An Epistemic and Psychological Comparison Between Holograms and Zoom as Educational Media

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Abstract

Deficiencies in online communication software inspired the HoloLearn project that proposes to aid hybrid education via a hologram. Yet the epistemic and psychological effects of this medium remain largely uncharted. To help integrate the hologram into a hybrid education system, the present study conducted experiments which explored the nature of the hologram itself. With a lecture on *Japanese History until 1603*, this research compared the hologram's twofold effects on students with Zoom, an already popular option for online lecturing. The study concludes that there is no statistically significant difference between the two teaching modalities, and also suggests that the hologram, depending on the viewer, can be either engaging or distracting. Flaws in experimental design and other external constraints might have exerted some influence on these findings.

1 Introduction

The Covid-19 pandemic lent sudden popularity to online communication tools, e.g. Zoom, whose conveniences and limitations subsequently also came to light. These defects have prompted researchers from the LDE Center for Education and Learning, the New Media Center and the TU Delft student council to conceive the HoloLearn project as an alternative to Zoom for online/remote/hybrid education with the aid of a hologram. However, the emergence of this new medium incites both enthusiasm and concerns, for good reason. Studies on the hologram as an educational tool have long been scarce. Integration of holograms into classrooms is hindered partly by the worrisome paucity of studies, and exploring what influence the hologram can have on students thus became the research topic of this paper. A similar study by Paredes and Vazquez (2020) compares holographic lectures with traditional/physical settings. The present study attempts to complement existing hologram research by examining its effects compared to Zoom lectures.

1.1 Research Question

The research question is: How does viewing the whole body of the teacher affect learning outcomes and flow experience for students?

Learning outcomes were measured by two tests, which, given the nature of the taught subject, were aimed at knowledge memorization instead of transfer. Flow is "a subjective state that people report when they are completely involved in something to the point of forgetting time, fatigue, and everything else but the activity itself" (Csikszentmihalyi, 2014, p.230). The research question investigates two underlying forms of effects, epistemic and psychological. Admittedly, these two aspects incorporate much more metrics outside the scope of this study, which focuses solely on learning outcomes and flow experience.

1.2 Hypotheses

The hypotheses were derived from the following analysis: Viewing the whole body of the lecturer, as enabled by a hologram, provides additional social cues. Zoom lectures, where students usually see just a "talking head", cannot include those social factors. Additionally, the presence of a full body image of the teacher might help students experience flow more intensely. Therefore, the two main hypotheses of the study are:

- H1: Holographic lectures lead to better learning outcomes than Zoom lectures

- H2: Holographic lectures lead to better flow experience than Zoom lectures

1.3 Outline

What follows is a brief outline of the paper. Firstly, a theoretical background will be provided in the Background section. Details of the experiments, including participants, materials, and procedure, are spelled out in the Method section. The results of the experiments are explained at length in the Results section and the Discussion section. The Responsible Research section discusses some ethical issues in the study, and ensures the reproducibility of the experiments. Finally, the Conclusion section concludes the whole paper.

2 Background

Scant attention has been paid to what effects the hologram can have on its receivers, and hologram as an educational medium was an idea even more obscure. Ghuloum (2010) surveyed British teachers for their opinions on 3D Hologram Technology, where only 45.5% of the respondents believed its effectiveness as a teaching tool, but no actual experiment on holograms was done. A more recent study conducted by Paredes and Vazquez (2019) employed actual holograms in the experiments, and the authors have garnered preliminary evidence which showed paltry improvement of students' learning outcomes in a holographic setting, compared to physical lectures. But in their study, a holographic session was also under the presence of a face-to-face teacher, which can complicate the conclusions. To view the medium from another perspective: hologram is a type of multimedia; the researcher Mayer (2014) proposed 12 general principles of multimedia learning by which educators are urged to abide. The personalization principle, related to H1 in this paper, hinges on the theory that "social cues in multimedia instructional messages can prime a social response in learners that leads to deeper cognitive processing and better learning outcomes" (Mayer, 2014, p.248). We can only accept this theory with reserve because Mayer framed this process as a theoretical framework, which means further evidence is needed to validate it. Nevertheless, as body language comprises an indispensable social cue, one has reason to expect the learning outcomes to be better in the hologram group.

