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A Study on Active Inquiry Learning Using Interactive Applications in Science Museum

Ryushi Sanada *, Yasuyuki Hirai †

Abstract

This study investigates the educational impact of digital learning tools such as interactive applications compared to video in promoting active inquiry learning in science museums. While digital learning tools are increasingly used in informal education, prior studies have largely focused on usability or factual knowledge, with limited attention to their alignment with constructivist learning or promotion of scientific reasoning. To address this gap, we developed two digital tools—an interactive application and a video—simulating scientific phenomena such as Mars' retrograde motion and the water pearl phenomenon. A field experiment involving 42 eighth-grade students in Japan used a crossover design: one group used the interactive application before the video, and the other in reverse order. Evaluation included pre- and post-questionnaires and analysis of open-ended responses using statistical methods and text mining. Results showed that interactive applications significantly enhanced students' interest, engagement, and exploratory behavior, while videos were more effective for structuring information and aiding retention. These findings suggest that interactive applications, when designed to support trial-and-error exploration and visual-numeric linkage, can effectively foster inquiry-based learning. The study highlights the importance of selecting media based on learning goals and stages and contributes design insights for developing digital tools in informal educational settings like science museums.

Keywords: Interactive Application, Inquiry-Based Learning, Science Museum

1 Introduction

Science museums provide opportunities to improve scientific literacy and foster a spirit of inquiry into science through hands-on learning programs such as science experiments. In recent years, digital learning tools such as interactive applications have been introduced to these learning programs, and research on their educational effects has been conducted [1][2].

Digital learning tools are considered effective in that they enable learners to learn through repeated manipulation and trial and error, increase their interest in learning tasks, and promote deeper understanding. In addition, the simulation functions and visual representations make it possible to observe and reproduce phenomena that would be difficult in actual classrooms or science museums, making it a tool of high educational value [3].

On the other hand, learning in science museums emphasizes constructivist learning through various dialogues between visitors and knowledge, such as "dialogue with actual materials," "dialogue with curators," and "dialogue among learners [4]. From this perspective, there is a

* Department of Design Strategy, Graduate School of Design, Kyushu University
† Strategic Design, Faculty of Design, Kyushu University

need to develop learning tools that encourage "understanding of relationships" and "active meaning making," rather than mere transmission of knowledge. However, evaluations of digital learning tools in science museums in existing studies have been limited to knowledge acquisition and usability evaluation, and the development of learning tools in line with the learning policies of science museums and verification of their effectiveness are insufficient.

The purpose of this study is to compare digital learning tools to identify and to compare it with video tools to clarify the characteristics and educational effects of a learning program that actively explores scientific relationships.

2 Research Methods

This study took the following two-stage approach to develop learning tools that support active inquiry learning and to verify their effectiveness. First, as the first step, we organized previous studies on learning programs using digital learning tools and clarified the requirements for the development of learning tools at science museums. Next, as the second step, we conducted a comparative experiment using digital learning tools such as interactive applications and video through a field survey to evaluate the educational effects of each tool.

2.1 Literature Survey and Identification of Learning Tool Requirements

The literature review was based on the following two main points

(1) Research on trends in the use of digital learning tools and their learning effects

(2) Policies of learning programs at science museums and the learning status of elementary and junior high school students

From the above survey, we will consider school education and science museum learning programs and extract the requirements for digital learning tools in science museum.

2.2 Field Study: Experimental Comparison of Interactive Applications and Videos

Based on the requirements obtained from the literature review, two types of learning tools (an interactive application and a video) were created and a comparison experiment was conducted with second-year junior high school students. The two scientific phenomena targeted were the "Mars retrograde phenomenon" and the "water pearl phenomenon (a strobe light-induced visual illusion)" which are also treated in science museums. Both phenomena are difficult to experiment with in the classroom and require visual and dynamic representation.

The interactive application shall be responsible for the effect of considering the relationship between objects by manipulating the parameters that cause scientific phenomena (orbital period/timing of strobe) and displaying the corresponding movements of the planets and water droplets. The video tools were made by recording the operation screen of the interactive application and adding subtitles to provide the same information as that of the interactive application.

The experiment was conducted using a crossover order, in which the order of experiencing the interactive application and watching the video was reversed for the two classes. After a pre-questionnaire was administered, the students experienced each tool, and post-experiment questionnaires, including a post-questionnaire and free-response questions, were collected.

2.2 Data Analysis Methods

Quantitative data from the questionnaires were obtained using the five-item method, and statistical analysis was conducted using R. Normality was verified using the Shapiro-Wilk test, equal-variance using the F test, and appropriate t-tests or nonparametric tests (Wilcoxon test) were performed. The significance level was set at $p<0.05$.

