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Contents

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・Original Article

A paper in this category has to be a logical and empirical report of the study, the review and the proposal by the author on the issue of digital art and design based on media technology. It also has to include the novelty and academic values which can be shared with ADADA members or the people who study digital art and design.
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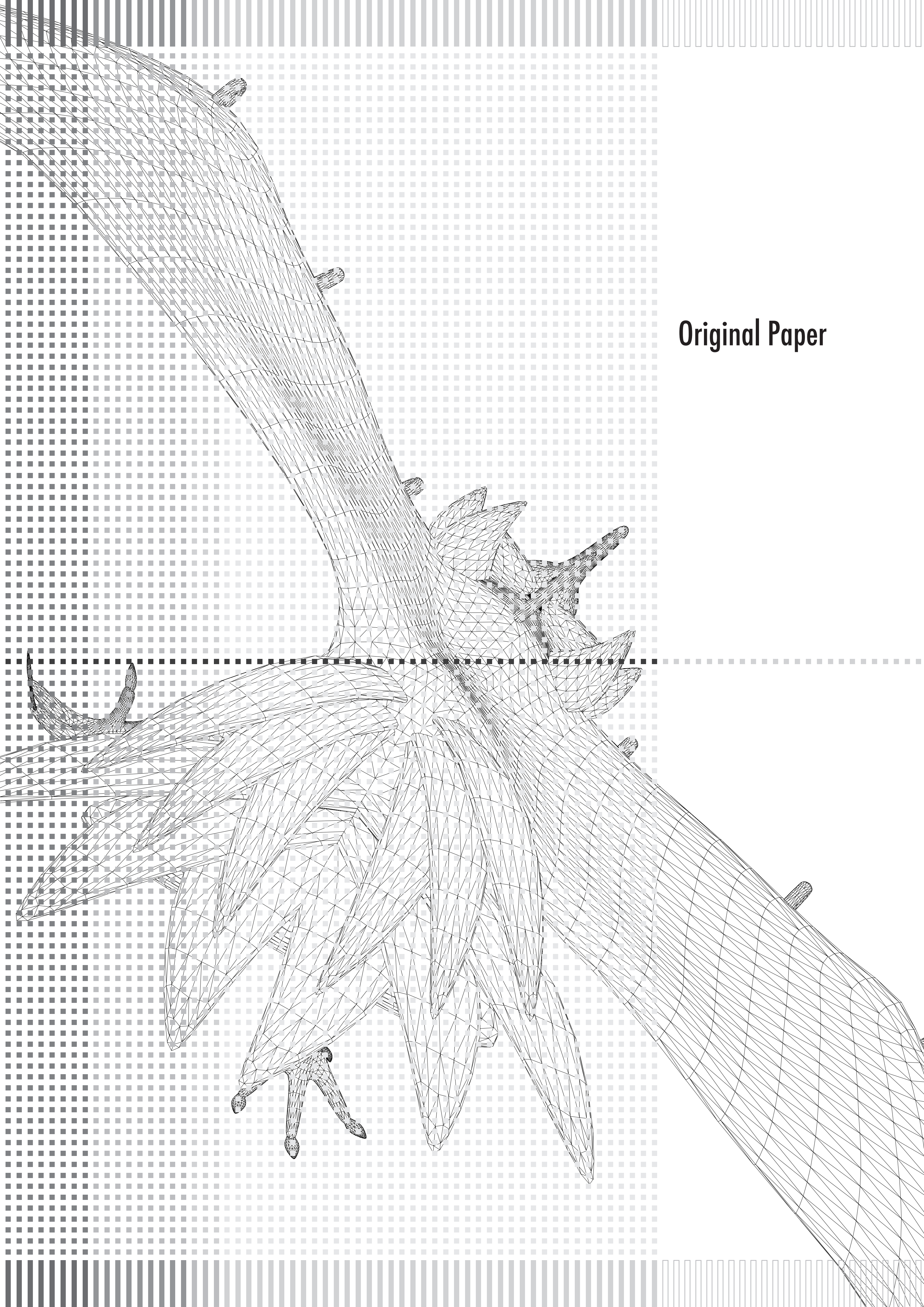
Original Paper



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Braille Pad Project: Proposal of a Braille Education Support System using a Tablet Device

Watanabe Shintaro
Tokyo Metropolitan University
shintaro.watanabe1@gmail.com

Haimes Paul
Tokyo Metropolitan University
haimes@tmu.ac.jp

Baba Tetsuaki
Tokyo Metropolitan University
baba@tmu.ac.jp

Kushiyama Kumiko
Tokyo Metropolitan University
kushi@tmu.ac.jp

Abstract

In this study, as teaching materials of early Braille education for visually-impaired children, we propose a Braille learning support system, which they play touching Braille by using tablet devices. The proposed system provides auditory and tactile feedback in conjunction with finger movement touching Braille, relying on placing conventional Braille teaching materials on the touchscreen surface of a tablet device. In doing so, the system is effective in point of making user to touch and trace Braille actively and accurately, linking own finger movement with sound. Also, we entertain that the system can be used as motivational teaching material in early stage of Braille education. In addition, because that consists of the system is simplified based on product on products for sale generally and widely distributed in Braille education, the system is estimated using widely. In this paper, we describe about the process of development, system, and consideration through exhibition of the system.

Keywords: Braille education, accessible, tablet device

1 Introduction

Visually-impaired children use Braille habitually as a way of learning. Therefore, in education for visually-impaired children, it is important to nourish the ability to read and write Braille effectively. In Braille education, it is hard to learn how to read and write Braille. Hence, it is necessary to use support devices to make learning Braille more efficient. Previously, refreshable Braille displays, which can create tactile outputs by connecting personal computers, Braille keyboards, which can enter text, and Braille typewriters, which can print Braille documents; were all commonly used. In recent years, information technology has made it possible to read and write Braille easily, meaning there is ample research and development [1][2][3][4]. However, these works focus on supporting to distinguish Braille characters on the monitor using vibration or audio feedback, and do not give much thought to experience of touching Braille physically. Especially, in the early stage of Braille education, it is important to touch Braille physically. Through this physical experience, visually-impaired children, who have underdeveloped tactile sense, can become familiar with Braille, improve their awareness of tactile sense, and practice how to touch Braille to read it in an efficient way. For such occasions, we consider teaching materials necessary to make visually-impaired children actively and physically touch Braille.

On the other hand, tablet devices, such as the Apple iPad have become common in recent years. Tablet devices are expected to be widely used for supporting education, for the reason that they have high functionality yet low cost compared with personal computers, and are portable [5]. Tablet devices make it possible to detect several fingers' location and movement simultaneously on a touchscreen within a high degree of accuracy. In addition, these devices provide visual and auditory feedback in response to users' touch actions instantaneously. For these distinctions, tablet devices have the induction of touching action. Thus, we assert applying tablet devices to early Braille education by incorporating the physical experience of touching Braille with touch interaction provided by the tablet's touchscreen.

In this study, we propose a Braille learning system, which provides effective support to visually-impaired children in the early stage of Braille education by using a tablet device and tangible Braille objects [Figure 1]. The system consists of a tablet device affixed to a custom wooden case that allows for sheets of Braille to be placed over the tablet's touchscreen. The movement of the finger tracing the Braille is detected via the touchscreen. The user, while tracing the Braille sheet, receives auditory feedback. The system can make the user touch Braille actively, and use it as motivational teaching material in the early stage of Braille education. In addition, the user links their own finger movements with sound, meaning they can focus on movements, improving sharpness and awareness of their tactile sense. We set out to implement this system in an education setting, and become widely-used in Braille education. For this reason, the constitution of the system is based on products that are widely available. Also, in the process of developing the system, we added audio functionality for teachers in special needs school which correspond to the special needs of those undertaking Braille education. In this paper, we describe related research and our own research agenda. Then we describe the system overview based on survey results and the system detail. Finally, in light of user feedback through exhibitions of the system, we further explain the system.

2 Related research

Braille characters are defined uniquely by a pattern formed in a rectangular space divided into six parts. Each character is distinguished by the presence or absence of dots represented in each divided region. In recent years, there are many works to develop accessible systems, where users can learn to read and write Braille characters by using the concept of Braille and various technologies.

"VBraille" by Jayant et al. [1], is a system where a user can read Braille characters by using a mobile device's touchscreen and vibration. The screen is split into six parts in the style of Braille regions. By controlling the vibration of the device's touchscreen (depending on the area touched), a user can read the Braille characters on the screen. Rantala et al. also developed a system that communicated Braille via a touchscreen with vibration [2]. They adapted the vibration method of the touchscreen to convey Braille characters, which change at regular intervals. For example, the alphabetical character "C" has dots in the first and fourth cells, if it is expressed in Braille. In this system, vibration is provided strongly in the first and fourth cells, and weakly in others, so a user can determine the existence of a dot. Frey et al. developed "BrailleTouch": a mobile-friendly Braille character input method that does not rely on visual feedback [3]. There are six keys on the touchscreen of a mobile device, corresponding to the six dots of Braille. By taking hold of a mobile device, turned around on the screen, a user can place six own long fingers on each keys and enter dot by touching each keys. Also, users can enter several dots in real-time. After entering them, users can get auditory feedback. While these aforementioned examples used ready-made touchscreen devices, Seim et al. used a custom-made device [4]. Their system supports learning to read and write Braille based on "Passive Haptic Learning". This device consists of a vibrating wearable glove device, and a button device, connected to a personal computer. By controlling vibrations based on Braille phrases, users can read and write Braille on the screen.

The systems described above, by controlling vibration and audio, can support learning Braille. However, they generally focus on recognising Braille characters on the screen, and do not consider recognition of physical Braille characters. In the early stage of Braille education, it is important that a child can use tactile sense actively and touch Braille physically. Hence, these systems can not be used as teaching materials for visually-impaired children.

Fig.1 Example of Using System

3 System requirements based on Braille education survey

In our study, we focus on providing auxiliary learning materials concentrated on the physical experience of early stage Braille education for visually-impaired children. It is important that these materials are suitable for special needs in Braille education, and have the potential to be widely used in schools. By canvassing teachers in a special needs school, we defined requirements below that our system needs to fulfill.

1. Encouraging the user to touch Braille actively.

Since the early stage of Braille education is aimed at visually-impaired children who have an underdeveloped tactile sense and have not learned the basics of Braille, it is important to create an independent-minded learning environment by making them to be interested in Braille, and to use the tactile sense of own fingers actively. Furthermore, it is necessary that visually-impaired children can learn independently without a teacher's support.

2. Acquiring basic finger movements for effective touch-reading of Braille.

In the early stage of Braille education, before learning the language system of Braille, it is important that visually-impaired children practice to acquire basic finger movements for effective touch-reading of Braille. This basic movement consists of a fine motion, forward and left-to-right scanning movement, and cooperative movement of hands. For learning these, it is necessary to encouraging users to trace Braille, and improve sharpness and cleverness of their tactile sense.