Given the immersive nature of hologram as opposed to Zoom lectures, its psychological impact (particularly flow experience) on students is equally worthy of examination. Flow is a mental state named by Csikszentmihalyi (2008), and describes an experience of intense concentration, with disappearance of self-consciousness. It is theoretically probable that the hologram creates a more palpable connection between the lecturer and students than Zoom lectures, so that the students are likely to experience flow more intensely. The empirical study by Paredes and Vazquez (2020) buttressed this conjecture, where they found higher levels of flow experience than traditional/physical classes. This insight leaves another question to be answered: how flow is affected by the hologram compared to Zoom lectures.

3 Method

3.1 Purpose of the Study

The purpose of the study is to conduct experiments by which the effects of the hologram on students can be measured in numerical scales. The teaching modality was the independent variable. The learning outcomes and flow experience were the dependent variables.

3.2 Participants

3.2.1 Participant Characteristics

The 12 participants in the Zoom (control) and hologram (treatment) groups are enrolled students at TU Delft with sufficient command of English. They major mostly in Computer Science and Engineering, with little intersection with Japanese history, which was taught in our experiments. To ensure an equal start for them, a pre-test was used to measure their understanding of Japanese history. Furthermore, no participant is of Japanese nationality.

3.2.2 Sampling Procedure

The participants were recruited through the social networks of the five researchers in this Research Project group. Taking into account their availability on either June 9^{th} or 10^{th}, we assigned each participant a group randomly.

3.2.3 Sample Size

For both the control group and the treatment group, there were six participants. This is indeed a small size, which rendered statistical analysis difficult and conclusions more tenuous. But the lack of time and other resources was a major hindrance to a larger sample.

3.3 Apparatus

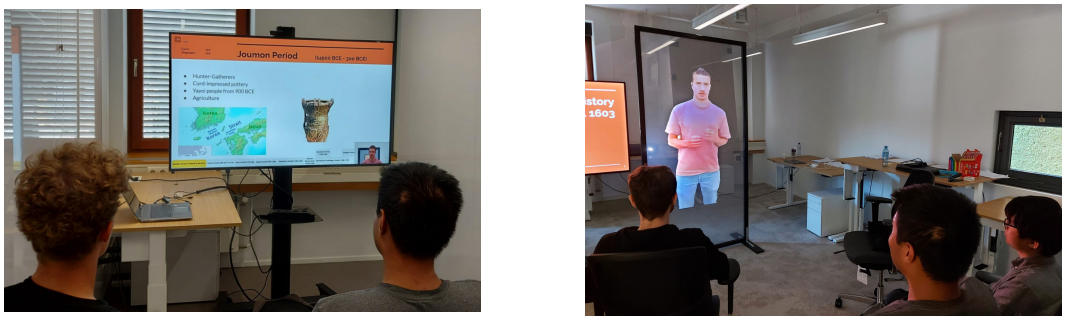
The experiments depended on the following software and technologies. OBS was the recording software used before the actual experiments. The video and audio files were merged, synced, and edited before being put into the apparatus listed below.

Monitors

Because the Zoom lecture was not live, a video was edited to imitate the typical layout of an online Zoom meeting. This resulted in a setting shown in Figure 1a.

HoloDisplay

The hologram display screen, developed by the HoloLearn project, was the main device in the holographic lecture. A Bluetooth speaker was put below the HoloDisplay so that sound could reach all participants loud and clear. A monitor alongside displayed the slides, aptly synchronized with the projected lecturer on HoloDisplay. An overview of this group looks like Figure 1b.



(a) Control group

(b) Treatment group

Figure 1: Settings for the two groups

3.4 Procedure

All participants first entered a room and stood at tables with consent forms. They first signed the forms and handed them to the researchers. After that, a pre-test was given to the participants as a measure of their mastery of Japanese history that was about to be taught through two different modalities. They completed the test, took the sticky notes as their random IDs, and entered two different rooms. Then began two lectures on *Japanese History until 1603*, a Zoom lecture for the control group and a holographic lecture for the treatment group. They were required to remain silent whiling watching the lectures, and asking questions was not possible as the lectures were recordings instead of live streams. Immediately after the lectures, they took the post-test that measured their learning outcomes. They were also asked to fill out a questionnaire, some questions of which were designed to measure their flow experience. When both items were completed and collected by the researchers, the participants left the rooms.

3.5 Materials and Measures

Two dependent variables were measured in this study via two tests and a questionnaire.

Learning Outcomes

Learning outcomes are the knowledge gained during the lectures, and they were measured by two tests before and after the lectures. The nature of a lecture on Japanese history required that the exams lean towards memorization of knowledge rather than transfer.