In addition to p-values, effect sizes were calculated using Cohen’s d to evaluate the practical significance of the differences observed. The calculations were performed in R using the “effsize” package, and effect sizes were interpreted according to conventional thresholds (small ≥ 0.2, medium ≥ 0.5, large ≥ 0.8).

For the free text responses, co-occurrence network visualization and word classification analysis were performed using the text mining tool KHCoder to eliminate arbitrary interpretations.

3 Literature Survey

3.1 Learning Programs Utilizing Digital Learning Tools

In recent years, the use of ICT in school education has accelerated, and especially since the “GIGA School Initiative” by the Ministry of Education, Culture, Sports, Science and Technology in 2019, classroom practices incorporating digital learning tools have increased. In the Ministry of Education, Culture, Sports, Science and Technology's (MEXT’s) report, “Learning Innovation Project: Demonstration Research Report,” learning using videos and simulators is positioned as “learning to deepen thinking,” and the following points are cited as the effectiveness of digital learning tools [5].

- Easy repetition of trials of learning tasks increases interest and deepens understanding
- Experiments and phenomena that are normally difficult to reproduce can be reproduced through simulation.

In a previous study of media comparison in school settings, Murakami et al. conducted an experiment for elementary school students on the subject of “basic operation of a gas burner. Comparing video and print materials, the video tools were significantly more effective in terms of both knowledge and skills, and the ease of understanding was also rated higher [6]. In addition, Itoi et al. compared manipulatable simulation-type learning tools with conventional learning tools consisting mainly of still images for university students and found that the former showed higher learning outcomes [7].

Iizuka et al. compared Flash-based operable educational tools with PDF and Web-based educational tools and found that the operable educational tools showed higher usability, although there were some issues with the learning content [8]. These results suggest that manipulatable learning tools have the potential to promote active learning for learners.

As for the implementation of digital educational tools in science museums, Iwasaki et al. developed tablet educational tools on the subject of “annular solar eclipse,” which were highly evaluated at a workshop for elementary school students [9]. Endo et al. used tablet learning tools about “electricity” at children's halls and science museums and obtained certain results in terms of “ease of understanding [10].

Regarding domestic and international research trends, a CiNii search using the keywords “science museum” and “digital learning tools” yielded 8 references, and a Google Scholar search using “science museum, digital learning” yielded 661 references. Although some of these include examples of advanced learning tools utilizing AR and other technologies [11], there are only a limited number of studies that compared media types (e.g., interactive applications and videos) and verified their educational effects.

3.2 Educational Perspectives in School and Science Museums: Towards the Design of Inquiry-Based Learning Tools

Learning in science museums is viewed from the perspective of “constructivist learning” or “science communication (SC),” which differs from traditional knowledge acquisition-based education. Takayasu defined “learning in museums” as contextual and constructivist learning based on individual life experiences and positioned it as “SC activities arising from personal context = intrinsic value [12]. This is the viewpoint that the process of visitors constructing their own values and meanings is learning itself, rather than being guided to correct answers by exhibits and learning tools.

Watanabe also sees SC activities as “activities that allow science and technology to permeate society through two-way communication, rather than one-way transmission of information from scientists,” and SC in science museums tends to emphasize the creation of meaning through personal experience [13].

On the other hand, a survey on the learning status of elementary and junior high school students shows that “independent, interactive, and deep learning” was included in the Guidelines for the Course of Study for the 2009 academic year [14]. In junior high school science, students are expected to form hypotheses and causal understanding through observation and experimentation, but the results of TIMSS 2011 and the National Assessment of Student Achievement suggest that there are issues with students' ability to interpret and express themselves based on experimental results [15][16].

Miyata points out that in elementary school students' explanatory writing, “they only enumerate facts and do not fully construct causal relationships,” and emphasizes that scientific understanding requires the ability to integrate and explain multiple factors [17].

Based on the above research, we set the requirements for the interactive application targeting learning in science museums. Based on the current Courses of Study and the issues in the learning situation that have been pointed out, we set the objectives of “being able to understand why this is so and the connections between knowledge,” and adding the perspectives of SC and constructivist learning, “being learner-centered” and “being able to construct knowledge by oneself without focusing only on the acquisition of knowledge. The following three items were set as requirements for the interactive application to meet these objectives.

