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Research Article

The Design and Usability of Virtual Reality Content Using Eyes for Students with Severe Disabilities

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Abstract

The purposes of this study were to develop the design of virtual reality content using eyes and to investigate the usability of the virtual reality content for nonverbal students with severe disabilities. A 360-degree video in which a narrator introduces scientific activities (momentum, earthquake, gravity, robot dance) and experiences them at Chungnam Science Education Center was produced. Next, the virtual reality content for the video were designed for users to manipulate image buttons with their eyes so that users can select and experience images. Users can select and view images of scientific activity by staring and blinking using the HTC-VIVE Pro Eye, which combines eye tracking technology. The virtual reality content using eyes were designed and developed in accordance with the guidelines for supporting self-determination of students with severe disabilities. In order to investigate the usability of the VR content, 37 special education teachers who had special teacher certificates and had experience in teaching students with severe disabilities answered questions after using the VR content. The teachers evaluated as "neutral" in some usability evaluation categories (e.g., Self-determination, Ease of manipulation, Ease of Understanding, Effectiveness, Efficiency of class preparation, Efficiency in teaching, Appropriateness of content organization). When developing VR contents for students with severe disabilities, developers can design visual images in order for students with severe disabilities to understand easily and establish user interface in users' eye conditions and operational capabilities. VR contents can be designed in relation to subject areas so that teachers can use them as educational materials.

Keywords

Eye Blinking, Eye Gazing, Severe Disability, Usability, Virtual Reality Content

1. Introduction

Students with severe disabilities are defined as students who need educational, social, psychological, and medical services due to physical, mental, and emotional problems or the complex emergence of these problems [1]. In particular, students with severe disabilities often cannot communicate smoothly in oral language, so they express their intentions through facial expressions, body movements, eye gazes, vocalizations, and gestures. Therefore, students with severe disabilities should be supported to communicate including all informal communication systems such as verbalizations, signs, gestures and use of augmentative devices [2-4].

Teaching methods using high technology can provide flexible learning activities that increase the autonomy of students with severe disabilities, build a self-directed learning environment, apply various teaching and learning methods, and expand the physically limited educational field to prevent

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disadvantages caused by lack of experience in using information [5]. Based on these advantages, virtual reality-based teaching methods that provide tasks in a virtual environment in a form suitable for individual purposes are being developed. Virtual reality is operated as an interactive simulation activity that makes students have a real-life experience [6].

According to South Korea's analysis of virtual reality-based programs applied to students with severe disabilities, 36.7% of virtual reality-based programs were successful in the "physical function and structure" area, and 63.3% were successful in "activity and participation area [4]. In the physical function and structure" area, functions related to the neuromuscular skeleton and movement were effective, and in the activity and participation area, communication and movement were effective. These results demonstrate that it is useful for students with severe disabilities to practice their target tasks in simulation situations that provide feedback through virtual reality-based teaching [5]. Most of virtual reality technology studies for students with severe disabilities dealt with physical and motor development and communication [4-8], and there are few studies on academic curriculum [9-12]. It is necessary to develop virtual reality content considering the characteristics of students with severe disabilities that can be used in subject areas according to their grade level through the academic curriculum at school [13].

In order to compensate for the lack of oral language of students with severe disabilities, virtual reality contents needs to be designed with non-symbolic communication modes (e.g. eye gaze) that can guarantee self-determination for students with severe disabilities. In this study, realistic VR content using eyes for nonverbal students with severe disabilities were designed with VR device which combines eye tracking technology.

Steve Jobs (1955-2011) said, "Design is not just what it looks and feels like. Design is how it works." For students with severe disabilities, how the content design works may be more important than how it looks and feels. User's usability evaluation is important to identify the usefulness of new technology and suggest improvements to the systems [14]. Therefore, in this study, a usability evaluation was conducted to find out whether students with severe disabilities use the VR contents comfortably and easily.

2. Designing VR Content

The concept of virtual reality content design that allows students with severe disabilities to communicate using their eyes was decided based on guidelines in 11 areas.

2.1. Guidelines for Designing VR Content Using Eyes

Design guidelines for developing virtual reality content using eyes for students with severe disabilities were set up on the 11 basic principles made by Kim and Lee (2016) [15]. The details have been established in 11 principle areas including metaphor, direct manipulation, see & point, feedback& dialogue, ease of operations, aesthetic perfection, understanding the user, accessibility, organization, economics, and communication (See Table 1). The guidelines have been applied to design and develop the virtual reality content.