Flow Experience

Although various methods that measure flow experience exist, they are not suitable for the present study because of long duration of measurement or because they are intended to measure flow in physical activities (Moneta, 2012). This study made use of the questionnaire developed by Paredes and Vazquez (2020) since our experiments are highly similar.

4 Results

The limited sample size of our experiments permitted only non-parametric statistical analysis, in particular, the Mann-Whitney U test. This section is divided into two subsections on learning outcomes and flow experience. The participants are referenced by their random ID and their group title initial, such as 3H (participant 3 in the hologram/treatment group). The Python script used to derive the statistics is in Appendix C.

4.1 Learning Outcomes

Test results of the control group and the treatment group are summarized in Figure 2. The maximum achievable score for both tests is 7, and minimum 0. Note that all but one candidate in the groups scored 0 in the pre-test, hence one blue bar visible, indicating the participants' near-zero knowledge of Japanese history before 1603.

The Mann-Whitney U test was performed firstly on the pre-test results of the two groups, with $U = 15$, $p = 0.40$, which indicates that there was no significant difference between the knowledge of both groups prior to the lectures. Regarding the post-test, learning outcomes in the treatment group (mean = 3.50) did not differ significantly from the control group (mean = 3.83) either, with $U = 17$, and $p = 0.60$. We cannot reject the null hypothesis,

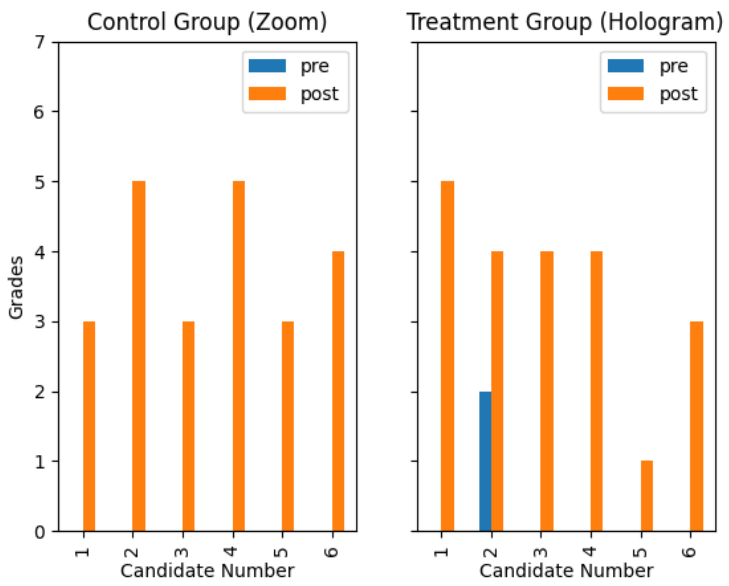


Figure 2: Pre-test and post-test grades

which means that there was no difference in learning outcomes of the Zoom lecture group and the holographic lecture group. Thus, H1 is not accepted.

The researcher also compared the Robot group ($p = 0.79$) with the control group and the VR group ($p = 0.65$) with the control group, and no difference is found either. For full statistics, the reader is invited to run the python script in Appendix C.

4.2 Flow Experience

The flow experience questionnaire is separated logically into two parts. The first 6 questions produce numerical values which collectively denote the intensity of flow experience, while the 7^{th} open question can record what the participants experienced under their teaching modality, to be discussed in the next section. Their flow experience in numerical scale can be seen in Figure 3. Scores ranged from 6 to 30. Higher score indicates better flow experience.

The one-tailed Mann-Whitney U test on the difference between the control group (mean = 18.83) and the treatment group (mean = 20.33) shows that $U = 12.5$, $p = 0.21$. This means that one cannot reject the null hypothesis, i.e. there is no statistically significant difference in the intensity of flow experience between the two groups. Thus, H2 is not accepted.

The researcher also compared the Robot group ($p = 0.64$) and the VR group ($p = 0.43$) respectively with the control group, and no difference is found either. Full statistics can be obtained by running the script in Appendix C.