(1) the relationship between visual continuity and numerical change should be clearly shown
(2) learners should be able to freely perform trials and manipulations
(3) be structured in an exploratory manner, without assuming correct or incorrect answers

These requirements form the basis for the interactive application design policy for the field study presented in the next chapter.

4 Field Survey

4.1 Purpose of the Survey

The purpose of this survey is to identify the educational characteristics of a learning program in which learners set their own experimental conditions and actively explore the relationships among scientific phenomena. Specifically, we will compare and verify the impact of each medium on learners' understanding and interest using an interactive application and video tools with equivalent information.

4.2 Outline of Implementation

- Implementation date: March 8, 2025
- Target: Two classes of 2nd graders at a municipal junior high school in Akita Prefecture (N=42)
- Design: Comparative experiment using a two-group crossover method (interactive application-precedence group and video-precedence group)
- Experimental order:
  * Interactive application → Video (Class A)
  * Video → Interactive application (Class B)

The main purpose of the experiment was explained to the teachers and students in advance, and it was made clear that the experiment was to measure the quality of the learning experience, not to evaluate learning. The questionnaires were anonymous and tracked using identification numbers to ensure participant confidentiality.

4.3 Tools Used

The following two scientific phenomena were the subjects of this study.

- Mars retrograde phenomenon: Mars appears to move in the opposite direction due to the difference in the orbital periods of the Earth and Mars.
- Water pearl phenomenon: A phenomenon in which water droplets appear to stop or move backward by irradiating strobe light on water droplets falling at a certain period.

4.3.1 Applications (interactive learning tools)

The interactive application allows the following operations.

- Mars retrograde: The orbital period of the Earth and Mars can be changed to see the change in motion.
- Water Pearl: Users can freely adjust the timing of falling water droplets and strobe light to experience changes in visibility.

Both interactive applications are designed to encourage hypothesis-testing learning by visualizing continuous changes through numerical manipulation.

These interactive applications were developed based on the three design principles outlined in Chapter 2 to promote active inquiry learning in science museums:

(1) a clear linkage between visual continuity and numerical change (e.g., planetary orbits and strobe intervals)

(2) allowing learners to freely manipulate parameters to facilitate hypothesis testing (e.g., real-time adjustments)

(3) an open-ended structure that avoids fixed correct answers to support exploratory and dialogic learning.

These features were intended to encourage independent thinking, foster peer interaction, and cultivate scientific reasoning through hands-on engagement.

4.3.2 Video (passive educational tool)

The video tool is a recording of the operation screen of the above interactive application, with subtitles added. The video was edited to provide the same information content as the interactive application, with a viewing time of approximately 1 minute.

4.3.3 Reference links (last viewed on April 15, 2025)

Mars Interactive application: https://openprocessing.org/sketch/1508327
Mars Video: https://www.youtube.com/watch?v=s0rylLov-Lo
Water drop interactive application: https://openprocessing.org/sketch/1502272
Water drop video: https://www.youtube.com/watch?v=1gI6xLLum24

4.4 Experimental Procedure

This survey was conducted on two classes (interactive application-precedence group and video-precedence group) using the following steps.

(1) Introductory explanation and preliminary questionnaire
As an introduction common to both classes, an overview of the experiment and a brief explanation of the scientific phenomena to be studied were given. Regarding the Mars retrograde phenomenon, the backward movement of Mars was presented, and the subject was introduced to the "orbit of the planet" as the cause of the phenomenon. An animation illustrating the water pearl phenomenon—where droplets appear to rise and stop—was shown. The components of the phenomenon were explained as "periodic light blinking" and "water droplets falling at regular intervals."

(2) Learning tool experience and post-questionnaire (by order)
In this study, the classes were divided into two groups: those that experienced the interactive applications and the videos in that order (hereinafter referred to as the "app-precedence group") and those that experienced the videos and the interactive applications in that order (hereinafter referred to as the "video-precedence group"), and the educational tool experience and questionnaire were conducted as follows.

【Flow of the "app first" group】
- Experience of the interactive application tools (3 minutes x 2 tools)
- Personnel divided into 10 groups of 2 per group to operate PCs.
- Questionnaire (4 minutes)
- Watch each video (approx. 1 min.) twice
- Questionnaire after the experiment (choice/free description)

【Flow of the "video first" group】
- experience the video tools
- view each video (approx. 1 min) twice
- Post-experience questionnaire (4 minutes)
- experience with the interactive applications (total of 6 minutes) - divided into 8 groups of 2 persons and 2 groups of 3 persons.
- Questionnaire after the experiment (choice/free writing)

4.5 Ethical Considerations in Conducting the Experiment

This experiment was conducted in the classroom by the researcher based on a pre-prepared procedure manual and explanation sheet. The following points were clearly communicated to the students:

- That the purpose of this experiment was not to assess academic achievement, but to evaluate the learning experience.
- That participation in the experiment was voluntary and that they could withdraw or ask questions at any time.
- That some questions may be intentionally left unanswered during the experiment.