2.2. System Operating Environment

In order to create a virtual environment that allows communication through the eyes of students with severe disabilities, the Unity program was used to develop it to run on the HTC-VIVE Pro Eye (See Figure 1). The hardware platform implemented a function of tracking the user's eyes using the HTC-VIVE Pro Eye product. Graphics NVIDIA GeForce GTX 970 and AMD Radeon R9290 were used for this VR device. Using Unity5 and Visual Studio 2019 (C# code) development tools, it was developed to insert scientific activity videos into the VR program and utilize pupil tracking technology and blinking and clicking technology. The user's gaze position and movement were identified using HTC-VIVE Pro Eve and the base station devices. Eye tracking technology in which Tobii XR is added to the camera object in Unity allows to identify eye movements.

Figure 1. *HTC—VIVE Pro Eye (left: top view, right: front view).*

Source: Bak, S. et al. (2021). Development and Exploration of the Applicability of Virtual Reality Content for Scientific Experience Activities Using the Eyes for Students with Severe Disabilities. *Korean Journal of Physical, Multiple & Health Disabilities*. *64*(1), p. 65.

2.3. Selecting Activities of VR Content

Learning activities in science were selected in the Basic Curriculum of Korea Special Education Curriculum as the VR content. The Korea Special Education Curriculum provides basic scientific concepts about natural phenomena that students with disabilities experience in their daily lives.

The content was produced based on four themes that are suggested in Science of the Basic curriculum of Korea Special Education Curriculum [16] and are also topics which are easy to learn scientific concepts selected by the Science Education Center of Chungcheongnam-do Education Office in Asan-si, South Korea. A 360-degree VR video which shows the narrator going to the four zones of momentum experience, earthquake experience, gravity experience and robot experience at the Science Education Center, introducing activities of each zone and experiencing them firsthand was produced.

The momentum experience zone contains an experience in which the narrator feels the difference in rotational speed while hugging and unfolding the body.

In the earthquake experience zone, the narrator informs the concept of the earthquake, real-time earthquake information, the earthquake damage, and evacuation instructions, and then experiences the intensity of the earthquake, including light earthquake, weak earthquake, and heavy earthquake.

In the gravity experience zone, the narrator informs the concept of gravity and shows how gravity works by placing a coin in a gravity experience device.

In the robot experience zone, robot performances in which robots dance to the songs of children and idol groups were demonstrated in a video in order to provide an experience of advanced science culture that combines advanced ICT and culture.

2.4. Design Concept of VR Content Using Eyes

The system was designed to make it easier for students with severe disabilities to operate the VR content using eyes tracking technology through their eyes in VR devices. Students with severe disabilities used the HTC-VIVE Pro Eye with pupil recognition function, and the teacher allowed the student to view the screen which they were viewing through the VR device on a PC monitor.

As can be seen in Figure 1, the title image and menu image were expressed as simple and intuitively recognizable images related to the contents of VR videos.

The title of the content included a photo of the actual building to give the user the feeling of going to the place, such as Roadview. For the menu images of exercise experiment, earthquake experience, gravity experiment and robot dance, actual photos were used to give the impression of going to the place of experience. Characters were added to each menu image using the Arial font, the default Roman font of Microsoft Windows to enable language guidance.

In order for students with severe disabilities to have various experiences, the earthquake consisted of light earthquake, weak earthquake, and heavy earthquake, and the robot dance consisted of 「Turning Mecard」 and 「Fancy」. For the detailed science experience activity image, pictograms drawn clearly and relative to the content of the experience activity video was used. (See Figure 2).

The image buttons are designed to make it easy for students with severe disabilities to select activities using their eyes. The user can move on to the menu image screen by gazing at the play button on the title image and then blinking. The menu image button is placed in the center of the VR screen for the user to click it, and the play button is placed in the middle of the image. A photo of the experiential facility within the Science Education Center was used as the menu image, and the names of the experiential activities in the image were expressed in text. Teachers can check where the user is gazing on the monitor. As soon as the user blinks and selects the menu image, related science experience activity images appear. Each science experience activity image is made of a single pictogram. The color changes when the user stares at the pictogram. When the play button appears on the pictogram, the user blinks to select it.

