	◯	◯
言いたいと思ったことは躊躇なく言えた	◯	◯	◯	◯	◯	◯	◯
自分の貢献度合いに満足している	◯	◯	◯	◯	◯	◯	◯
チームメンバーの貢献度合いに満足している	◯	◯	◯	◯	◯	◯	◯
チームメンバーと意思疎通を図ることができた	◯	◯	◯	◯	◯	◯	◯

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Figure B.4: Questionnaire for second proof of concept