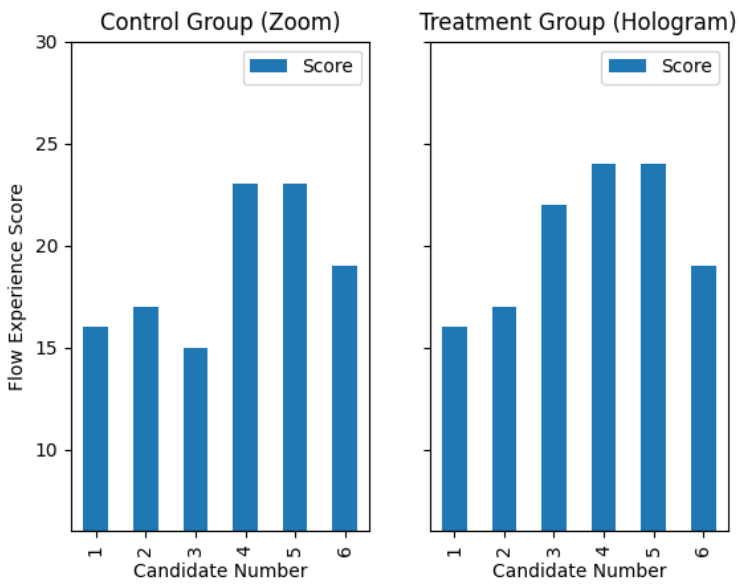


Figure 3: Flow experience scores

5 Discussion

The two hypotheses laid out in the first section cannot be accepted based on the collected data, and the research question is answered negatively: there is no statistical difference in learning outcomes or flow experience between the two teaching modalities. Besides the data points, there are other less obvious issues here that merit further discussion.

5.1 Learning Outcomes

Learning outcomes did not show a statistically significant difference. But the feedback on the 7^{th} question of the flow experience questionnaire hinted at some less conspicuous factors whose influence on the learning outcomes is discussed below.

Teaching Subject Japanese history is a subject with which the participants of sciences and engineering are supposed to be unfamiliar. The research group members did have this subject chosen to ensure an equal start for all participants, yet the sheer amount of Japanese names, titles, and places on the slides might have had their minds preoccupied to the point that the hologram could not convey any more meaningful information. A drastically different subject, such as mathematical analysis, probably would not suffer from this problem, and could yield surprising results.

Tests Except the instructions on top of the paper, the pre-test and post-test are formulated exactly the same, as shown in Appendix A, although the participants were unaware of this fact beforehand. How much the pre-test might have influenced participants' attention to the lecture slides is difficult to estimate, but a different version of post-test could have produced grades dissimilar to the present ones.

5.2 Flow Experience

The full answers from the participants may be found in Appendix D. Only excerpts are listed below to illustrate some points worthy of note.

Hologram as an interesting medium In the control group, quality of the lecture became the point of attack. 1Z characterized the video lecture as "Quite monotone", and 6Z thought the teacher was not "too knowledgeable", nor "passionate", and that he "was just reading" and "didn't give explanations for anything". In the treatment group, no critical comments on the lecturer himself were given. 3H and 4H mentioned that the hologram piqued their interest, that it "feel[s] more like a classroom and less like a YouTube video" and "the projection of the lecturer on full size made the lecture feel more interactive".

Hologram as a distracting medium 1H and 6H, conversely, complained of the hologram's distracting nature in the lectures: "a moving light image is extremely distracting", and "sometimes I got distracted by the hologram". Flow in the treatment group might have been curbed because of this distraction. Whereas in the control group, diversion of attention was not attributed to the "talking head" in the Zoom video, but to the Japanese names.

Overwhelming slides What the treatment group and the control group both acknowledged is that the information on the slides was far more essential to their understanding than the hologram/the talking head. 2H wrote: "it was a lot of information to process and retain", 5H agreed: "it was lots of information to keep track of", and 6H confirmed: "The contents on the slides were a lot". In the Zoom group, where the lecture video was the sole focus of the participants, the excess of information still rendered their experience less satisfactory. 2Z wrote: "[the lecture] went by quickly for too many topics", 3Z was "distracted by the amount of names that were dropped" and 5Z was confronted by "too many names of people and periods at once". In retrospect, our research group did devise a lecture with an equal start for all, but the excessive information presented to the participants might have disabled the benefits of the hologram altogether. Csikszentmihalyi (2008) produced Figure 4 to show that when challenges are beyond skills, people tend to experience anxiety instead of flow. With information on the slides that came to the participants thick and fast, they probably deviated from the "Flow Channel", shown in the figure below. This may have contributed to the absence of difference in flow experience.