Prior consent was obtained from the vice principal and homeroom teacher before the experiment was conducted. The questionnaires were anonymous and were managed by number identification so that individuals could not be identified.

4.6 Creation of the Questionnaire Items

The evaluation of the learning program was conducted from both quantitative and qualitative perspectives. A five-item questionnaire was used for quantitative evaluation, while open-ended questions were used for qualitative evaluation.

(1) Pre- and post-questionnaire

The questions of the pre- and post-questionnaire were designed based on the design intent and learning objectives of this study, referring to the evaluation index of Takahashi et al [18] (Table 1).

* The questions in Table 1 are retrograde Mars, but the Water Pearl phenomenon questions have been rewritten and implemented.

1. Are you interested in ~?
2. Do you think it is fun to do?
3. Can you imagine how ~ looks like in action?
4. Can you think of many reasons why ~ happens?
5. Would you like to tell your friends and family about?

Each item was answered on a 5-point scale from “Not at all (1 point)” to “Very much (5 points)”.

(2) Questionnaire after the experiment

The following four items were set for the purpose of evaluating impressions of the overall learning experience and comparative evaluation of the educational tools.

1. Which did you think was more enjoyable, the interactive application or the video (choice type)
2. Which did you think was easier to understand, the interactive application or the video (selective)?
3. What did you think was good about the interactive application (free format)
4. What did you think was good about the video (free format)

Through these questionnaires, we aimed to gain a multifaceted understanding of the characteristics of each tool and learners' responses.

Table 1: Survey Item Extraction

Educational Objective	Evaluation Framework	Evaluation Tool Question Items
Develop interest and curiosity in the mysterious motions of science through digital learning programs	Positive attitude toward science (learning) and society	・Are you interested in the motion of stars? ・Do you think learning about the motion of stars is fun?
Be able to imagine how the scientific phenomena addressed in the program appear to move	Understanding of concepts and visualization of scientific phenomena	・Can you imagine how Mars appears to move during retrograde motion? ・To what extent can you think about why Mars appears to move in retrograde?
Feel that you have understood the cause of the scientific phenomenon in your own way	Acquisition of scientific knowledge and conceptual understanding	・To what extent do you understand why the retrograde motion of Mars occurs?
(This item was excluded because it is not intended to assess the ability to make scientific judgments.)	Scientific methods and ways of thinking	(No corresponding evaluation tool items are set for this framework)
Feel like talking about the scientific phenomenon with people around you	Application (responding to social situations, decision-making)	・Would you like to talk to your friends or family about the retrograde motion of Mars?

4.7 Analysis Method

In this study, learning effects were analyzed from both quantitative and qualitative data. The following is an overview of each analysis method.

(1) Quantitative data analysis

The results of the pre- and post-questionnaire responses using the five-question method were quantified and statistically analyzed. The most positive response ("strongly agree") was given a score of 5, and the most negative response ("completely disagree") was given a score of 1, and the score for each item was calculated.

Statistical analysis was performed using the statistical software "R" and the following procedures were used.

- Test of normality: Shapiro-Wilk test
- Test for equality of variances: F-test
- Comparison between groups:

* With correspondence (prior and posterior comparison of the same group): Student's t-test or Wilcoxon signed rank test

* No correspondence (comparison of interactive application and video groups): Welch's t-test or

Wilcoxon rank sum test

Statistical significance was accepted if the p-value was less than 0.05.

In addition to p-values, effect sizes were calculated using Cohen's d to evaluate the practical significance of the differences observed. Cohen's d was computed using the "effsize" package in R, with values interpreted according to conventional thresholds (small ≥ 0.2, medium ≥ 0.5, large ≥ 0.8).

(2) Analysis of Qualitative Data

Text mining methods were used to eliminate arbitrary interpretations by the analysts for the free text responses. After correcting notational distortions (e.g., unifying "understand" and "know") and correcting errors, a co-occurrence network analysis was conducted using the text analysis software "KHCoder".

In the analysis, frequently appearing words and their co-occurrence relationships were visualized, and the strength of the relationship between words was evaluated by the Jaccard coefficient, which was calculated as the "number of documents containing words A and B" divided by the "number of documents containing word A or word B."