Momentum | Light earthquake | Gravity | Robot dance

Figure 2. *Science activity images.*

Source: Bak, S. et al. Development and Exploration of the Applicability of Virtual Reality Content for Scientific Experience Activities Using the Eyes for Students with Severe Disabilities. *Korean Journal of Physical, Multiple & Health Disabilities.* 2021, *64*(1), p. 70.

For example, if the menu image of the earthquake experience activity is selected by blinking, the science experience images of light, weak and heavy earthquakes are activated immediately. When the user selects "weak earthquake" as shown in (Figure 3), the color of the image changes and a play button is generated. When the user blinks and selects the play button, an image of a weak earthquake is sent to the video, allowing the user to experience it.

Menu image (Earthquake) Weak Earthquake Activating the video

Figure 3. Activating science activity.

Source: Bak, S. et al. (2021). Development and Exploration of the Applicability of Virtual Reality Content for Scientific Experience Activities Using the Eyes for Students with Severe Disabilities. *Korean Journal of Physical, Multiple& Health Disabilities. 64*(1), p. 70.

Icons such as play buttons, stop buttons, and home buttons were set up so that students with severe disabilities can freely choose them on their own. As shown in (See Figure 4), symbols commonly used in popular video media were used for the play, stop, and home buttons so that users could feel familiar with them. When the user gazes at an icon, its color changes, and then when the user blinks, it is selected.

play button stop button home button

Figure 4. *Icons.*

Source: Bak, S. et al. (2021). Development and Exploration of the Applicability of Virtual Reality Content for Scientific Experience Activities Using the Eyes for Students with Severe Disabilities. *Korean Journal of Physical, Multiple & Health Disabilities.64*(1), p. 70.

Table 1. *Guidelines for designing and developing VR content using eyes.*

Categories	**Guidelines**
Metaphor	1) Menu images are intuitive using real photos. 2) Images of science experience activities are represented by pictogram. 3) Play button, stop button, and home button as icons are symbols encountered in everyday life.
Direct manipulation	The content proceeds with the user's gaze and blink.
See & point	1) The result of the manipulation should be immediately displayed on the screen to determine the causal relationship. 2) The operation button is configured to select the forward and backward direction.
Feedback & dialog	1) Immediate feedback can be provided by checking the progress of the content on a monitor in real time. 2) The presented object provides both visual and audio information at the same time.
Ease of operations	1) The image button is located in the center of the field of view so that it can be clicked without significantly deviating from the user's field of view. 2) By fixing the UI to the camera in the program, the image button can be easily clicked by moving the image button no matter which direction the user looks. 3) Users can freely select and repeat the desired activity through the play button, stop button, and home button.

Categories	Guidelines
	4) No time limit is set so that users can easily manipulate the content.
Aesthetic	1) The color of the image button is reversed so that users and teachers can easily see which object the user is staring at. 2) The science experience activity images are simple and familiar graphics, and their color contrasts with the background color for high readability. 3) The science experience activity image uses simple pictogram so that the contents of the video can be understood easily and intuitively. 4) The number of control buttons must be less than 4 on a single screen. 5) Play button, stop button, and home button can be easily recognized and utilized using those of general video media. 6) Content graphics are implemented to give a feeling of direct experience using actual science activity videos.
Understanding the user	1) The content is developed based on the characteristics and needs of users. (special teachers and students with severe disabilities) 2) The content is developed through evaluation of users. (special teachers and students with severe disabilities)
Accessibility	1) The size of the image button has been adjusted so that it can be easily recognized within the VR screen. 2) Text indicating the content of the image is presented in words at the bottom of the image. 3) The interval between image buttons should be 5 or more so that other image buttons are not clicked regardless of the user's intention. 4) Narration is included in all science activity videos, so users can know that the video is playing through sound even if they are looking elsewhere. 5) When the user's eyes stares at an object, the color of the object changes in real time. 6) The image button can be operated only with the user's eyes without the user's hand or body movement. 7) The desired object can be controlled by blinking after looking at it without complicated conditions such as the number of blinks and gaze time.
Organization	1) Buttons are placed in a predetermined position in the content. 2) The menu image button placed in the center of the screen blinks and disappears when clicked, the introduction video is executed, and the science experiment image button, home button, and stop button are activated. 3) When clicking the science experiment image button placed at the bottom of the screen by blinking, the play button is activated above the clicked image button. 4) The play button is placed above the clicked science experiment image button blinks. When clicked, all the science experiment image buttons and the play button are deactivated, and the stop button is activated at the top right of the screen. 5) All science experiment image buttons are activated when clicking the stop button located at the top right of the screen by blinking. 6) When you click the home button on the upper right of the screen by blinking, the video stops, all icons and all science experience image buttons are deactivated, and then the menu image button is activated.
Economics	1) Time and expense are saved because you can experience it without visiting the place. 2) Experiences can be repeated freely without limit. 3) Videos in the content are used as teaching and learning materials.
Communication	1) Communication is possible through staring and blinking. 2) When staring at the image button presented on the screen, the color is inverted in real time, making it easier to check. 3) Images are used to the maximum, and texts are expressed in simple words. 4) Before playing the science experiment video, it is possible to know the meaning of the activity to be seen by presenting an implicit image. 5) Icons and image buttons are used identically to simplify the rules required for operation.