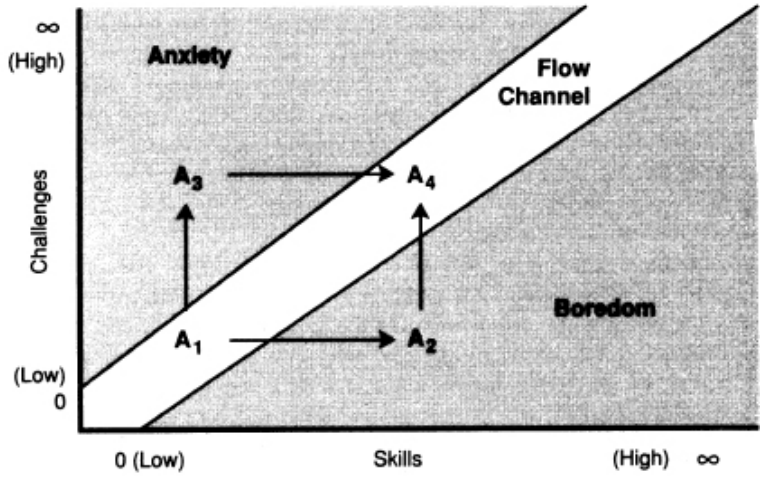


Figure 4: Two dimensions of flow experience (Csikszentmihalyi, 2008, p.74)

5.3 Implications for the HoloLearn Project

Despite the inconclusive observations in the preceding subsections, the paper so far has failed to address another subtler problem. If it is overlooked, the value of the present study will be diminished. The problem is described here, in the hope that the argument below would provide a new understanding of the current theme and give impetus to further research.

Although technological innovation is an earmark of TU Delft, the technology of HoloLearn is in itself detached from its full potentials, unless it "becomes a medium as it employs a particular symbolic code, as it finds its place in a particular social setting" (Postman & Postman, 2005, p.84). Accompanying this transformation inevitably is an epistemic bias which stems from the structure of the technology itself. As history suggests, a new medium often bears a purpose from its inventors, usually to circumvent the monopoly of older media, and to imitate and extend their functions (Kovarik, 2015). The first printed books looked like manuscripts in form, and the first photographs captured objects of painting. Similarly, our study made special efforts to ensure that the hologram and the Zoom lectures conveyed exactly the same message. But it is more prudent to postulate that the form of human communication determines partially the ideas that may be most easily exchanged, that is, the medium shapes the content. Therefore, we expect that a medium carries an epistemic bias, whose influence on its receivers must be treated with caution and skepticism. For example, Ong and Hartley (2012) regarded writing, as opposed to speech, as a medium promoting analytical and logical thinking. Postman lambasted the profusion of television in the US because the medium's entertaining nature runs counter to serious public discourse (Postman & Postman, 2005). What this implies is that learning outcomes and flow experience, two variables measured in the present study, may be trivial in the sense that the hologram as a medium has the power to alter the content of the curriculum possibly without much notice. Students under this new condition might think of and reason about vastly different things. Whether the hologram leads to better learning outcomes or flow experience becomes a matter of only secondary importance. This reorientation of epistemology, to some extent unpredictable and fraught with intellectual uncertainties, can be controlled in part by an education philosophy from the institution that admits the medium.

The traditional classroom and the hologram can coexist without clash only if the education philosophy of the institution permits their integration. For instance, Postman (1979), noting the dangers of "holding" an education philosophy, favored the thermostatic view of education: that the chief function of education is to conserve tradition when innovation is prevailing in the culture (or vice versa), and to reveal the biases of the predominant information environment in a culture and oppose them with different media. He noted that the forms of communication comprise an information environment, and any intrusion of a new medium thus brings changes in intellectual predispositions. Educators' job is to remain alert to changes in the information environment, and to inspect biases therein to restore intellectual balance in pupils' minds. Under this view, the hologram would not be granted entrance into classrooms, for it fosters the same biases as other electronic media. Naturally, one may hasten to argue against such a philosophy. But the contention here is that for any education institution, such as schools or universities, there needs to be an instance of education philosophy, and all educational affairs should serve this credo. It appears unclear what the education philosophy of the HoloLearn project is, or whether there is one at all. Regardless, it is imperative that the members and leaders of the project identify or create the philosophy. Once it exists, the hologram must be assessed under its criteria, before we give a verdict on the value of the hologram as a medium. To allow premature integration without a thorough understanding and examination is to place students' intellect in peril.

6 Responsible Research

From the outset of the study, the researchers did their utmost to collate a minimum amount of data from participants. By the end of the experiments, only their names (for consent forms), exam results and answered questionnaires were collected on paper. We have taken special measures to ensure their anonymity. To match the two exams, we assigned random ID's to participants so that the results cannot be traced back to any individual. All the data and consent forms are saved separately by the five researchers, and no one else has access. Furthermore, the data on paper will be destroyed after the end of the project, while digital versions will continue to be available as appendices of this paper.