Through these analyses, we attempted to extract learners' response tendencies and characteristic keywords for each tool.

4.8 Results

4.8.1 Score change of pre- and post-questionnaire

In the pre- and post-questionnaire using the five-item method, the scores increased in many items for both tools. In particular, significant improvement was observed in the "interest" and "enjoyment" items after the interactive application experience.

* Interactive applications: Statistically significant score increases in 4 out of 5 items ($p<0.05$)
* Video: Significant score increase in 3 out of 5 items ($p<0.05$)

In addition, both interactive application and video increased scores on items such as "Imagining the movement of scientific phenomena" and "Recalling causes," indicating a learning effect.

Table 2: Comparison of the points before and after the study program
(the phenomenon of the retrograde movement of Mars)

Question Item	Group	Pre	Post	p-value
Are you interested in the motion of stars?	App	3.3 ± 0.94	4.4 ± 0.86	0.0002441
	Video	3.4 ± 1.15	3.8 ± 0.89	0.01562
Do you think learning about the motion of stars is fun?	App	3.6 ± 1.02	4.6 ± 0.66	0.0004883
	Video	3.7 ± 0.86	4.0 ± 0.82	0.0625
Can you imagine how Mars appears to move during retrograde motion?	App	2.8 ± 1.04	3.9 ± 0.99	0.001953
	Video	2.4 ± 0.94	4.2 ± 0.72	2.29E-05
To what extent can you think about why Mars appears to move in retrograde?	App	1.8 ± 0.87	3.1 ± 1.12	0.0001221
	Video	1.6 ± 0.49	3.5 ± 0.94	1.91E-06
Would you like to talk to your friends or family about the retrograde motion of Mars?	App	3.4 ± 1.01	3.9 ± 0.85	0.0625
	Video	3.5 ± 0.99	4.2 ± 0.78	0.0009766

Table 3: Comparison of the points before and after the study program (water pearl phenomenon)

Question Item	Group	Pre	Post	p-value
Are you interested in the water pearl phenomenon?	App	3.7 ± 1.14	4.8 ± 0.54	0.001953
	Video	3.7 ± 1.05	4.0 ± 0.71	0.0625
Do you think learning about the water pearl phenomenon is fun?	App	3.9 ± 0.89	4.8 ± 0.54	0.003418
	Video	4.0 ± 0.90	4.2 ± 0.83	0.3125
Can you imagine how water droplets appear to move in the water pearl phenomenon?	App	3.1 ± 0.89	3.9 ± 1.09	0.01105
	Video	3.4 ± 1.15	4.5 ± 0.58	0.003418
To what extent can you think about why the water pearl phenomenon occurs?	App	2.8 ± 0.94	3.7 ± 1.00	0.0009766
	Video	2.4 ± 0.94	3.8 ± 0.79	0.0001221
Would you like to talk to your friends or family about the water pearl phenomenon?	App	3.7 ± 0.91	3.9 ± 1.26	0.2578
	Video	4.1 ± 0.95	4.4 ± 0.72	0.1719

4.8.2 Comparison of point increase

A comparison of the difference in pre- and post-use scores (amount of increase) between the learning tools showed the following trends (see Table 4).

For "interest" and "enjoyment," the amount of increase was significantly higher for the interactive application ($p < 0.05$), with Cohen's d values exceeding 0.7, indicating medium to large effect sizes.

For other items, an increasing trend was observed for both interactive applications and videos, but no significant difference was confirmed, and the corresponding effect sizes were small or negligible ($|d| < 0.5$).

This result suggests that the interactive applications have a high effect on motivation to learn and affective aspects.

Table 4: Proportional comparison of point increase for interactive applications and videos

Question Item	Topic	App Gain	Video Gain	p-value	Cohen's d (App-Video)
Are you interested in ~?	Mars	1.2 ± 1.15	0.4 ± 0.65	0.02117	0.7824205
	Water	1.1 ± 1.20	0.3 ± 0.62	0.03507	0.8140456
Do you think learning about ~ is fun?	Mars	1.1 ± 1.02	0.3 ± 0.63	0.01739	0.8489632
	Water	0.9 ± 1.01	0.3 ± 0.54	0.03368	0.7212157
Can you imagine how ~ appears to move?	Mars	1.2 ± 1.24	1.8 ± 1.24	0.09782	-0.4907259
	Water	0.8 ± 1.12	1.0 ± 1.40	0.8626	-0.1154476
To what extent can you think about why ~ occurs?	Mars	1.3 ± 1.04	1.9 ± 0.92	0.0642	-0.611038
	Water	1.0 ± 1.07	1.3 ± 1.23	0.3488	-0.2959431
Would you like to talk to others about ~?	Mars	0.5 ± 1.02	0.6 ± 0.77	0.412	-0.1477098
	Water	0.3 ± 0.83	0.4 ± 0.96	0.9363	-0.1084652