Source: Bak, S. et al. Development and Exploration of the Applicability of Virtual Reality Content for Scientific Experience Activities Using the Eyes for Students with Severe Disabilities. *Korean Journal of Physical, Multiple & Health Disabilities.* 2021, *64*(1), pp. 65-66.

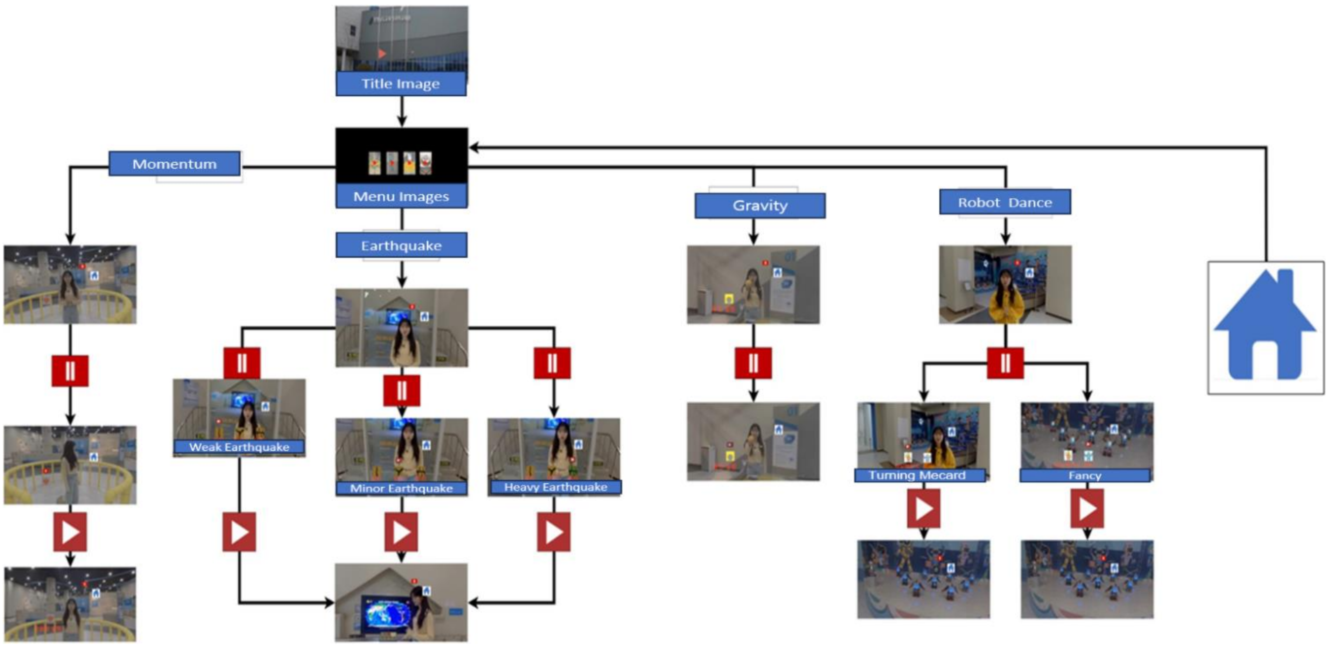

Figure 1. *Data Flowchart.*

Source: Bak, S. et al. Development and Exploration of the Applicability of Virtual Reality Content for Scientific Experience Activities Using the Eyes for Students with Severe Disabilities. *Korean Journal of Physical, Multiple & Health Disabilities.* 2021, *64*(1), p. 68.