The results obtained in the experiments are products of the following factors, including but not limited to: the participants, the teaching materials and subject, lecturing devices, and testing materials, on which the reproducibility of this study depends. Experiments involving human subjects, especially in such a small sample size, produce results dependent on the participants. For each group, merely 6 participants were recruited, and a much larger sample is needed to perform a sound statistical analysis. Most devices employed in the experiments belong to the HoloLearn project, access to which warrants a research purpose; some others are free software and paid hardware (e.g. monitors), and reproducibility of the study thus rests on all of these as well. Furthermore, it is not inconceivable that for other subjects, such as mathematics or linguistics, experiments would have produced different results and hence different conclusions. Therefore, the findings of this study are also contingent on the exact nature of the subject being taught. The pre-test and post-test are found in Appendix A. The questionnaire which measured flow experience is located in Appendix B.

The author presented all the aggregated and anonymized data transparently in this paper, and unless specifically mentioned in square brackets, no data points were omitted or modified. The procedure through which data were generated and collected was documented at length in the Method section. Thanks to the anonymity of the research data, conclusions thus drawn are not based on the characteristics of participants. In addition, no argument in this paper originates from any political, economical, or religious biases. Errors in data processing or data analysis might have occurred in this study. Therefore, corrections and suggestions are also highly appreciated.

7 Conclusions and Future Work

This paper has as its purpose to answer the research question: How does viewing the whole body of the teacher affect learning outcomes and flow experience for students? The results of the experiments conclude that no statistically significant difference in learning outcomes or flow experience can be found between the two groups, the first of which could see the whole body of the teacher on a hologram, and the second of which could see but a talking head. The present study has attempted to parallel the experiments by Paredes and Vazquez (2020), though not of the same duration or magnitude. An interesting finding here is that some participants found the hologram engaging, and others, distracting. The veracity of this observation depends on future work.

At this point, the researcher must reiterate that the experimental design was not without flaws, e.g. too much information given in one lecture. One logical improvement therefore is to pace the narration at a moderate rate, so that students are not inundated with too many facts at once. This leaves more mental resources for the students to process extra information

from the hologram as well. Future research with bountiful resources at its disposal may also conduct similar experiments that teach diverse subjects, last a longer period, and include more participants with different backgrounds. If technological difficulties can be overcome, a live-streamed lecture mediated by HoloDisplay is an ideal improvement, in which case the classroom becomes truly interactive.

Although the Discussion section tends to evoke ambivalence instead of clarity, more research in the future might discover and validate the hidden value of the hologram. In the meantime, students of TU Delft, as foremost stakeholders of this progressing research, ought not to be kept in the dark. Announcements on new findings can be made to inform students who may be the first beneficiaries of this technology.

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A Pre-test and Post-test

PRE-TEST

In the interest of the research, you may skip questions if you do not know the answer.

1. Which period denotes the first Shogunate?
   - Sengoku Period
   - Kamakura Period
   - Muromachi Period
   - Kofun Period

2. How did Taira no Kiyomori gain power in the court?
   - Staged a coup d'état, ousting the Emperor
   - Fighting and winning in a lot of battles and gaining favour from the court
   - He came from a family of high nobility and status
   - Having his daughter marry the Emperor

3. Which one of the following battles took place at sea?
   - Battle of Yashima
   - Battle of Ichi-no-tani
   - Battle of Sekigahara
   - Battle of Dan-no-ura

4. After losing the battle against Ashikaga Takauji, Go-Daigo sets up the…
   - Northern Court
   - Western Court
   - Southern Court
   - Eastern Court

5. Oda Nobunaga lived in the…
   - Heian Period
   - Sengoku Period
   - Joumon Period
   - Nara Period

6. What is **not** correct about Minamoto no Yoshitsune?
   - Fled from battle during the Genpei War
   - He is the half-brother of Minamoto no Yoritomo
   - He is chased down due to suspicion and forced to commit suicide when surrounded
   - According to rumour, escaped to Mongolia and re-surfaced as Genghis Khan

7. How many times did Japan invade Korea during Toyotomi Hideyoshi's rule?
   - 1 time
   - 2 times
   - 3 times
   - 4 times

POST-TEST

In the interest of the research, please answer every question.