4.8.3 Post-Experiment Questionnaire: Analysis of Free Descriptions

The participants were asked to respond to free descriptions of "what they thought was good" about the interactive application and the video. The descriptions consisted of the following number of words and vocabulary:
* Interactive application: 77 sentences/605 words (number of words used: 308)
* Video: 56 sentences/402 words (number of words used: 212)
Frequent words and co-occurrence networks extracted by text mining are shown in Figures 2 and 3.

In the interactive application, action words such as "manipulate," "try," "move," and "change" were frequent, indicating that learners were confirming their own hypotheses as they explored

In the video, many words related to clear communication of information, such as "explain," "understand," and "easy to see," were used, suggesting that they contributed to the organization and promotion of understanding of the learning content.

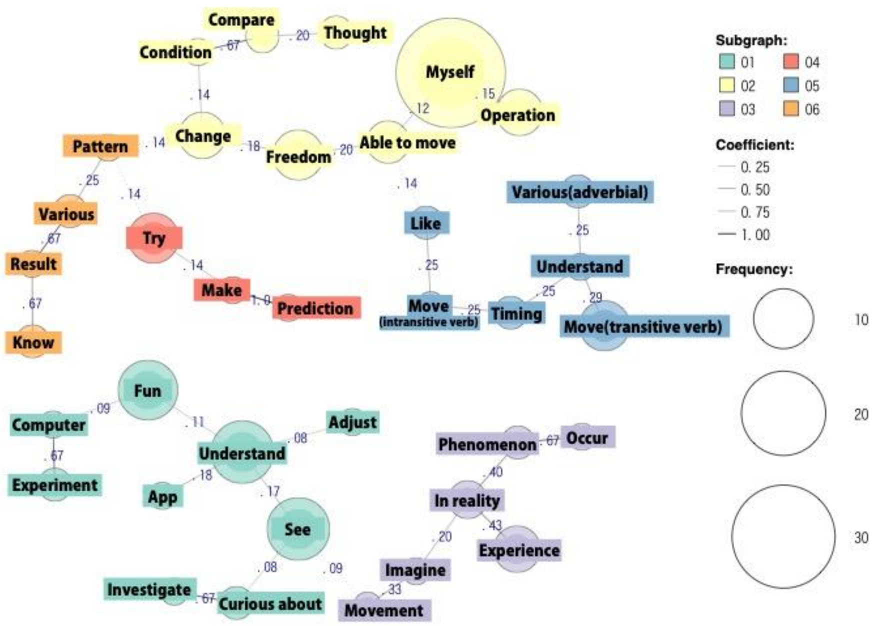

Figure 1: Co-occurrence network of "good points of the interactive application"
*This figure is translated and displayed from the analysis in Japanese

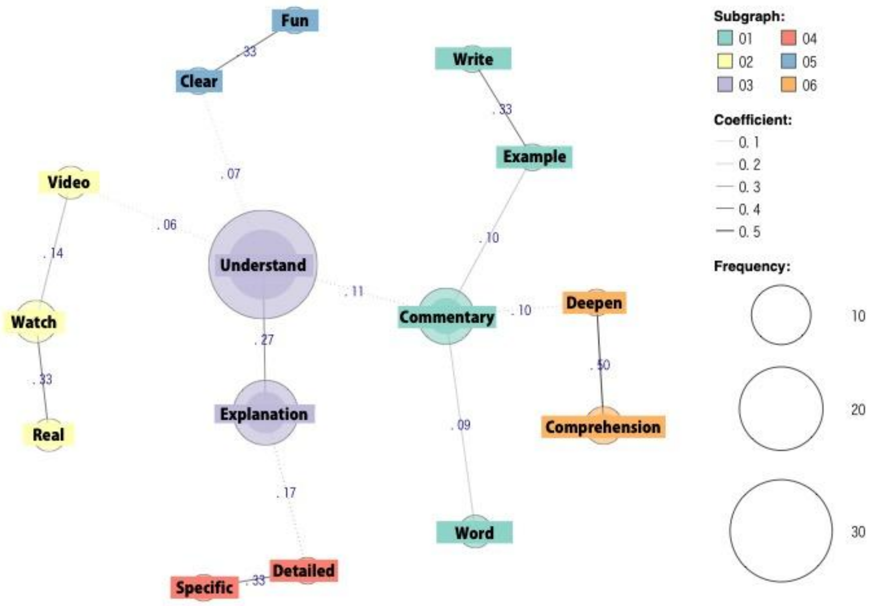

Figure 2: Co-occurrence network of “good points of the video”

*This figure is translated and displayed from the analysis in Japanese

4.8.4 Post-experiment questionnaire: tabulation of choice-type items

The distribution of responses to the choice-type questions (“Which is more fun?” and “Which is easier to understand?”) in the post-learning questionnaire is shown in Figures 4 and 5.