Table 2. *Usability evaluation questionnaire.*

	No	Categories	Descriptions
Student's perspective	1	Media interest	Students think that learning using this content is more fun than learning through textbooks or the Internet.
	2	Reality	Students feel as if they are experiencing it directly from the content.
	3	Safety	Students are able to experience activities that cannot be directly experienced due to safety concerns.
	4	Self-determination	Students are able to express their intentions by staring and blinking.
	5	Ease of manipulation	Students are able to manipulate the image button of this content with their eyes.
	6	Ease of understanding	When students use the content, they understand the content of a subject area well.
	7	Effectiveness	Students are able to achieve educational goals well by using the VR content.
	8	Arousing interest	Students are interested in learning content when using this VR contents.
	9	Motivation	Students are likely to want to study in the field using this VR contents.
	10	Extensibility	Students are likely to want to study using the same content in other subject areas.
Teacher's perspective	1	Goal appropriateness	The VR content was developed in accordance with educational goals of academic curriculum.
	2	Content appropriateness	The content of this VR was developed by reflecting objectives of a subject area.
	3	Efficiency of class preparation	The VR content can be used as class activities and educational materials.
	4	Efficiency in teaching	The VR content can to be effective for teaching students.
	5	Appropriateness of content organization	The VR content was properly structured to be used by students with severe disabilities
	6	Interesting and fun	The VR content seem to be more fun than teaching through textbooks or the Internet.

No	Categories	Descriptions
7	Easiness	The VR content can be used in non-face-to-face classes.
8	Economics	The VR content can be used continuously, reducing the time and cost required for reproduction
9	Usefulness	The VR content is likely to be useful in other fields besides a subject area.
10	Extensibility	Realistic virtual reality contents need to be produced for subject areas.

Source: Bak, S. et al. Development and Exploration of the Applicability of Virtual Reality Content for Scientific Experience Activities Using the Eyes for Students with Severe Disabilities. *Korean Journal of Physical, Multiple & Health Disabilities.* 2021, *64*(1), p. 72.

3. Usability of VR Content Using Eyes

Teachers with experience in education with severe disabilities evaluated the usability of VR content using eyes. Their responses were quantitatively analyzed.

3.1. Participant

Table 3. Demographic information of participants (n=37).

Classification		n (%)
Gender	Male	21 (56.8)
	Female	16 (43.2)
Responsible school level	Kindergarten	8 (21.6)
	Elementary school	13 (35.1)
	Middle school	7 (18.9)
	High school	9 (24.3)
Special Education Experience(year)	Less than 5 years	18 (48.6)
	More than 5 to less than 10 years	7 (18.9)
	More than 10 to less than 20 years	9 (24,3)
	Less than 20 years	3 (8.1)
Educational experience for students with severe disabilities(year)	Less than 5 years	22 (59.5)
	More than 5 to less than 10 years	8 (21.6)
	More than 10 to less than 20 years	6 (16.2)
	Less than 20 years	1 (2.7)

A usability evaluation was conducted on 37 special teachers working at special schools for severe disabilities in South Korea. All of the teachers had special teacher certificates and had experience in teaching students with severe disabilities (See Table 3). The average experience of the teachers in special education was 6.58 years, and the average experience of teaching students with severe disabilities was 5.01 years.

3.2. Usability Evaluation Scale

With reference to the usability evaluation scale [11] of Kim and Lee(2016), four people consisting of special education expert, occupational therapy expert, computer engineering expert, and content developer revised the evaluation items together. Five experts, one principal with more than 20 years of experience in education with severe disabilities, one computer engineering professor and three graduate students with experiences in content development verified the validity of the revised one. The usability evaluation scale consists of a total of 20 items, including 10 items from a student's perspective and 10 items from a teacher's perspective (See Table 2). The special teachers scored 5 points for "strongly agree", 4 points for "agree", 3 points for "neutral", 2 points for "strongly disagree", and 1 point for "disagree" using the 5-Point Likert Scale foreach evaluation item. As a result of calculating the internal consistency reliability of the evaluation tool, Cronbach's αlpha scored .92 in the evaluation scale as a whole, .86 from the student's perspective, and .87 from the teacher's perspective.