3. Ease of implementation in schools and ability to be used widely.

Generally, supporting devices for special needs is expensive because they require a long time to develop. Furthermore, they often require special equipment. For this reason, it is hard to introduce such devices in schools or for them to be used widely. Therefore, it is necessary that the constitution of a system is simplified, and is based on products that are widely

available. Also, it needs to promote the use of existing devices already used in schools generally.
Based on these four requirements, here we introduce an overview of our system.

4 System

4-1. System overview

In this study, we propose a tactile Braille learning system for early stage education of visually-impaired people, to provide effective support using a tablet device and tangible Braille objects. The proposed system relies on placing conventional Braille teaching materials on the touchscreen surface of a tablet device. By touching the Braille on the sheet, touch interaction is detected via the touchscreen, making it is possible to obtain feedback through sound. Therefore, the system encourages the user to actively engage with the Braille and undertake self-motivated learning (requirement 1).
In addition, by working with a teacher in a special needs school, we made several Braille patterns, which consist of simple figures based on line shapes, and have start and end points [Figure 2]. The shapes offer finger movement directions: these Braille patterns encourage users to trace Braille. There are also many kinds of shapes, such as lines, curves and angles, which create several kinds of tracing movements. Braille patterns become more complex as page numbers increase. Users can therefore practice in accordance with children's stage of learning and development. Additionally, aural feedback is provided as finger positions and movements change, so users can correlate finger movements with sound and condition their fingers appropriately. For this reason, users can trace Braille finely without moving away from it. By detecting via a multi-touch screen, users can use multiple fingers. For these reasons, the system encourages users to improve the sharpness and cleverness of their tactile sense, and acquire basic movement of fingers for effective touch-reading of Braille (requirement 2).
Braille sheets, which are used in our system, are commonly used in Braille education. Teachers can create and edit Braille sheets using authoring software or a Braille printer, which are used in schools generally. If the sheets become dirty or dots become flat from repeated use, teachers can simply print new Braille sheets. Desideratum the system needs else is only tablet devices and case. For these reasons, the system can be used widely in schools (requirement 3).

4-2. System configuration

The system consists of an Apple "iPad Air 2" affixed to a custom wooden case that allows for sheets of Braille to be placed over the iPad's screen [Figure 3]. These Braille sheets come in three thicknesses: 90g, 110g and 135g: for the purpose of touch accuracy, we are using 90g. These sheets are a standard size of 258mm by 196.5mm, and have binding holes on both sides. On the other hand, the "iPad Air 2" is 240mm by 191mm. Braille sheets are placed over the iPad, and the binding holes of sheets are laterally placed on the iPad. We use these holes to affix the case. Thus, the Braille sheets are fixed firmly on the iPad's touchscreen, and the makes possible that detecting finger positions or movements on Braille sheets via the touchscreen. Also, the user can set this interactional sequence without visuals, because the binding holes of the sheets and the case's pegs are tangible.

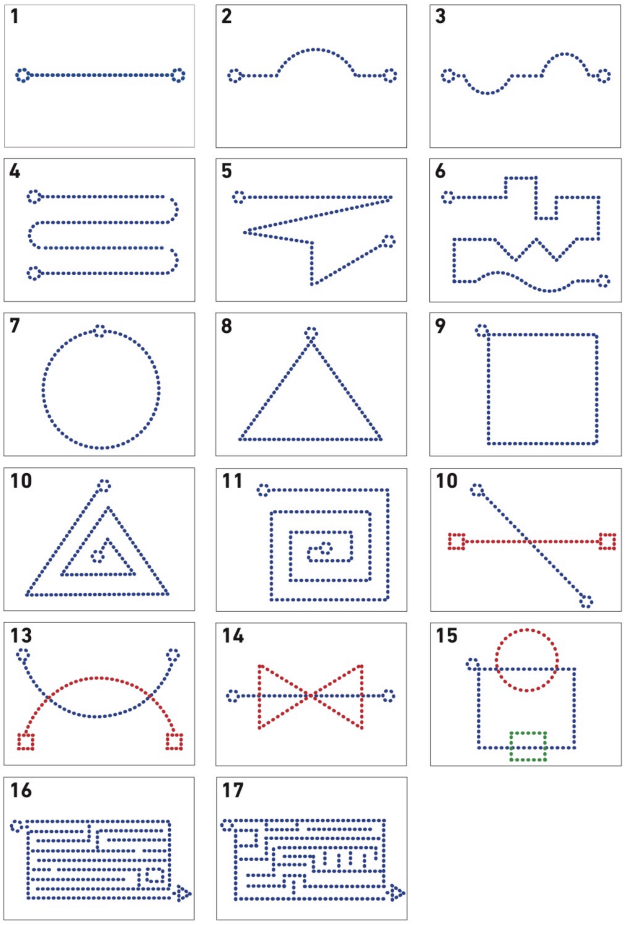

Figure 2: Graphics of Dot Pattern

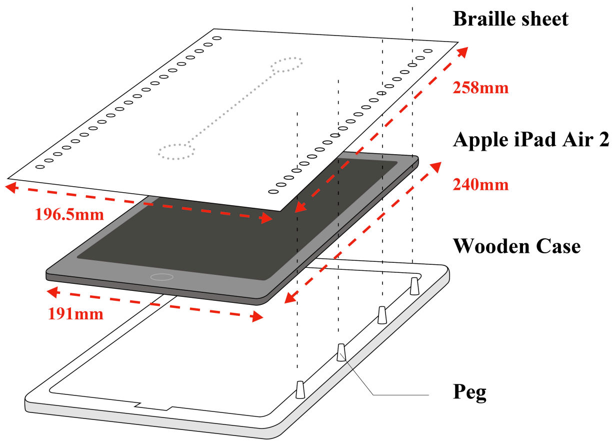

Figure 3: System configuration

Case has a figure that will accommodate the iPad, including its speaker. Thus, the sounds described in the previous section are outputted through the iPad's speaker, which then vibrates the case. To test which material propagated vibrations strongly, we made cases with plastic, acrylic and wood. Consequently, we selected a wooden case, which propagates vibration strongest [Figure 4].

4-3. Application

The application runs on a conventional iPad. The application was developed in JavaScript, using jQuery and P5.js JavaScript libraries. The application is divisible into two modes according to execution through a program.

4-3-1. Lock-mode (Initial state)

This mode is the initial state when the application runs. Generally, visually-impaired need to grasp the overall structure and layout of Braille spatially, before they read its details. If auditory feedback is provided while they do so, it can be confusing. Hence, in the initial state of application, if a user touches the Braille, no feedback is provided.

4-3-2. Trace-mode

The mode makes a transition from lock-mode to trace mode if the user taps the start button. In this mode, a user can get auditory feedback along with finger movements. If a user changes a page, the mode changes to lock-mode.

4-4. Framework of application

The application consists of four parts, 1) Collision detection, 2) Page switching control, 3) Setting of touch determination, 4) Auditory feedback control.

4-4-1. Collision detection

The application needs to load two lots of graphic data in advance with each page. One is the graphics, which matches the Braille pattern [Figure 5]. It is displayed for sighted-people. The other shows collision detection between finger and Braille [Figure 6], which is not displayed. Each area of the graphics is color-coded according to its subject. The application recognises each functional area, start button, end button, page switching button, area of touching detection. From these colors, the application can then execute collision detection. Here we introduce each function and color data.

1. Start button: Red (255, 0, 0)
2. End button: Blue (0,0,255)
3. Page switching button: white (255, 255, 255)
4. Area of touching detection: Green (0, 255, 0)
5. Area not applicable: Black (0, 0, 0)

The area of touching detection establishes how strictly to judge the accuracy of tracing movements. To ascertain the area of touching detection, which is suitable for learning, we experimented with two teachers (one is sighted, one is visually-impaired) and one visually-impaired student. As a result, if the area is narrow, it is too difficult for users to trace. Conversely, if the area is too wide, it is determined that the user has traced the object successfully even if they have not traced it correctly. We increased the area in steps of 5 pixels. Through feedback from the three aforementioned people, we found that 25 pixels is the optimal area for learning.

Figure 4: Wooden Case

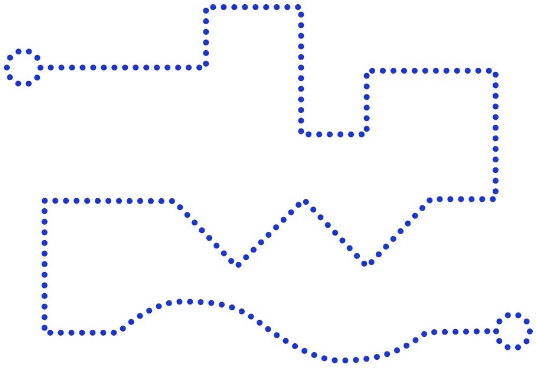

Figure 5: Example of Dot Pattern Graphics

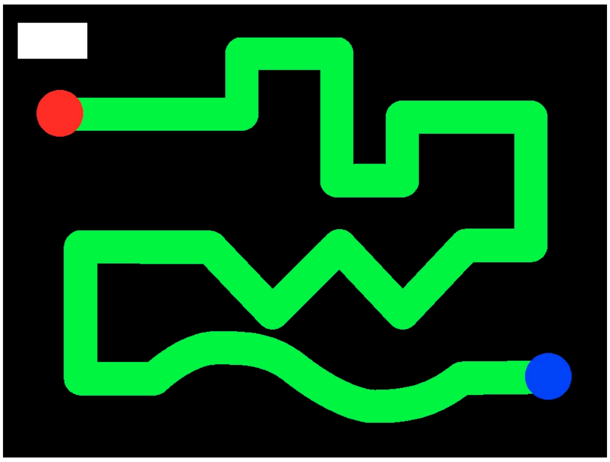

Figure 6: Example of Collision Detection Graphics

4-4-2. Page Switching Control
Each dot pattern and Braille sheet is numbered [Figure 2]. When the application runs, the first page is displayed. If a user taps the page switching button once (white [Figure 6]), the next page is displayed. Pressing the page switching button on the final page returns users to the first page.

4-4-3. Setting of touch determination
In this application, touched Braille are recognised by detecting when a finger touches the iPad's screen. In Braille education, for effective touch-reading of Braille, bimanually touch-reading is recommended. In bimanually touch-reading, one finger is primarily used, with the second finger and fourth finger also used. However, when it shifts emphasis from the first finger to others, fingers are often disengaged from Braille. Therefore, even if a finger is disengaged, it is necessary to detect other fingers touching Braille at one time. While the program is running, the application observes this alteration constantly (up to ten fingers), by using multi-touch technology. Thus, it detects touching data for all fingers, and program is implemented in line with the collision detection graphics displayed at that time. For this reason, aural feedback is provided as an auxiliary function to finger touching.