* The majority of respondents who answered “enjoyable” chose the interactive application as the learning tool

* Video was slightly more dominant in the “easy to understand” responses

These results reflect the differences in the characteristics of each educational tool, with interactive applications contributing to arousing interest and promoting action, and videos contributing to organizing information and assisting understanding.

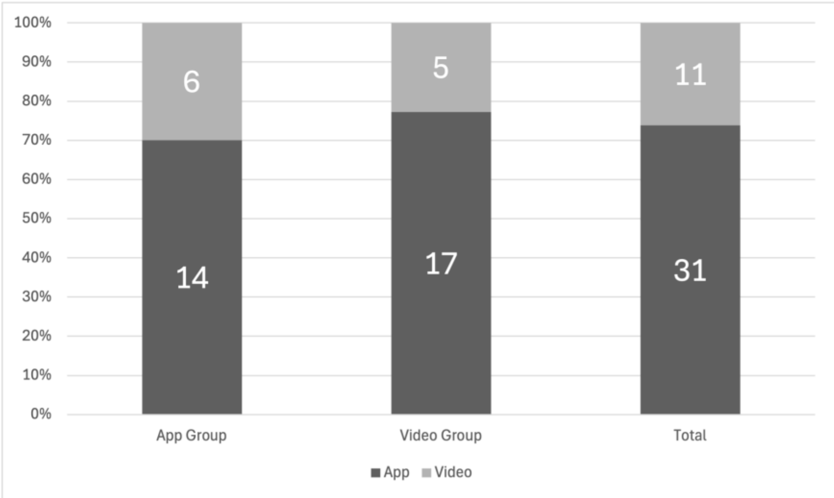

Figure 3: Results of the “Which do you think is more enjoyable, the interactive application or the video?

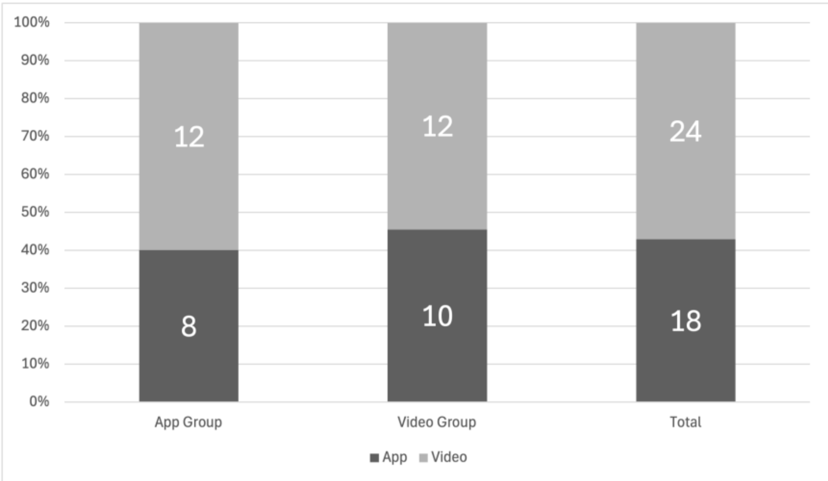

Figure 4: Results of the “Which do you think is easier to understand, the interactive application or the video?

5 Discussion

In this study, we conducted an experiment to compare the learning effects of two types of digital learning tools, an interactive application and a video, on scientific phenomena for science museum. Based on the results obtained, the characteristics and educational significance of each learning tool are discussed below.

5.1 Effects on Interest and Enjoyment

The results of the questionnaire showed a significant increase in scores for “interest” and “enjoyment” after experiencing the interactive applications. In particular, the interactive application exceeded the video in terms of point increase, and the difference was statistically significant. This result suggests that the process of learners making hypotheses and checking the results through their own operations strongly affected the affective aspect.

In the free descriptions, there were many words that indicated active behavior, such as “try,” “change,” and “investigate by myself,” suggesting that the interactive application experience brought out learners' independent behavior. This is an extremely important result in terms of evoking the “joy of learning” in inquiry-based learning.