3.3. Results of Usability Evaluation

Special teachers evaluated the usability of the VR content by dividing it into cases where students with severe disabilities use it and cases where teachers use it directly in class. As a result, they positively rated 4.13 and 4.16 from a student and a teacher's point of view, respectively(See Table 4). However, there are differences in the results of the teacher's evaluation by the category of evaluation tools. Assuming that students with severe disabilities actually use it as an educational content, they evaluated Self-determination, Ease of manipulation, Ease of Understanding and Effectiveness as "neutral" from student's perspective. Also, they evaluated Efficiency of class preparation, Efficiency in teaching, and Appropriateness of content organization as "neutral" from teacher's perspective.

Table 4. *Usability Scale Scores by Category.*

Student's perspective			**Teacher's perspective**		
No	**Categories**	**M (SD)**	**No**	**Categories**	**M (SD)**
1	Media interest	4.32 (.88)	1	Goal appropriateness	4.16 (.69)
2	Reality	4.22 (.79)	2	Content appropriateness	4.05 (.78)
3	Safety	4.62 (.59)	3	Efficiency of class preparation	4.05 (.74)
4	Self-determination	3.65 (1.14)	4	Efficiency in teaching	3.78 (.71)
5	Ease of manipulation	3.46 (1.09)	5	Appropriateness of content organization	3.43 (1.07)
6	Ease of understanding	3.92 (.76)	6	Interesting and fun	4.36 (.82)
7	Effectiveness	3.92 (.79)	7	Easiness	4.32 (1.00)
8	Arousing interest	4.57 (.55)	8	Economics	4.27 (.99)
9	Motivation	4.22 (.82)	9	Usefulness	4.51 (.56)
10	Extensibility	4.38 (.59)	10	Extensibility	4.65 (.54)
	Total	4.13		Total	4.16

4. Discussion

The results derived in this study are discussed in relation to previous studies as follows. First, the realistic VR content was developed based on guidelines for virtual reality content using eyes for students with severe disabilities. In Korea, virtual reality technology for students with severe disabilities is mainly used for physical, motor, and communication development [4-8]. In this situation, this study designed the realistic virtual reality content that can be used in science classes for nonverbal students with severe disabilities. This study is significant in that it extends the use of VR content to academic achievement. As Browder et al. (2008) [13] mentioned, students with severe disabilities can experience and learn about scientific phenomena in science. Teachers can effectively teach by using VR contents as educational materials.

Second, special teachers positively reported responses in usability for the virtual reality content using eyes with an average of 4.13 points and 4.16 points out of 5 points from the perspective of both students and teachers. These result suggest that the realistic VR content reflect the characteristics of communication modes of students with severe disabilities and the need to use new technologies in academic curriculum. However, some usability evaluation categories(e.g., Self-determination, Ease of manipulation, Ease of Understanding, Effectiveness, Efficiency of class preparation, Efficiency in teaching, Appropriateness of content organization) were evaluated as "neither agreed nor disagreed" from perspectives of both students and teachers. From the perspective of students with severe disabilities, the VR content need to be designed in consideration of the ability to understand visual images, eye condition (e.g., eye size, eye-to-eye distance, use of both eyes, eye intensity), and the ability to operate the content with eye gaze and blinking. From teachers' perspective, VR contents should be designed to be used as educational materials and achieve educational goals in schools.

In order for realistic virtual reality contents to be available to users, they need to be developed for students with severe disabilities to decide and choose by their communication modes. They should be investigated usability of each content to evaluate user interface. [14]

5. Conclusions

This manuscript is written through review and interpretation of Bak et al.'s article [17] in terms of the design and usability of virtual reality contents for nonverbal students with severe disabilities.

Virtual reality contents have been developed that allows students with severe disabilities to choose and decide on their own using their eyes which is a non-symbolic communication mode. It is necessary to prepare design guidelines of virtual reality contents and verify the usability of the contents by reflecting the educational needs of students with severe disabilities. Through this, students with severe disabilities can experience various phenomena in academic curriculum that offered in regular schools. It is possible to provide flexible learning activities that increase the autonomy of students with severe disabilities, build a self-directed learning environment, and expand the physically limited educational field. In addition, disadvantages caused by lack of experience in using information can be prevented.

Abbreviations

VR Virtual Reality
ICT Information Communication Technology

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Author Contributions

Sunhi Bak is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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