4-4-4. Auditory feedback
While a user's finger is touching any Braille on the sheet, continuous electronic aural feedback is provided. In this application version, the change rate of the pitch depends on the rate of tracing. For this, when the Braille object is being traced, a transmutative pitch will sound. The range of this pitch is 55.00Hz –3520.00Hz (six octaves), which is within the range of human hearing. It makes users become more aware of changes in their finger movements. Towards the upper-right corner of the screen, the pitch becomes increasingly higher, while in the lower-left, it becomes increasingly lower. This variation in tone is in a seamless manner, as opposed to twelve distinct tones. Users can feel the pitch shifting more clearly, which sharpens their focus on tracing. Users can correlate finger movement with sound, and adjust their own finger appropriately. Thus, it improves the sharpness and cleverness of a user's tactile sense. This sound feedback is ongoing while any finger is touching Braille, from the start button point to the end point. If the user keeps their finger on the screen and successfully traces the object in the correct sequence, a sound will inform them once the end of the object is reached. Hence, a user can trace Braille finely without moving away from Braille, in the lead up to end point from the start button.

5 User feedback
To examine the effects that the system had on users, we collected user feedback and observed people using the system. The current system was presented at the exhibition "Digital Contents EXPO 2015", at the Japan National Museum of Emerging Science and Innovation in October 2015. It was also presented at the "20th General Japan Information Processing Society of Japan –Interaction 2016" exhibition at the Japan Science Museum in March 2016. Initial user testing was undertaken in the form of experiments and interviews with more than one hundred people in each exhibition. The subjects were fully-sighted adults who conducted the testing while their vision was blocked.
Some comments from these subjects included: "tracing is a simple way of facilitating the recognition of Braille" and, by obtaining feedback via sound and vibration it "can be expected to improve the autonomy of Braille learning". We also often observed several users playing, where they repeatedly practiced tracing the Braille until completion – even when their finger moved away from Braille. We observed that most users explored the system independently without specific instructions.

6 Discussion, future work
Through observations and user feedback, we determined that the proposed system allowed users to enjoy touching Braille, by encouraging them to actively trace Braille using their own tactile sense. In addition, we find that the system provides fully-sighted a good opportunity to become interested in Braille. Hence, our system is predictably effective for fully-sighted people to come closer towards knowing and understanding the experience of being visually-impaired. In future work we will undertake a quantitative study with visually-impaired children. About improved performance, we would like to explore how to adjust the page displayed on the screen automatically, when users fix a Braille sheets on the tablet surface. Additionally, it is necessary to examine how electronic sounds as a feedback mechanism can be designed adequately for visually-impaired children and Braille education.

7 Conclusion
In this study, by providing effective support to early-stage Braille learning, we proposed a system that places emphasis on the experience of touching and using Braille, by combining a touchscreen tablet device with conventional teaching materials. We implemented the functionality of providing tactile and auditory feedback, triggered by touching Braille. Early testing of the system with fully-sighted subjects suggested that the system is effective at allowing the user to touch and trace Braille effectively. In the future, we plan to undertake multiple rounds of testing with visually-impaired subjects to analyse the usefulness of the system proposed here. Additionally, we will test variations of our tactile and auditory feedback in order to strengthen the cognitive links between the Braille sheet and the application. In doing so we will further examine the possibilities of utilising touchscreen tablet devices in the education of those with visual impairment.

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IndexAccess : A GUI Movement System by Back-of-Device Interaction for One-Handed Operation on a Large Screen Smartphone

Hidaka Shiori
Tokyo Metropolitan University
hidaka-shiori@ed.tmu.ac.jp

Baba Tetsuaki
Tokyo Metropolitan University
baba@tmu.ac.jp

Haimes Paul
Tokyo Metropolitan University
haimes@tmu.ac.jp

Abstract

The use of large screen smartphones has been increasing yearly. Large screens have many advantages in that they can display a lot of information at once. However, when people operate smartphones with one hand, several usability problems can occur due to the posture of the user's hand when holding the device. Among those problems, a significant one we have noticed was that it is difficult to reach the top of the screen with the thumb. In this paper, we propose "IndexAccess": a system to assist the one-handed operation of comparatively large smartphones by pulling down the GUI on the screen by back-of-device operation using one's finger (excluding the thumb). In this study, we implemented the IndexAccess system with an application for iOS and a sensor module. After this, we conducted an experiment to investigate the performance and effectiveness of this system on usability by comparing it with Apple's Reachability in an experiment. Consequently, IndexAccess enables the participants to point more rapidly in the upper half area of screen than Reachability. On the other hand, the participants touched slower in the lower half of the screen than Reachability. It is thought that one of the reasons for this is the prototype was detecting the position of the index finger and moving the display at all times. Consequently, we will improve the usability of IndexAccess by using a pressure-sensitive touch panel instead of a photo-reflective sensor. We will also attempt to move the display not only vertically but horizontally.

Keywords: user-interface, smartphone, back-of-device

1 Introduction

The size of smartphone screens has been increasing since smartphones were first introduced. Specifically, while screen sizes were previously less than 3.5 inches (71.1mm × 53.3mm) as of 2010, they are often now more than 5 inches (101.6mm×76.2mm) as of 2015. Large screens have some advantages – on legibility for instance, by displaying characters and images larger; and by allowing users who have comparatively large fingers to point and tap the GUI easily. Whereas in terms of usability for users having relatively small hands (hereafter referred to as small-hand users), a large screen has the disadvantage that when they hold and operate smartphone with one hand, the area their thumb can reach is limited (Figure 1). It is possible that to touch the upper part or the edge of the left and right of a large screen with the thumb, though it requires the user to stretch their hand or to shift the position in which they are holding the device. Because of the risk of dropping a device like this, users change between one-handed operation and two-handed operation frequently depending on the purpose. For instance, we usually scroll on the screen in one hand and use the other hand to touch the search window or the back button in the top of screen. A two-handed operation referred to here is considered in on of the following two ways: (1) holding a device in one hand, and operate with the other hand, and; (2) holding a device in two hands from both sides, and operating with both thumbs.

There is ample research and several examples that assist one-handed operation of a large screen smartphone using the front touchscreen [1][7]. In these ways, a thumb is the only digit used in almost all operation. Based on this, we assume that using the fingers other than the thumb in the area except the front touchscreen is an effective way to improve one-handed operation. This is, as it were, role-sharing of the fingers.

In this paper, we introduce IndexAccess, a back-of-device (BoD) interaction system that enables users to reach and tap the whole of the screen easily, enhancing usability of a large

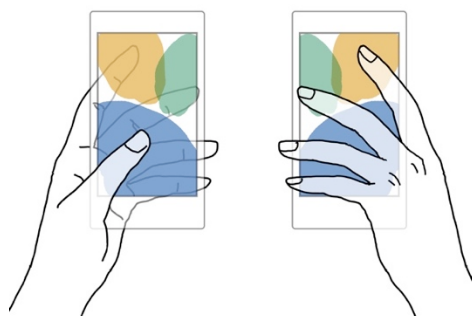


Figure 1: The possible area for each finger (thumb: blue; index finger: yellow, middle finger: green) to touch on the 5 inch smartphone.

smartphone during one-handed operation.

2 Related works

There is a lot of previous research on BoD interaction and they discuss a wide range of purposes.

Firstly, before smartphones first appeared, there are some studies that focused on the characteristic of feature phones and PDAs (Personal digital assistant) having keys and buttons on the front side of the device. Hiraoka et al. (2003) [4] put 12 keys on the back of a device to reduce the buttons on the front side and to make the screen larger. Okada et al. (2009) [5] allowed users to do pointing operations on a feature phone.

Secondly, some studies focused on the problem of occlusion when users touch the screen. Wigdor et al. (2007) [2] suggested LucidTouch, which provides feedback as if a finger on the back of the device can be seen through the device. Baudisch et al. (2009) [3] focused on the devices have a small screen device that is keenly influenced by the occlusion of the finger like a wearable device.

Thirdly, some studies focused on problems due to large screen devices. MagStick, by Roudaut et al. (2008) [6], is a cursor which moves in a direction that is opposite to the direction the thumb moved and is attached to a target. This allowed users to point at a target but not to select it. Conversely, TouchOver asserted by Onishi et al. (2014) [1], sends operations done in the lower area of the screen to the upper area to operate the lower area indirectly. This allowed not only pointing in the GUI but also tapping or selecting. In addition, there are studies that describe allowing easy one-handed operation by way of operating on screen directly. Karlson et al. (2008) [7] presented ThumbSpace, which reduced the size of GUI and display in the lower area of the screen. Tosa et al. (2013) [8] proposed LoopTouch, a device that has a touch sensor on the front and back of the device to operate GUI components that a user's thumb cannot reach. Hakoda et al. (2015) [9] presented a tactile interface system using a hole on the back of device. Finally, as an important advanced example, there is Apple's Reachability which is provided in iPhones from model 6 running iOS8 or above. When users tap the home button twice, the GUI moves downward a certain fixed length.

These studies address the problem of the unreachable area by moving the GUI and operating in the area that is reachable by the thumb. However, some of the moving GUI operations are done with the thumb. It increases the operation route of the thumb, which can lead to fatigue. Additionally, some of them fix the distance that users can move. There is a possibility that the fixed distance can not accommodate various hand sizes. However, in this present study, we suggest a more intuitive operation of movement.

3 IndexAccess

IndexAccess is an interactive system that assists to manipulate the GUI in the area where the thumb can not reach easily. There are two main features of this system.

Move GUIs downwards flexibly

As a solution to the unreachable area problem, we used a method that moves the GUI in the thumb's unreachable area downward and enables the user to touch them within the reachable area. In this way, users can tap the GUI as they see it. Moreover, in order to manage various hand sizes, we aimed that the users can move the GUI as far as they need flexibly.

Back-of Device interaction with index finger

As a way of implementing flexible moving, we adopted a BoD interaction with the index finger. In a related work [9], the index finger was used for simple detection of whether a hole in the back of device is covered or not. In this system, we detect the vertical distance that the index finger has moved with some sensors and link it with the distance that the GUI is moving. This way allows users to operate intuitively as if they touch the screen from the back of device and pull down the screen directly.

In other related works, the thumb does all operation of moving the GUI as well as regular input (e.g., tapping a button), the thumb's tasks are increasing. Therefore, such a role-sharing of operation between all of the fingers can reduce reliance on thumb movement, therefore reducing fatigue.

4 Prototype system

Figure 3 shows the system flow of IndexAccess. We implemented this prototype, which consists of a sensor module and a smartphone running our application. We used an iPhone 6 (dimension of device: 138.14mm x 66.97mm x 6.85mm, dimension of screen: 4.7inch (104.05mm x 58.5mm), resolution: 750 x 1334) as an example regarded as a large smartphone which can be difficult to use in one hand for the small-handed user.