1. Which period denotes the first Shogunate?
   - Sengoku Period
   - Kamakura Period
   - Muromachi Period
   - Kofun Period

2. How did Taira no Kiyomori gain power in the court?
   - Staged a coup d'état, ousting the Emperor
   - Fighting and winning in a lot of battles and gaining favour from the court
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   - 1 time
   - 2 times
   - 3 times
   - 4 times

B Flow Experience Questionnaire

2. Flow Experience

For each statement put **X** in the appropriate box.

1. I enjoyed my class in Japanese history.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

2. The Japanese history class seemed tedious.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3. The Japanese history class kept me attentive.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

4. I was easily distracted in the Japanese history class.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

5. The Japanese history class stimulated my curiosity.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6. The Japanese history class was indifferent to me.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7. Describe in words your experience in the Japanese history class.

C Python Script

```
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
from scipy.stats import mannwhitneyu


def compare_tests_with_Zoom(treatment, zoom, label=""):
    print("Comparing learning outcomes of the {} group with Zoom".format(label))

    zoom_pre = zoom["pre"]
    zoom_post = zoom["post"]
    treatment_pre = treatment["pre"]
    treatment_post = treatment["post"]
    n1, n2 = len(zoom_post), len(treatment_post)

    # plotting the data points
    fig, axes = plt.subplots(1, 2, sharey=True)

    def to_df(pre_series, post_series):
        df = pd.DataFrame([pre_series, post_series]).transpose()
        df.columns = ["pre", "post"]
        df.index = 1 + np.arange(len(pre_series))
        return df

    zoom_df = to_df(zoom_pre, zoom_post)
    treatment_df = to_df(treatment_pre, treatment_post)
    zoom_fig, treatment_fig = axes[0], axes[1]

    zoom_fig.set_ylim([0, 7])
    zoom_fig.set_title("Control Group (Zoom)")
    zoom_fig.set_xlabel("Candidate Number")
    zoom_fig.set_ylabel("Grades")
    zoom_df.plot.bar(ax=zoom_fig)
    treatment_fig.set_ylim([0, 7])
    treatment_fig.set_title("Treatment Group ({})".format(label))
    treatment_fig.set_xlabel("Candidate Number")
    treatment_df.plot.bar(ax=treatment_fig)

    plt.savefig('tests Zoom vs {}.png'.format(label))

    # Mann-Whitney for the pre test and post test:
    print("Pre test:")
    U1_pre, p_pre = mannwhitneyu(zoom_pre, treatment_pre)
    U2_pre = n1 * n2 - U1_pre
    U_pre = min(U1_pre, U2_pre)
    print("Mann-Whitney for the pre-test : U = {}, p = {}".format(U_pre, p_pre))

    print("Post test:")
    zoom_post_mean = np.mean(zoom_post)
    treatment_post_mean = np.mean(treatment_post)
    U1, p_post = mannwhitneyu(zoom_post, treatment_post, alternative="less")
    U2 = n1 * n2 - U1
    U = min(U1, U2)
    print("Zoom mean = {}, {} mean = {}.".format(zoom_post_mean, label, treatment_post_mean))
    print("Mann-Whitney for the post-test : U = {}, p = {}\n".format(U, p_post))


def tests():
    print("\n1. Evaluating tests:")
    zoom = {"pre": np.zeros((6,)), "post": np.array([3, 5, 3, 5, 3, 4])}
    hololearn = {"pre": np.array([0, 2, 0, 0, 0, 0]), "post": np.array([5, 4, 4, 4, 1, 3])}
    robot = {"pre": np.array([1, 0, 0, 0, 0]), "post": np.array([4, 3, 3, 4, 3])}
    vr = {"pre": np.zeros((5,)), "post": np.array([1, 3, 5, 4, 4])}

    compare_tests_with_Zoom(hololearn, zoom, "Hologram")
    compare_tests_with_Zoom(robot, zoom, "Robot")
    compare_tests_with_Zoom(vr, zoom, "VR")


def compare_flow_with_zoom(treatment_data, zoom_data, label=""):
    print("Comparing flow experience of the {} group with Zoom".format(label))

    # question 2, 4, 6 need to be inverted to (6 - score)
    inverted = [1, 3, 5]
    zoom_data[:, inverted] = 6 - zoom_data[:, inverted]
    treatment_data[:, inverted] = 6 - treatment_data[:, inverted]

    zoom = zoom_data.sum(axis=1)
    treatment = treatment_data.sum(axis=1)

    # plotting the data
```

```
    fig, axes = plt.subplots(1, 2, sharey=True)
    zoom_fig, treatment_fig = axes[0], axes[1]

    zoom_df = pd.DataFrame(zoom)
    zoom_df.index = 1 + np.arange(len(zoom))
    zoom_df.columns = ["Score"]
    zoom_fig.set_ylim([6, 30])
    zoom_fig.set_title("Control Group (Zoom)")
    zoom_fig.set_xlabel("Candidate Number")
    zoom_fig.set_ylabel("Flow Experience Score")
    zoom_df.plot.bar(ax=zoom_fig)

    treatment_df = pd.DataFrame(treatment)
    treatment_df.index = 1 + np.arange(len(treatment))
    treatment_df.columns = ["Score"]
    treatment_fig.set_title("Treatment Group ({})".format(label))
    treatment_fig.set_xlabel("Candidate Number")
    treatment_df.plot.bar(ax=treatment_fig)

    plt.savefig("flow Zoom vs {}.png".format(label))

    # mean values: for reporting purposes
    zoom_mean = np.mean(zoom)
    hololearn_mean = np.mean(treatment)
    print("Zoom mean = {}, {} mean = {}.".format(zoom_mean, label, hololearn_mean))

    # Mann-Whitney tests
    U1, p = mannwhitneyu(zoom, treatment, alternative="less")
    n1, n2 = len(zoom), len(treatment)
    U2 = n1 * n2 - U1
    U = min(U1, U2)
    print("Mann-Whitney post test : U = {}, p = {}\n".format(U, p))


def flow():
    print("\n2. Evaluating flow experience:")
    zoom_data = np.array([[3, 3, 2, 3, 2, 3],
                          [3, 4, 3, 2, 4, 5],
                          [3, 4, 3, 4, 3, 4],
                          [4, 2, 4, 3, 4, 2],
                          [4, 2, 3, 3, 4, 1],
                          [3, 4, 3, 3, 4, 2]])

    hololearn_data = np.array([[3, 4, 2, 5, 4, 2],
                               [4, 4, 2, 4, 4, 3],
                               [4, 4, 4, 2, 4, 2],
                               [4, 2, 4, 2, 4, 2],
                               [4, 2, 4, 2, 4, 2],
                               [4, 2, 3, 4, 3, 3]])

    robot_data = np.array([[4, 2, 4, 2, 4, 2],
                           [3, 4, 2, 4, 4, 2],
                           [2, 4, 1, 3, 2, 3],
                           [5, 3, 5, 1, 5, 1],
                           [3, 4, 2, 4, 2, 4]])

    vr_data = np.array([[2, 2, 2, 5, 3, 3],
                        [5, 2, 4, 2, 4, 2],
                        [4, 4, 3, 3, 4, 3],
                        [4, 4, 2, 4, 4, 2],
                        [4, 3, 3, 3, 3, 3]])

    compare_flow_with_zoom(hololearn_data, zoom_data, "Hologram")
    compare_flow_with_zoom(robot_data, zoom_data, "Robot")
    compare_flow_with_zoom(vr_data, zoom_data, "VR")


if __name__ == '__main__':
    print("This script evaluates learning outcomes and flow experience")
    tests()
    flow()
```

