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RESEARCH ARTICLE

SUV: Students' Understanding Visualizer to Support Instructors in Synchronous Online Lectures

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ABSTRACT Due to the COVID-19 pandemic, university instructors shifted their classes online to ensure the continuation of numerous students' learning. Although researchers created and evaluated tools to support students and instructors in classes in various settings, the tools to help university instructors in synchronous online education are still under-examined. To fill this gap, we introduce Students' Understanding Visualizer (*SUV*), a system that visualizes students' understanding in real-time during synchronous online lectures. To explore instructors' experience and *SUV*'s usability, we conducted a lab-based usability session with eight university instructors in South Korea by asking them to perform a series of tasks with *SUV* and share their experience. The interview results of this study revealed the benefits *SUV* would give in actual synchronous online lectures by delivering students' understanding of lectures to instructors. Moreover, we found instructors' challenges in using our system and potential features to be added to *SUV* to enhance the users' experience. Based on the findings, we propose design opportunities for creating tools that allow instructors to give synchronous online lectures more effectively and in interactive ways.

INDEX TERMS Distance learning, instructors, online lectures, students' understanding, visualization.

I. INTRODUCTION

During the COVID-19 pandemic, the education sector was one of society's most hugely impacted sectors [1]. With the strong advice of the World Health Organization (WHO) to avoid crowded places, close-contact settings, and confined enclosed spaces, schools had no choice but to cancel in-person classes for everyone's safety. As the number of COVID-19 cases surges, 61 countries fully closed their schools by April 21st, 2020, affecting over 1.5 billion learners and interrupting learning for at least 9 out of 10 students worldwide [2]. Moreover, more than 1,300 colleges and universities in all 50 states in the US canceled in-person classes or shifted to online in the spring semester 2020 [3]. In the fall 2020 semester, 10% of institutions were converted to entirely online, 34% to primarily online, and 21% to a hybrid. However, despite efforts to continue education online, various factors prevent students and instructors from building success

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in online education. Since students and instructors are not in the same space physically, they often have difficulties communicating and staying connected to each other [4], [5], [6], [7]. Obstacles such as a lack of experience using technology as a medium for learning or teaching [8] and limited access to technology [9], [10] make online education more challenging. Also, instructors and students had a short time implementing and adapting to distance learning. Especially considering that online education would continue even after the pandemic and the education sector would be in dire need of it in unavoidable situations such as the pandemic, timely support for instructors and students is imperative.

There have been multiple studies about supporting traditional classroom learning for students and instructors before the pandemic, such as proposing wearable devices measuring students' emotional, behavioral and cognitive engagement in class and allowing students to monitor their own engagement [11], [12]. Moreover, some researchers suggested a system that helps instructors' professional development by capturing pedagogically-relevant classroom data beyond what a human observer in a classroom can do [13]. Simultaneously, researchers investigated various ways to support online learning before the demand for online learning accelerates during the COVID-19 pandemic. Primarily, there was already an increasing growth and adoption of education technology [14]. Prior studies showed how technology is capable of supporting and improving the online learning of students and instructors by proposing various tools and methods. For instance, He et al. [15] developed a tool that shows the students' progress in online courses so the students can utilize it to plan out their schedule for watching course videos. Moreover, Granjo and Rasteiro [16] developed a tool called a *LABVIRTUAL* that would help students in Chemical Engineering prepare for their labs by providing interactive videos. Glassman et al. [17] proposed a tool called Mudslide, which allows students to mark the parts of the lecture slides they were confused about from the recorded videos. Also, Shobana and Kumar [18] presented the *I-Quiz* system that captures and analyzes learners' non-verbal behavior and provides insights regarding their level of knowledge acquisition in a synchronous online learning environment. While multiple studies focused on developing tools to support students and instructors in online classes, the tools to help university instructors in synchronous online education are still under-examined. Therefore, further research is necessary to develop tools that would assist instructors in real-time online learning and evaluate the developed tools to see if it is feasible in synchronous online classes.