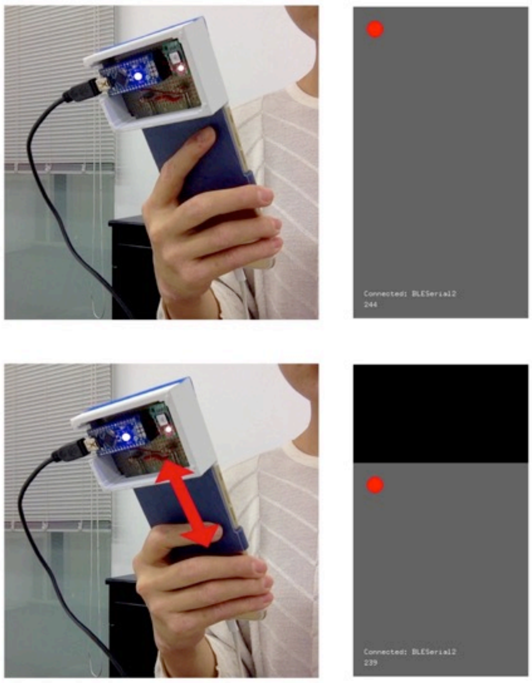


Figure 2: Moving of index finger on back of the device (left) and the GUI on the front screen (right).

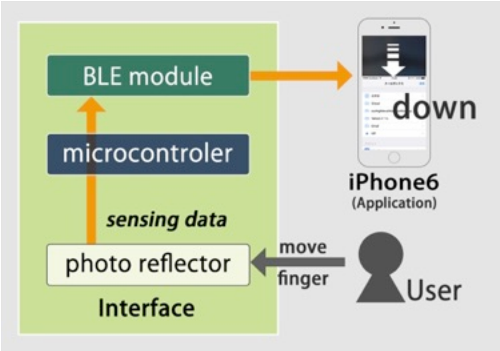


Figure 3: The system flow of IndexAccess.

4.1 Sensor module and Mounting tool

Figure 4 shows the circuit diagram of the sensor module. This module is consisted of a photo-reflective sensor (ROHM Corp.'s RPR-220) and a Bluetooth Low Energy (BLE) module (ASAKUSAGIKEN Corp.'s BLESerial2) and built on a universal circuit board (72mm x 47mm). We used the photo-reflective sensor to detect the position of the index finger on the back of the device because it was easy to implement. The data from the sensor was sent via the microcomputer to the iPhone 6 using BLE.

As shown in Figure 2, we attached this module to the back of the iPhone 6 with an original mounting tool that we modeled with 3D CAD software (Rhinoceros for Mac) and printed with a 3D Printer (Figure 6). Due to the characteristics of a photo-reflective sensor, the data we captured is not from measuring the distance of index finger movements but an absolute distance from the sensor to the index finger. Therefore, we designed this tool so as to make it possible to slide vertically and adjust the position of the sensor for each user. Additionally, we prepared two modules varying the position of the photo-reflective sensor. One (shown in Figure 5) has two photo-reflective sensors in a position closer to left and right, another has one sensor in the center of the width of the smartphone.

4.2 Application

We aimed to create an intuitive interaction where users feel as if they are touching the GUI directly and dragging it physically from the back of device. In this study, we demonstrated this BoD interaction with simple graphical feedback on the front screen as shown in the right side of Figure 7. We drew a rectangle the same size as the screen as a hypothetical GUI. We set coordinates (0,0) at the left upper corner and coordinates (320, 568) at the right lower corner on the iPhone 6's screen. This rectangle's Y-coordinate changes within the range of $0 \leq y \leq 370$ according to the data received from microcomputer. Thus, this interface moves downward from the start position but does not move upward. Additionally, this prototype system does not have the function of switching between ON and OFF, therefore the interface follows movement of the index finger on the back of device at all times.

5 Performance evaluation experiment

We conducted an experiment to investigate the operational performance of IndexAccess. This experiment consisted of performance check tests and a questionnaire about using a smartphone on a daily basis. In the tests, we asked participants to do a simple pointing task and recorded the time taken and accuracy rate. In addition, to compare the performance of IndexAccess and Apple's Reachability, we asked participants to do the same content and the same amount of tasks using both of the two systems.

5.1 Participants

Nine participants (five males and four females, aged 22-35) took part in this experiment. All participants use a smartphone everyday. Seven of the nine users were right-handed, the others were left-handed. The period they had used a smartphone varied from 21 to 84 months and the average was 46.4 months.

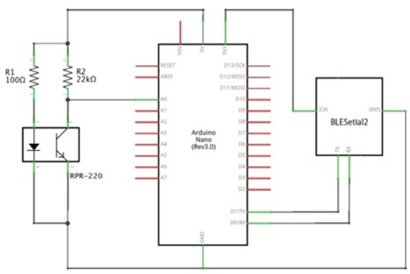


Figure 4: The sensor circuit diagram of the sensor module.

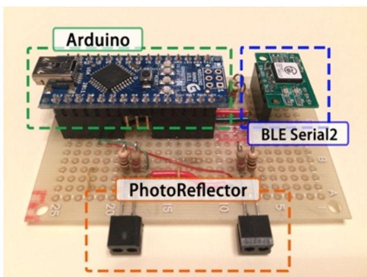


Figure 5: Sensor module built on the universal circuit board.

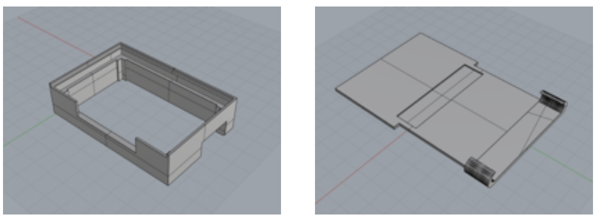
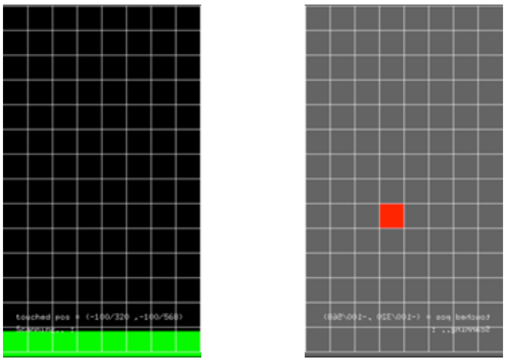


Figure 6: Jig modeled with 3D CAD

5.2 Apparatus

We used an iPhone 6 (dimension of device: 138.14mm x 66.97mm x 6.85mm, dimension of screen: 4.7inch (104.05mm x 58.5mm), resolution: 750 x 1334). We prepared an application for iOS specifically for this experiment and installed it on the iPhone 6. Figure 7 shows the GUI displayed on the front screen while participants did the tasks. The screen is divided into 112 cells consisting of 8 by 14 squares having one side of 7.3mm so that the screen is fully filled. This square is larger than that having one side of 7mm that is the size unaffected on accuracy by the size of tip of their thumb [10]. As shown in Figure 7, a large green rectangle button on the bottom of the screen is a start task button and a small red square is a target button.
In this experiment, we set the following two phases as one task, and 112 (cells) tasks as one session.



Inactive Phase Pointing Phase

Figure 7: GUI of the application for the experiment Inactive phase (left), Pointing phase (right).

Inactive phase (first time): In this phase, a start button appears on the bottom of the screen. When participants tap the button, the interface is switched to the pointing phase.
Pointing phase: In this phase, a target button appears. Participants tap the target button and the interface proceeds to the next task. The time from when the pointing phase GUI appeared to when the target button touched was recorded. We also recorded whether the user tapped the correct area or not. No matter whether they touched the correct area of the target or not, the phase went to the next stage.
Inactive phase (from the second time): After a 0.8 second delay, the start button appears again.

The target button appeared at a random cell for each task. In the experiment using IndexAccess, as mentioned previously, the interface follows the movement of the index finger at all times. Therefore, when participants touch the bottom of the interface, they should use their index finger to display the whole interface on screen. We set the start button on the bottom of the screen because we want participants to put the interface back into its original place so as to show the whole of the interface before the target button appears.

5.3 Procedure

User instructions

At first, we asked participants to sit down and hold the device in one hand as they would hold their own smartphone. In order to investigate realistic performance of the IndexAccess and Reachability, we instructed all of them to use the same holding position and integrate it the way they would normally hold such a device. In addition, we asked them not to shift the position if possible and rely on the function of IndexAccess and Reachability to do the tasks. Under these conditions, in cases where the area in which the target button appears is unreachable for their thumb (in spite of using IndexAccess or Reachability), we asked them to tap the point nearest to the target. We told them that we recorded the time from the start button touched to the target button touched and the correct-error of each pointing action. Accordingly, we told that they should not put an emphasis on performing quickly but with accuracy.

Experiment

Before beginning the main experiment, we created a practice session so as to allow the participants to get used to one-handed operation using IndexAccess and Reachability. In IndexAccess, during the practice session, they could move the module sensor vertically and decide the best position. After fixing that firmly, they started the main experiment.
In the main experiment, first they used IndexAccess and did the five sessions, and next they used Reachability and did the same number of sessions. The total number of tasks we required of them was 1120 (112 cells x 5 sessions x 2 systems). The time that this experiment took was 55-75 minutes for each participant.

5.4 Result

Some of the participants used their left hand to do the tasks. Therefore, we flipped the data of the participants horizontally.

Figure 8 shows the average pointing time and error rate with the depth of a color per cell on the screen. In the figure of the pointing time, the average pointing time is longer, the darker the color. We numbered each cells filled on the screen as in the left of Figure 8. In the figure of the error rate, the rate is higher for the darker the color it is. The average pointing time for all cells on the whole screen (cell IDs 1-112) using IndexAccess is 1188.28 milliseconds (SD = 259.83), and that using Reachability is 1114.41 milliseconds (SD = 167.07). Similarly, in the upper half part of the screen (cell IDs 1-56), the average pointing time using IndexAccess is 1408.67 milliseconds (SD = 320.00) and for using Reachability is 1529.13 milliseconds (SD = 235.71). In the lower half part (cell IDs 56-112), using IndexAccess is 975.62 milliseconds (SD = 282.43) and using Reachability is 714.25 milliseconds (SD = 114.60) (Figure 9).

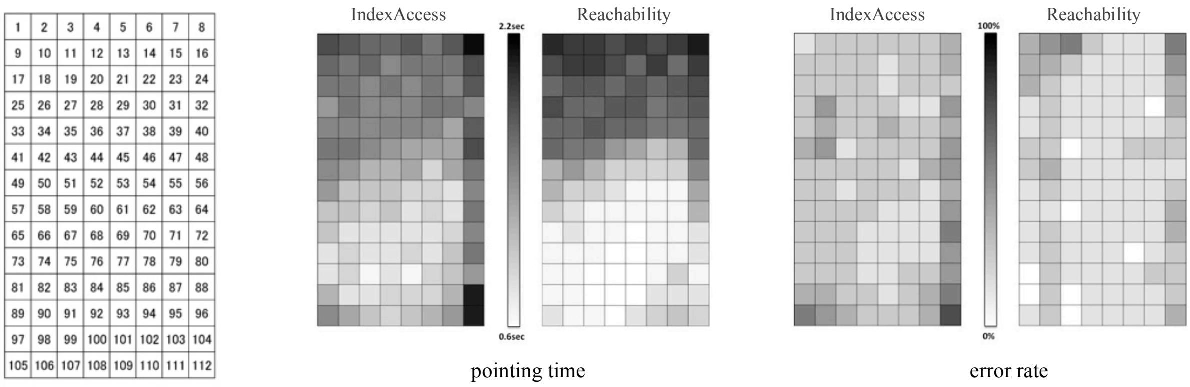


Figure 8: The ID of cells filled on the screen (left) and
the result of the experiment: the data of each cells with depth of the color (center and right).