D Answers to the Open Question

1H:
The info in the slides is important. But a moving light image is extremely distracting. I noticed that I didn't pick up any knowledge in the first 5 minutes, after mentally blocking out the video of the lecturer I could follow along much better.

2H:
I felt interested at the start, but it was a lot of information to process and retain so half way through zoned out a bit.

3H:
Took me back to my years in high school. But having the virtual teacher definitely helps it feel more like a classroom and less like a YouTube video. Having the lecturer be able to interact more with students would definitely make it even more like a classroom.

4H:
It was entertaining. Seeing the projection of the lecturer on full size made the lecture feel more interactive. I was more motivated to ask questions and to not wander off.

5H:
It was fun. The names are hard to get. Might be better to have a shorter one cuz it was lots of information to keep track of.

6H:
Hologram kept me interested in the class. The contents on the slides were a lot and sometimes I got distracted by the hologram.

1Z:
Quite monotone which is especially harder to follow with all the hard names to remember.

2Z:
Went by quickly for too many topics but was overall interesting.

3Z:
It was interesting but I mainly was distracted by the amount of names that were dropped and the difficulty of pronouncing them.

4Z:
I learned new things and found it interesting.

5Z:
Very interesting material just too many names of people and periods at once if you are not used to such names.

6Z:
The teacher did not seem too knowledgeable. The slides had too much text and the lecturer was just reading. The teacher didn't seem passionate and didn't give explanations for anything.