5.2 Influence on Understanding of Phenomena and Causal Reasoning

In the questions “Imagining the movement of phenomena” and “Recalling causes,” both the interactive application and the video increased scores, indicating a learning effect. In particular, in understanding the “Mars retrograde” and “water pearl phenomenon,” which include abstract movements, both the interactive application, which enables the visual capture of continuous changes, and the video, which has an organized structure, are considered to have functioned effectively.

On the other hand, a comparison of the amount of point increase by the digital learning tools showed no significant difference, suggesting that interactive applications and videos are complementary in terms of promoting understanding of cause-and-effect relationships.

5.3 Effect on Willingness to Share with Others

In the question “Do you want to tell your family and friends about what you have learned?”, a significant increase in score was observed only after the video experience. This suggests that videos have a structure that makes it easy to explain the content learned to others.

On the other hand, observations during the interactive application experience showed that the interactive application encouraged immediate interaction and collaboration among learners, such as adjusting experimental conditions while sharing operating procedures with each other. This indicates that the interactive application is more suitable for “thinking together with peers” style learning than “teaching others.

5.4 Utilization According to the Characteristics of the Learning Tools and Learning Stages

As is clear from the text mining results, interactive applications and videos have different lexical tendencies, requiring the selection of learning tools according to learners' cognitive styles and objectives. Specifically, it is effective to use the interactive applications as inquiry-based learning tools that support hypothesis generation and relationship building, and the videos as introductory learning tools that support clear knowledge organization and comprehension.

The junior high school students who were the subjects of this experiment were in the developmental stage of logical thinking and causal reasoning, and the experience of manipulating the interactive applications was compatible with their development.

5.5 Implications for Digital Learning Tool Design in Science Museum

The application in this study was created with three requirements: “visual and numerical linkage,” “free operation,” and “non-correct composition”.

As a result, it was confirmed that these are effective guidelines for designing educational tools that elicit learners' interest, promote collaboration with others, and encourage hypothesis testing behavior.

These findings provide an important perspective for the development of digital learning tools in science museums, aiming to create learning tools that are not merely explanatory tools but also "triggers" for dialogue and thinking.

5.6 Limitation

This study has several limitations that should be addressed in future research.

First, the learning effects examined were short-term and limited to immediate post-intervention responses. Future studies should investigate long-term retention and behavioral changes to better understand the sustained impact of digital learning tools in informal educational settings.

Second, the current evaluation focused primarily on affective and conceptual learning outcomes, such as interest and basic understanding. Future research should consider incorporating assessments of higher-order learning outcomes, including scientific reasoning and explanatory writing, to capture deeper levels of inquiry-based learning.

Finally, the participants were limited to Japanese eighth-grade students. Therefore, caution is needed when generalizing the findings to other age groups or cultural contexts. To strengthen the generalizability of the findings, follow-up studies should involve more diverse populations.

Despite these limitations, this study provides important implications for the design and implementation of interactive digital tools in science museums.

6 Conclusion

The purpose of this study was to compare two types of digital learning tools, interactive applications and videos, in learning programs at science museums, and to examine the characteristics and effectiveness of learning in which learners actively explore the relationships among scientific phenomena.

First, through the literature review, it was shown that educational tools required in science museums need to be designed based on "constructivist learning" and "science communication. Based on this, this study developed an interactive application that meets the following three requirements and conducted a comparative field study with video.

(1) the relationship between visual continuity and numerical change should be clearly shown
(2) learners should be able to freely perform trials and manipulations
(3) be structured in an exploratory manner, without assuming correct or incorrect answers

The results of the comparative experiments with second-year junior high school students confirmed that the interactive applications were remarkably effective in arousing interest and increasing the enjoyment of learning, especially in terms of promoting active inquiry behavior and dialogue among learners. On the other hand, videos played a role in supporting clear organization of information and retention of understanding and were found to be particularly suitable for beginning learners and for learning in the introductory stage.

These results suggest that more effective learning programs can be designed by using both interactive applications and videos for different learning objectives and stages. In addition, the interactive application experience activated inquiry-based thinking, such as hypothesis formation and relationship building, indicating its potential as a learning tool to support "independent, interactive, and deep learning" in science museums.

In the future, it is necessary to conduct further empirical studies that respond to the diversification of target age groups and learning content, and to aim for the advancement of design guidelines and evaluation methods for digital learning tools in science museums. As a part of this effort, this study provides a direction for new learning design that supports the understanding of scientific phenomena and the development of a spirit of inquiry.

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