Figures 10 and 11 show the result of nine participants in each session using IndexAccess and Reachability. These graphs show the change of the average pointing time and error rate of each participant over the five sessions. The average pointing time means that the average time taken to tap the target button in each task. Through the five sessions, five participants had come to point at the target faster and more accurately. However, the other four were faster but increased the number of errors or were more accurate but slower. In the first session, the average of all participants was 1.3 seconds (SD = 2.5) and the error rate was 17.9 percent (SD = 12.0), and in the fifth session, the average time was 1.1 (SD = 1.8) second and error rate was 16.7 percent (SD = 12.7). Thus, the decrease of pointing time and error rate was 16 percent and 6.7 percent respectively.

We compared the 45 sessions (9 participants x 5 sessions) data in these two situations using IndexAccess and Reachability in following three areas: the whole area of screen, the upper half area, the lower half area. We used the paired t-test in the whole area, and Wilcoxon rank sum test in the upper and lower half area. From the calculation comparing the average pointing time on each cell on whole of the screen, there is no significant difference between them ($t(45) = -1.911$, $p = .062 > .05$). Similarly, the calculation of Wilcoxon rank sum test comparing that on the upper half part of screen shows that the average pointing time using IndexAccess is larger than that using Reachability significantly ($W = 689$, $p = 0.008695 < .01$); and on the upper half of the screen, that using IndexAccess is smaller than that using Reachability significantly ($W = 1634$, $p = 1.658e\text{-}07 < .01$).

5.5 Discussion

According to Figure 10, in the first session, the data of a participant who took the longest time to point was approximately twice that of another participant who took the shortest amount of time to point. One reason for such a difference is that the participants had various hand-sizes and some of them did not match with our prototype because of the position of the photo reflective sensor which was fixed position on the sensor module.

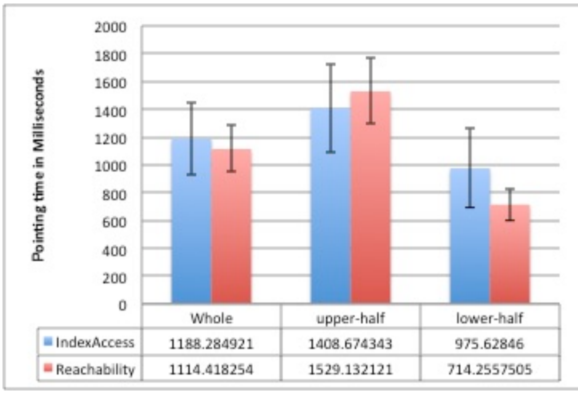


Figure 9: Average of the pointing time over the two systems and the three areas.

From the result comparing IndexAccess and Reachability in the upper area and the lower area, IndexAccess is demonstrated to be more effective in the upper half area of the screen than Reachability. However, in the lower area, Reachability is estimated to be more effective. One reason for this result is that the posture of their hand while they touch the target appearing in lower area was difficult. As mentioned in the experiment category, our prototype did not have the function switching this interaction between ON and OFF. Therefore when they touched the target appearing nearby the lower edge, they should move their index finger up on the back of device to pull up the GUI.

In Figure 8, a rightmost line of both the pointing time and the error rate has particularly dark color on either case using either IndexAccess or Reachability. From this, it can be determined that this was the hardest area for the participants to operate speedily and accurately. We suggest that not only vertical movement of the GUI but also horizontal movement of the GUI is an effective way of addressing this.

6 Conclusion and future work

In this study, we proposed and implemented the IndexAccess system. It is based on the hypothesis that the problem of unreachable areas in one-handed operation of smartphones is

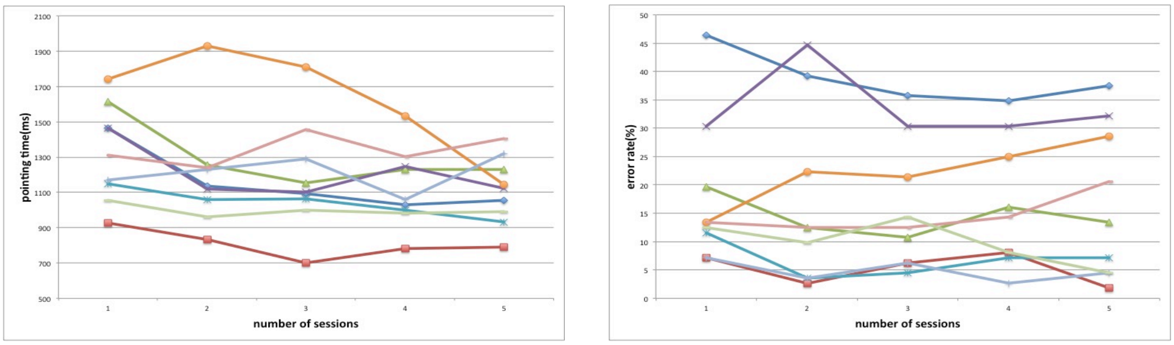


Figure 10: Nine participants' result in whole area of the screen (cell IDs 1-112)
The changes of the pointing time and error rate over the five sessions using IndexAccess.

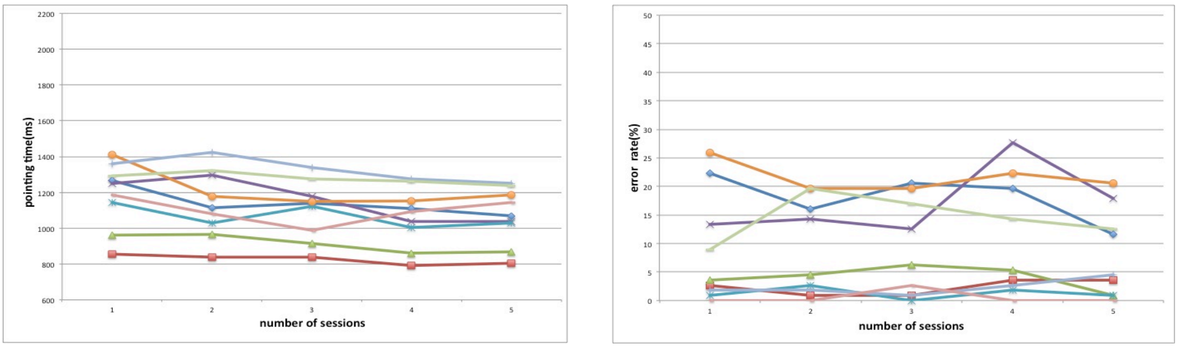


Figure11: Nine participants' result in whole area of the screen (cell IDs 1-112)
The changes of the pointing time and error rate over the five sessions using Apple's Reachability.

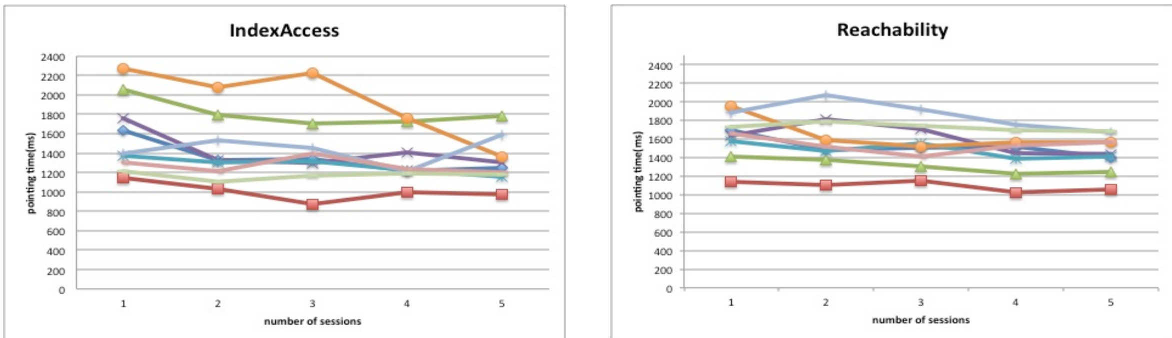


Figure 12: The result in upper half area (cell IDs 1-55)
The changes of the pointing time over the five sessions using IndexAccess and Reachability.

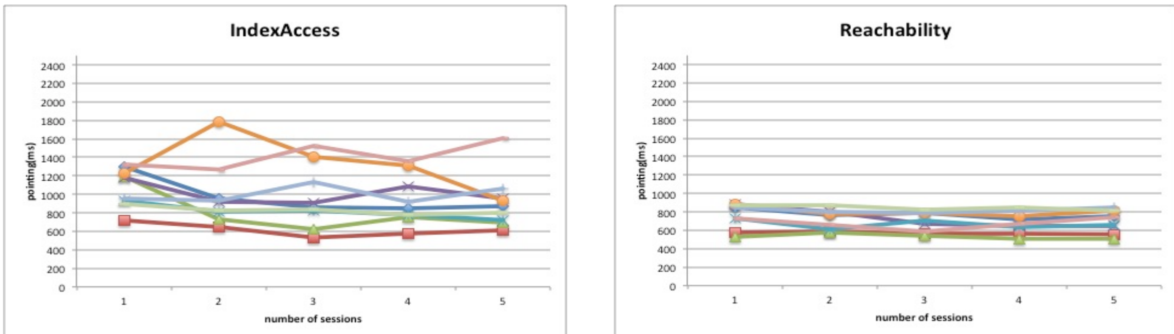


Figure 13: The result in lower half area (cell IDs 56-112)
The changes of the pointing time over the five sessions using IndexAccess and Reachability.

solved by using the fingers (excluding the thumb) on the back of the device and to move the GUI vertically on the screen by the BoD interaction.

We conducted an experiment to investigate the effectiveness of this system by comparing it with Apple's Reachability, which, like our system, moves the GUI vertically. From the results described above, we can assert two main points about this prototype.

The first point is that in the upper half area on the screen, there is a possibility that IndexAccess allows users to reach more rapidly with their thumb than Reachability. However, in the lower half part of screen, we left some problems with this prototype. Secondly, the area unreachable with the thumb is not only the area near by the top of the screen but also the right and left edge of the screen. Additionally, the result in the questionnaire we carried out at the same time as the experiment, all the participants answered the function moving the GUI horizontally may effective.

As immediate future work, we will implement another prototype using a touch panel in order to control the moving and stopping more easily, and will also add a function to move the GUI horizontally.

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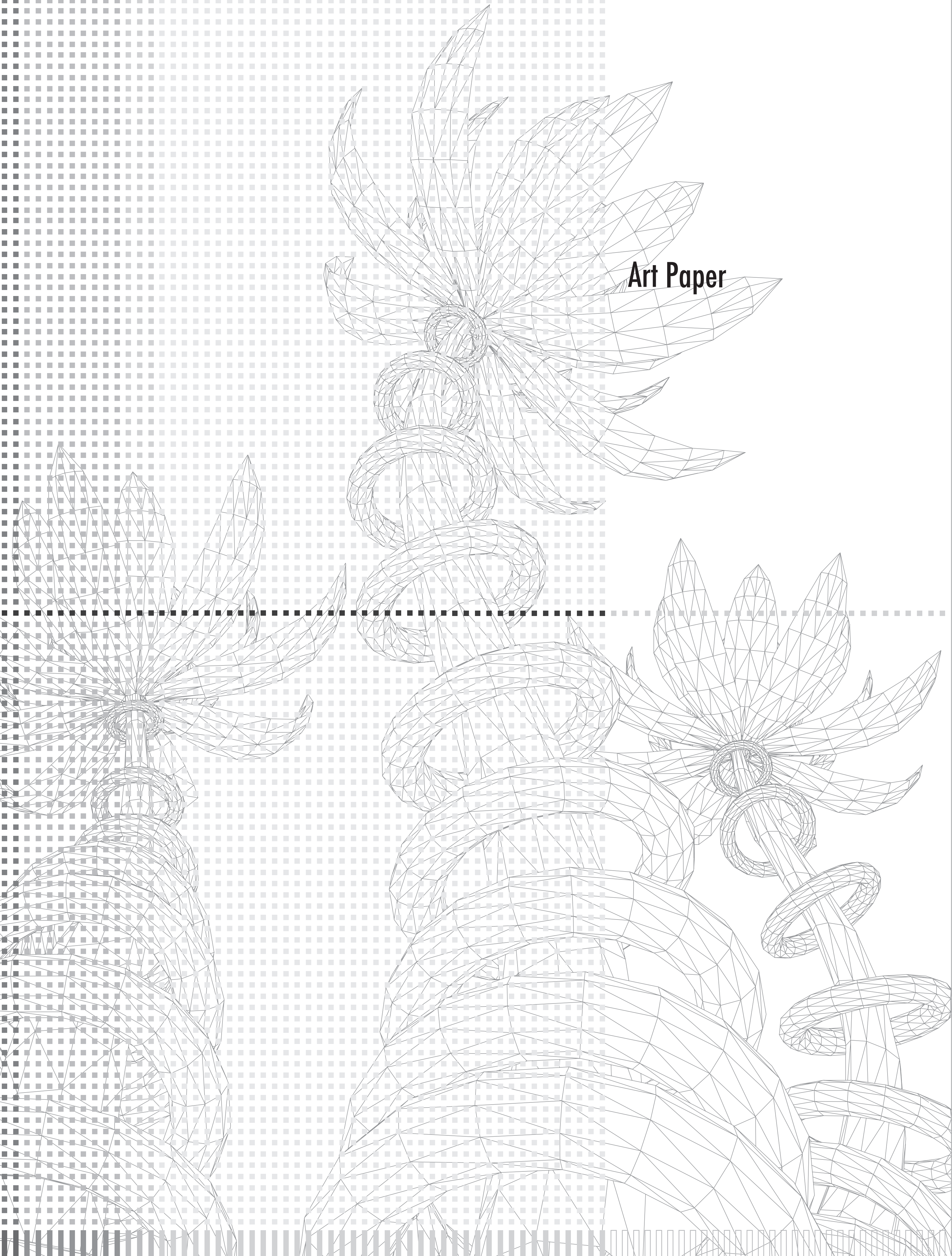
Art Paper



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Moreno Quiroga Jacobo
Kyushu University
jacobo.mq@gmail.com

Izumoto Chika
Kyushu University
1ds10166r@gmail.com

Kaneko Kosuke
Kyushu University
kosukekaneko@kyudai.jp

Yonemoto Shiori
Kyushu University
yonemoto@museum.kyushu-u.ac.jp

Kim Daewoong
Kyushu University
dwkim@design.kyushu-u.ac.jp

Planning and Developing a Museum Outreach Program for Schools

Bringing educational content from the museum to the classroom

through digital and physical materials

Abstract
In this research we explored various approaches for the design of an outreach program that worked as an educational support tool from a museum to schools. We developed a loan kit that provided teachers with a variety of activities included in a lesson-plan that they could easily insert into their regular curriculum. With the use of tablets for expanding content from textbooks via augmented reality and introducing replicas for hands-on learning along with digital content, we created a lesson that was engaging for the students and also presented the educational content from the museum. Furthermore, a session with a professor from the museum was also included as part of the lesson. In this section, the students had the opportunity to speak directly with an expert from the museum. "The human body and its movement" loan kit was developed and tested in three schools from Miyazaki Prefecture, the process of its production and our findings from the tests are presented in this document.

Keywords: Educational Digital Content, Museum Outreach Program, Replicas and Hands-on Learning.

1 Introduction

1-1. Collaboration between schools and museums

Schools can use museums as a form of educational support; through guided visits, classes on the museum and hands-on experiences, students can get a deeper understanding of a topic compared to what they would get at a regular class at school. The Ministry of Education, Culture, Sports, Science and Technology of Japan recognizes this fact, and in its Elementary School Curriculum Guidelines for Science it was stated that collaboration between schools and museums & centers for learning science should be promoted [1]. Since then, museums in Japan have started to offer more activities directed towards school groups in order to both serve as educational support and interest students in subjects exhibited in the museum. However, not all schools can get access to the activities that museums offer. Across Japan, there are towns

Table 1. Reason of why schools find difficult using museums in their classes (translated from the original)

	Elementary Schools (N＝514)	Junior High Schools (N＝663)
There is no museum or appropriate facility nearby	70.0%	64.6%
There is no time for going to the museum	46.3%	64.7%
A trip to the museum cannot be adjusted in the schedule of the subject's classes	18.3%	39.7%
An educator that leads the activity cannot be ensured	13.4%	17.8%
Correlation with the school's curriculum cannot be clarified	8.2%	4.7%
There is no knowledge/technology for using the museum in class	12.3%	13.6%
Learning efficacy of the activity cannot be clearly identified	7.0%	5.1%
There is no information about the museum exhibits and events	5.6%	5.6%
Transportation and/or admission costs are not covered	46.7%	51.0%

located in difficult-to-reach places, such as mountains and islands; and while some of these places have local museums and institutes, many of the schools located there have a hard time accessing the benefits that come with the collaboration between schools and museums, because of transportation expenses and time.

A questionnaire research on elementary schools and junior high schools, performed by the Japanese National Museum of Nature and Science, shed light on various points regarding the collaboration between schools and museums [2]. According to this study, the main reason why schools find it difficult to use museum activities in their classes is because there is no museum or appropriate facility near them (70%). The next reason is because of transportation and attendance costs (46.7%). Finally, the next most selected reason was the lack of time for going to the museum (Table 1). From this, we can conclude that schools far from museums face problems with transportation expenses and time spent, which makes it difficult for them to visit these institutions in order to benefit from the educational activities and programs that they offer.

Additionally, through interviews with elementary school teachers we carried out, we learned that the educators have to deal with different additional issues aside from preparing and teaching their classes, which leaves little time for visiting a museum since it would become a great burden for them. Because of the above, it is necessary to think about programs that museums can offer for schools located far away, without demanding excessive time and effort from the educators. These have been called **outreach programs**, and they have been implemented increasingly in museums around the world.

1-2. Outreach programs

As the name suggests, "outreach" means to reach out to somewhere located far from the point of origin. In museum educational programs, it refers to the idea of bringing museum-achieved experiences to remote places in order to transmit its knowledge. While there are many ways of doing this, our research focuses on two: long-distance classes and loan kits.

1-2-1. Long-distance classes

One way of reaching schools located far from the museum is through virtual classes given via Internet. The Asahiyama Zoological Park's "i-Network Class"[3] is one example of this. Several cameras were placed inside the animals' cages at the zoo, and the zoo staff gives explanations about the animals while showing the real-time footage. The students can watch the animals in their current conditions and listen to the appropriate explanations from their classrooms, allowing them to experience the zoo and still learn directly from a representative from the institution. This program allows the school to avoid transportation and time costs, while also letting the students see the animals and listen to the experts at the institution. However, in this type of class, the students are not able to experience freely looking at the animals or touching them in sections like the petting zoo. While they can get educational benefits by taking the virtual class, they would lack some experiences that cannot be transmitted through video only.

The advantages of a virtual class taught by the professionals at the zoo, museums and other institutions are that the students can actually listen to the experts and get a unique opportunity to ask them questions without leaving their classroom. The experiences that are lacking from this video-only activity could be achieved through other methods, like with loan kits. Furthermore, these other activities could be experienced before the actual session with the experts, in order for the students to immerse themselves in the topic and get a richer experience.

1-2-1. Loan kits

Loan kits are educational sets directed at schools in order to teach about topics related to a museum, serving as a support tool that utilizes and puts into practice the knowledge from the museum. They include different educational materials that aim to cover a specific topic, including illustrated books, games for learning, and sometimes objects for touching and observing, such as replicas of objects from the museum's collection. Schools can obtain loan kits for free for short periods of time so they serve as a way for the museum to outreach.

One example of these sets is the KyuuPack [4], which offers four kinds of activities: looking and reading, interacting with tangible objects, trying to build something, playing with puzzles and games. Loan kits aim to offer educational assistance not only by giving out books and information, but also by offering activities that engage the students. Through different learning paths, like using games and touching things, the students' curiosity is stimulated and enjoyable experiences are offered in order to keep them motivated, making sure that the activities remain in the students' memory along with the content they learn. The activities that allow students to touch and experience things with their own hands, called hands-on activities, are especially relevant to this study.

We performed a visit and interview at the Osaka Museum of Natural History, and also borrowed loan kits from the institution for analyzing. The kits included not replicas, but real animal bones, along with explanatory charts and a book about animal bones. Bringing real bones to the classroom would allow students to have a hands-on experience by presenting them with authentic objects. However, no explanation of how these elements should be introduced in the class was included in the kit, while also lacking any extra games or activities that could be performed with them. While the museum offers support for the teachers via on-site workshops and dedicated telephone lines, the loan kits may create a burden for the teacher since it is him who will have to study the specialized topics and plan how the class should go, without having specific references or ideas offered in the kit.

Using the outreach programs explained above as a starting point, our goal in this research was to design, develop and test a loan kit that both included a variety of activities for supporting learning in the classroom, along with the inclusion of a session taught by an expert in the museum. For this purpose, a variety of digital technologies were used in order to secure enjoyable activities for the kit and facilitate the transmission between museum and schools of the content.

2 Methods and Content Planning

2-1. Conception of the loan kit

First of all, the outreach program we planned had to offer a lesson plan for the teachers in order to avoid putting too much burden on them. This class had to include a variety of activities that would interest the students and let them learn while having fun. In order to achieve this, tablets were considered as a way to provide different activities inside one device: a textbook with augmented reality content that would expand the regular reading process, video game components (like the inclusion of characters and mini-games), and hands-on objects like replicas made in 3D printers that could be used along with the digital content. Furthermore, a twenty minute video lesson by a museum expert would be included, where the students would listen to a short lecture and then asked questions.

We collaborated with the Kyushu University Museum, and started developing the loan kit based on the museum's collection of human and animal bones. In order for the kit to be relevant for the students, it had to link the museum's knowledge with the current school curriculum. For this reason, the fourth year elementary school science unit, corresponding to the human body and its movement, was selected as the target subject. The topics in this unit dealt with the human bones, muscles, articulations and movement, while also including information on their animal counterparts. We also planned to approach schools in rural parts of Miyazaki Prefecture for the testing, so the contents of the kit were mainly based on the school textbook used in that area.

2-2. General explanation and contents

The loan kit was initially planned to cover three school lesson blocks of forty-five minutes each, in order to complete all the activities prepared. However, after an initial meeting with the teachers and heads of the schools that would collaborate in our tests, we decided to extend the class one more block because they suggested that the students needed more time for assimilating the content. In the class, the students would go through the topics of the textbook divided in 4 sections: *bones*, *articulations and movement*, *muscles* and *animals*. Finally, they would receive a twenty minutes class taught by an expert from the museum.

The basic structure for each section in the class is as shown below (Figure 1).

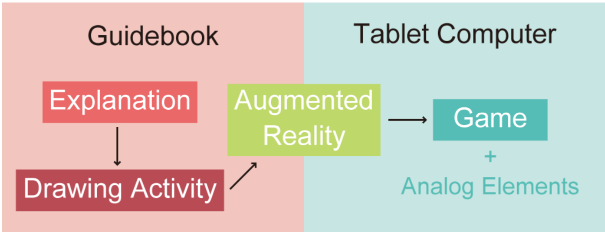

Figure 1. Flow-chart for each section on the class.

First, an introduction to the topics would take place in a paper textbook where the students read aloud along with their teacher, similar to a regular class. Then, the students would carry out a drawing activity corresponding to that section; for example, imagining what the bones look like and then drawing them inside a human silhouette. In the next step, students would grab the tablet computers and point them at the textbook to look at augmented reality videos. Finally, with the tablet on hand, the students would look for the corresponding analog elements of the section and play games that incite them to observe and touch the replicas repeatedly.

The reasoning behind this process was to begin with an introduction through traditional teaching methods of reading and drawing, in order to present both the teacher and the students with a familiar teaching environment. Then they would be directed towards the digital materials through augmented reality content that appear on what otherwise looks like a regular textbook. Finally, the games alternated between virtual reality and augmented reality, which was intended to make the students interact with the replicas in front of them over and over. This way, the tablets are not the main focus of the lesson, but rather a tool that can enrich the experiences with other materials.

The final version of the kit included the items listed below (Table 2). Their specifications are explained in the next chapter.

Table 2. "The human body and its movement" loan kit contents

Students' Textbooks	*One printed copy for each student*
Teacher's Guide	*A printed guide explaining the class plan*
Teacher's tutorial DVD	*Portrays each step in a mock-up class*
Tablet computers	*Nexus 5, with the application installed*
Boxes Set	*Contains the parts of the human skeleton*
Human Skeleton Replica	*With an NFC tag appended to each piece*
Animal Bone Replicas	*A Lion skull and leg, and a frog skeleton*
Augmented Reality Targets	*Additional pictures for the games*
Hint Cards Sets	*23 cards per set, one set for each student*

3 "The human body and its movement" loan kit

3-1. Teacher's guide and DVD

A printed guide with the steps for the class progress was prepared in order to present the lesson plan to the teacher. In addition, after meeting with the heads of schools and teachers, we realized that it was necessary to devise a more detailed way to introduce the materials since all of the teachers had little or no experience in using digital educational materials during class. For this reason, we prepared a DVD with a mock class where every step was visually presented and explained, this way the teacher could jump from one step to another, from the preparation of the replicas to the game's instructions. This preparation for accurately transmitting the mechanics of the kit was necessary in order to relieve the teachers of burden as much as possible.

3-2. Textbook

The loan kit was required to be meaningful for the students learning process, so it had to include actual content that they would study according to the established curriculum. Furthermore, by presenting a familiar element in the kit, both the teacher and students would feel less overwhelmed. For this reason, the textbook we made included the same content as the textbook used in the schools in Miyazaki Prefecture [5]. We also followed similar design patterns as regular textbooks, such as highlighting important parts in bright colors and including a mascot character that provided hints (Figure 2).

Figure 2. Drawing activity on the textbook, explained by a panda character on the side.

In the textbook, an "AR (Augmented Reality) page" was included in each section, with pictures that started moving when looked at through the application on the tablet. For example, this served to show the behavior of the muscles correspondent to different body movements (Figure 3). With this, the students had their textbooks expanded, using the tablet as a tool to allow them to see content beyond the paper.

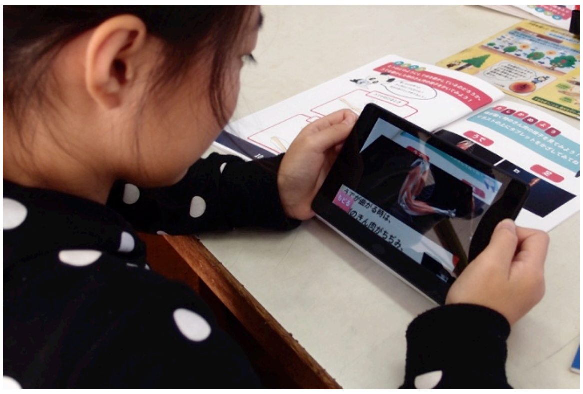

Figure 3. Augmented reality videos will trigger on the tablet when pointed at the image targets

3-3. Objects for *hands-on* learning

A human skeleton replica along with a lion's head and leg, and a frog skeleton were produced using a 3D printer (Figure 4). The human bones had near-field communication (NFC) tags attached to them, while some small image targets were put on the animals bones; this was done in order to use the bones in the games explained in the next chapter.

While real bones would provide a different kind of impression for the students (as with the Osaka Museum's loan kit presented above), replicas can effectively bring them the experience of touching objects that would be difficult to access if they were authentic. For example, we learned from one of our visits to the Kyushu University Museum that human skeletons are treated with special care and respect in Japan, so they cannot be carelessly handled. Furthermore, 3D printing allowed us to reproduce a lion's head and leg, and an

Figure 4. Human and animal bone replicas

enlarged frog skeleton, which allowed the students to have rare animal parts in their hands and a bigger reproduction of an otherwise very small and fragile one.

Aside from the bone replicas, a set of boxes with image targets on top of them was also included in the kit, which also presented an opportunity for hands-on learning. When learning about human bones, it is more important to feel interest towards one's body and think about the mystery surrounding its composition rather than, for example, memorizing all the bone names [6]. For this reason, the boxes were conceived with the purpose of hiding the human bones replicas and first make the students imagine how the bones look like by feeling their own bodies, and afterwards revealing them in such a way that the students could feel the thrill of discovery. The boxes also had different image targets attached to the lids in order to be used in the augmented reality games (Figure 5).

Figure 5. The bones were hidden inside the boxes

3-4. Strategies for engaging with game elements

Various ways for keeping the students interested and facilitating their engagement with the class were devised based on current video game logic and components. Foremost, the students had to choose from four characters whose 3D models and voices would accompany them through the games (Figure 6). The students had the option to select between two boy and two girl characters, similar to video games that ask the players to choose a main character to control at the start of the game. They were designed with the intent of presenting variation, in order to attract different tastes and allow the students to relate to them differently. Each character had a personality that changed the way they talked and reacted when, for example, an answer on the game was correct or incorrect.

Figure 6. Four different characters were designed

A set of 23 cards that included the topics of the class and provided additional explanations was designed. These cards were obtained digitally in the game, but after finishing each section, the students would also receive the physical version. By having a collection component, the students would be interested in getting all of them, and they would also serve as a type of flash cards for learning and remembering the topics of the class.

The games varied from section to section, but always attempted to alternate between the tablet screen and the hands-on materials in order to avoid staying in the digital component for too long. In the bones section, the students had to first look for bones on three different augmented reality stages that appeared on top of the boxes (Figure 7). Once they were all collected, they had to assign them to the parts of the body of the character to clear the game, and then they would open the boxes to discover the replicas. This was intended to generate curiosity about what would be inside the boxes, and establish a process of first making the students look at the bones in digital form before actually holding them in their hands.

Figure 7. The students touching objects in augmented reality

In the articulations and movement section, the students had to assemble articulations by reading the NFC tags on the human bones with the tablet and matching the appropriate parts (Figure 8). Then they would assign the articulations to the character in augmented reality to make them dance. With this, the students were urged to repeatedly hold the bone replicas, identify their different forms and look at which bones matched in order to form an articulation. The dancing character served as an incentive to look at all of the main articulations.

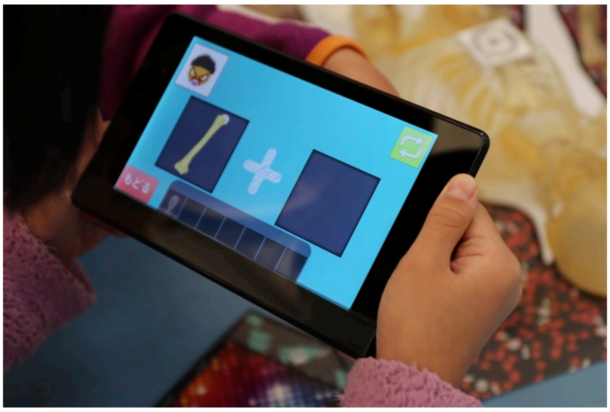

Figure 8. Matching bones digitally through NFC tags

In the muscles section, the students had to assemble the skeleton on top of a large image target mat. When looked at through the tablet, a muscular system model appeared. By touching the marked parts that appeared, the students would play a series of muscle training mini-games (Figure 9). This was intended to make the students associate body movements with the muscles used in them. In the fast paced mini-games, the character was shown performing the corresponding movements repeatedly.

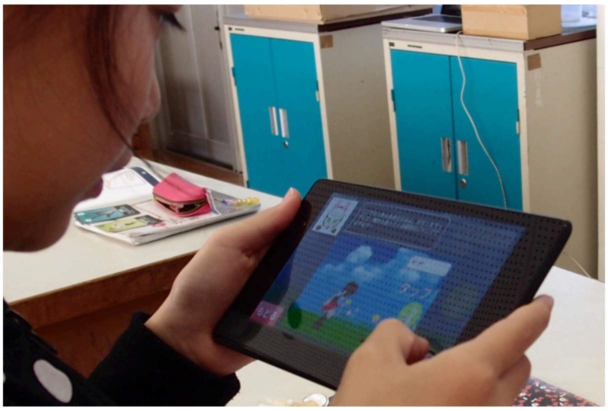

Figure 9. Mini-game about jumping over obstacles

Finally, in the animal section, a quiz game would take place. The students had to point the tablet towards the augmented reality targets in order to trigger a quiz, which asked them to search for the answer by observing the animal and human bones, for example by assigning the corresponding bones to the bodies (Figure 10). For each quiz, they would receive a character for a password and, at the end, they had to combine them with the ones found by other students in order to input the full password and clear the game. The quizzes asked the students to touch the replicas and compare between the animal and human bones, which incited them to observe and analyze the different parts. Additionally, other animals that were not made into replicas were shown as 3D models via augmented reality.

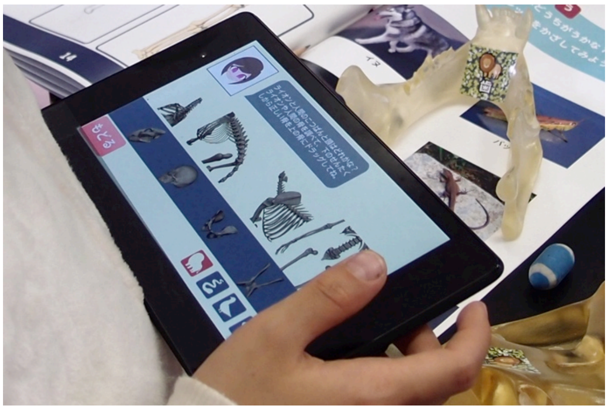

Figure 10. Observing the replicas for solving the quizzes

3-5. Session with the museum expert

At the end of the class, the students had to write questions that they would like to ask the expert from the museum. By doing this session at the end, the students would already have background knowledge of what they learnt through the day and could think about questions related to the topics they had been studying.

We contacted the Kyushu University Museum and met with one of its affiliate professors in order to present them the loan kit and to agree on the topics that would be presented in the class & how the session would take place. The professor would connect via Skype through a tablet and start a video call with us. We would have the camera pointing at the students and start the 20 minutes session (Figure 11).

Figure 11. Long-distance class with the museum professor

The professor would explain about four-legged animals and two-legged animals and use the replicas that the students would have in their hands to make examples, also showing parts of the objects in the museum with the camera. Afterwards, the students would ask questions about topics related to the class. Through this, the students would have actual contact with an expert from the museum with a virtual class that also used the objects they have been manipulating throughout the day.

4. Testing in elementary schools

We tested the loan kit, "The human body and its movement", in three elementary schools from Miyazaki prefecture: Kozaki Elementary School of Shiiba Town, Sakatani Elementary School of Nichinan City and Katagami Elementary School of Nichinan City. A total of 31 students ranging from third to sixth grades participated in the classes planned for the loan kit. Their respective science teachers taught the class and we assisted as supporters, in case any problems with the materials arose, and as observers. The physical layout of the class had the students with their textbooks and tablets in front of them, and the rest of the materials in the center of the tables (Figure 12). Depending on the activity, the students would stand up, grab their tablets and perform the different activities.

Figure 12. Example of the layout of the class

The teacher's guide, DVD, a tablet with the application, and part of the image targets and replicas were prepared and sent through mail to each of the schools one week before the testing dates. We sent it beforehand in order to allow the science teachers to get to know the dynamics of the kit and prepare themselves before the class. Additionally, we offered assistance via e-mail and phone for any questions and problems they could have.

The tests were made in the following order: First, we set up the loan kit parts and had a brief conversation with the teacher in order to solve questions and explain the final details. Then, the class of four blocks took place, with a small recess between each block. Later, the twenty-minute session via Skype with the professor from the museum was carried out. Finally, the students and science teachers would answer a questionnaire about our research, and a meeting with the school's heads and science teachers was made, where we would receive comments and observations about the kit.

4-1. Results from observations

In general, we observed that the students had a positive response towards all of the contents of the loan kit. A few students had trouble with the games, but both the teacher and other students were able to help them progress through them. Many of them did not have much experience manipulating a tablet, however they adapted quickly. The activities went smoothly in most of the cases, and the students showed interest and seemed to have fun. Many of them also looked surprised when they realized the class was already over, having lost track of time. One issue we noticed was that, in all of the three schools, the planned time for the class was either not enough or just barely enough, so we actually had a fast-paced lessons.

Regarding the usage of the contents, we observed that the behavior of the students required us to make a few changes along the way, so we went to adapt the order of the class plan. For example, once the students had the human bone replicas in their hands, they were instantly eager to put them in order, so it was more effective to assemble the human skeleton immediately after they took the parts out of the boxes. Another change was the timing; when the students received the printed hint cards, we planned on distributing them at the end of each section. However, receiving the physical card at the moment they got the card on the digital screen resulted in a more exciting activity, since they felt instantly rewarded and collecting the cards represented a clear objective for the games. Finally, there were some technical problems with the tablets regarding the NFC tags recognition before the last test, so we had to assign one tablet per two students. However, this resulted in a more enriching experience for the students since they collaborated and went through the digital activities more smoothly compared to the performance in other schools.

The long-distance class session with the museum professor was accomplished trouble-free in every case, and the professor was able to give explanations to the students while showing them around the museum and making comparisons with the replicas they had in front of them. The only instance in which we found that the time provided was not enough was in the school with the biggest number of students: the professor was not able to finish answering all of the questions the students had, even though the time estimate had seemed appropriate.

4-1. Results from questionnaires

4-1-1. Students

A seven-point questionnaire was distributed to the students after the class, the total results from the three schools for each of the questions is presented below (Table 3).

At the end of the questionnaire, an open question about the student's thoughts on the class was made. All of the comments were positive: the students wrote about how fun it was to go through the class with the tablets and how they would like to have one class like this again.

Table 3. Overall results from the students' survey

	Very much	*Yes*	*Neither*	*No*	*Not at all*
Q1. Was "The human body and its movement" class fun?	97%	3%	0%	0%	0%
Q2. Was "The human body and its movement" class easy to understand?	81%	19%	0%	0%	0%
Q3-1. Were the games fun?	95%	5%	0%	0%	0%
Q3-2. Were the games easy to play?	37%	10%	23%	19%	11%
Q4. Were the explanations of the tablet and its use easy to understand?	97%	3%	0%	0%	0%
Q5. Was learning through touching human and animal bones easy to understand?	74%	26%	0%	0%	0%
Q6. Would you like to try a class that uses tablets and materials from the museum again?	97%	3%	0%	0%	0%

4-1-2. Teachers

The science teachers' questionnaire had more detailed questions and open answers, since there were only three of them. For this reason, we present the relevant points summarized below:

- Neither of the teachers had ever used museum content in their classes. When asked about the reason, they answered it was because of time issues and distance from museums.
- The class with the loan kit was praised for effectively interesting and engaging the students with the learning content. However, one of the teachers said that it needed more work before suitability for regular class use.
- The teachers' opinion towards digital materials after the class was that they are interesting and surprising. However, one teacher considered their implementation in class was still a difficult matter.
- They considered that the replicas greatly helped to better understand the lesson content, and that they interested the students.
- While the hint cards attracted the students' attention, their educational usage was not encouraging enough.
- The time planned for covering the topics was considered insufficient. The teachers felt the class had to be covered very fast.
- Regarding the multiple activities and games, the teachers had mostly positive answers, and considered them important for improving the students' willingness to learn and better understand the content. However, in a few cases, the games were thought to be not educational enough and stayed too much on the entertainment side.
- The teachers considered the session with the museum's professor a positive and valuable experience for the students. However, one of the teachers said that the content explained was too difficult for elementary school.
- Finally, two of the teachers answered they would like to use this sort of loan kit in the future, but the remaining teacher expressed reluctance to use it in class. However, the latter suggested using it as an extra-curricular activity inside the school.

5 Conclusions and Discussion

In this research we developed a museum loan kit aimed at schools that have difficulty accessing museums. It included a variety of activities that could engage and transmit educational content to the students in order to promote collaboration between museums and schools. Presented below are the conclusions we achieved from our observations and the results from questionnaires and interviews carried out after the tests in elementary schools of Miyazaki prefecture:

The students considered the class interesting and fun, and they demonstrated interest in participating in this kind of activity again. Even if there was an initial introduction through the traditional textbook, the class was not limited to this but went through connecting digital and analog content that proved effective for stimulating the students' willingness to learn. The objective of this research, planning a museum support tool for schools that would result enjoyable for the children, was achieved. Furthermore, the experiment results suggest that it was effective. We identified an issue with the difficulty setting in the games: we received mixed results when students were asked whether the games were easy to play. However, this did not seem to affect their enjoyment while playing them, and it also presented an opportunity for the students to help each other clear the games. This could lead us to think that since the students were deeply engaged in the games, their difficulty did not represent an obstacle for continuing to attempt and achieve the goals planned. Moreover, by maintaining a level of difficulty for the games instead of making them too easy, the children were compelled to clear the games because it provided them with a sense of accomplishment. We could observe that the difficulty of the games did not have a negative impact in their appreciation according to the children. A comparison of this experience with one with easier games would entail a different kind of research.

On the other hand, from the teachers' side we learned that, while the contents could engage the students, there is still work to do regarding the balance of games and educational elements. Moreover, the main problem with our loan kit was its expected class time management, which could be reworked at a later date by better analyzing the time required for the students to complete the different activities planned, and how the time in a regular class is managed. One obstacle we had from the beginning was asking the teachers to adopt a completely different class model within their regular teaching style. Additionally, while one of the teachers felt reluctant of them, the others gladly received the idea of using materials such as the ones presented in our loan kit in their classes.

The replicas were successfully implemented with the digital games, and the constant interaction with them helped the students understand the lesson's content. They were also beneficial for the session with the museum's professor, since they used them as examples and compared them to the museum objects, while the students could actually look and touch them.

The goal of the long-distance class session was also achieved, as there was a direct connection between the students and the museum, the museum's professor being its representative. The teachers also considered this class a valuable experience for the students, and while some of the content explained by the professor were somewhat advanced for the students' level, the museum's knowledge reached the students.

Regarding the technology used, NFC tags and augmented reality had some minor technical issues, but ultimately they were sustainable enough for the class plan we proposed. The 3D printed replicas were overall well crafted and accurate, and while some unavoidable damage happened to delicate pieces due to their constant manipulation, they were easily repaired.

In our research we served as a link for connecting a museum with schools that do not have easy access to it. We maintained contact with both the museum and schools, presented our project and went to improve it along the way with their suggestions. We consider that this communication channel was critical for developing satisfactory results. With the design of both digital and physical content, we developed materials for a class planned on the foundations of the current school curriculum and the museum's exhibitions. The previous conclusions lead us to think that a path towards offering this kind of outreach programs can still be expanded by creating opportunities to collaborate between museums and schools.

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Edited By Nagisa, Niwata
Shiori, Hidaka

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