To extend the line of research on the development of technology for supporting instructors in synchronous online lectures, we explore six research questions (see Table 1). Our pilot study was composed of three main stages: 1) setting design goals, 2) developing a system, and 3) evaluating a system (see Fig.1). We first set design goals that were inspired by the systematic review of the literature [19], addressing **RQ1.** Next, we developed Students' Understanding Visualizer (*SUV*) that would support university instructors in synchronous online lectures by presenting students' understanding of lectures in real-time as a graph format. Finally, aiming to answer research questions **RQ2-6**, we conducted lab-based usability sessions with eight university instructors. The results from the surveys and interviews showed that *SUV* would be usable and feasible for instructors to use in synchronous online lectures. We also found that instructors would struggle using *SUV* while conducting online lectures when their students' understanding is presented as a graph. Moreover, after analyzing the evaluations of *SUV*, we present design opportunities for designing the system that is applicable in actual synchronous online lectures and would enhance the interaction between the student and instructors. Hence, our study makes the following contributions:

1) We present the process of developing Students' Understanding Visualizer (*SUV*), a system that supports university instructors in synchronous online lectures by allowing instructors to check students' understanding of lectures in real-time.
2) We investigate the usability of *SUV* by conducting lab-based usability sessions with eight university instructors.
3) We propose design opportunities to improve the usability and feasibility of *SUV* in achieving a better user experience.

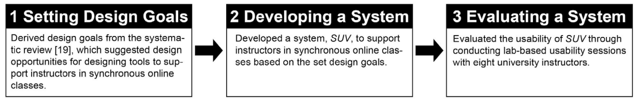

FIGURE 1. Overview of our pilot study. Our study was composed of three parts: 1) setting design goals, 2) developing a system, and 3) evaluating a system.

II. RELATED WORK

This section summarizes previous studies on developing and evaluating the tools to support students and instructors in the asynchronous and synchronous online learning environment. We then present their limitations and explain the necessity of further study to support instructors who deliver synchronous online lectures.

A. TOOLS FOR SUPPORTING ASYNCHRONOUS ONLINE LECTURES

A growing body of research has examined asynchronous online education. Many tools have been proposed to support students and instructors in an asynchronous online learning environment. Compared to the traditional classroom environment, online learning tends to rely heavily on online resources and educational materials accessed via electronics.

1) DEVELOPED AND EVALUATED TOOLS FOR STUDENTS

Prior studies proposed various tools to assist student learning in the asynchronous online environment [15], [16], [18], [20], [21], [22], [23], [24], [25], [26], [27]. Tools were designed to build an interactive learning environment by

TABLE 1. Research questions we aimed to answer in this study.

Research Questions
RQ1: What are the design goals for creating a system that support university instructors in synchronous online lectures?
RQ2: What is the usability of our developed system, Students' Understanding Visualizer (*SUV*)?
RQ3: What would be the benefits for university instructors when using *SUV*?
RQ4: What would be the challenges for university instructors when using *SUV*?
RQ5: What potential features do university instructors want to add to *SUV*?
RQ6: What are the design opportunities for creating tools to support instructors in synchronous online lectures?

collecting direct inputs (e.g., recorded lectures [16], [23], [24], [25], educational images, and infographics [25]) from the instructors and letting students interact with those inputs on virtual platforms [16], [23], [24], [25] to ensure student learning. Mavlankar et al. [23] created a system allowing users to choose region-of-interest from the recorded lecture videos by controlling pan, tilt, and zoom. The researchers observed that students utilized the system to watch different regions of lecture videos during a 3-month pilot deployment at the university. Similarly, Granjo and Rasterio [16] developed a system letting students choose specific segments from the recorded lecture videos based on their interests, finding that students evaluated the system as beneficial for laboratory work preparation and self-regulated study. Different from the other two studies [16], [23], Che et al. [24] proposed a system analyzing the voices of the lecturers in recorded videos and highlighting the contents of online lectures (e.g., subtitles) that the lecturers emphasize. Ahmed and Hasegawa [25] designed a platform letting instructors upload not only videos but also simulations, scientific images, and infographics for teaching students laboratory experiments, which was evaluated as helpful by instructors.

Other four studies developed tools for building a collaborative learning environment by collecting direct inputs (e.g., students' answers for class activities [21], [26], and student profiles [22], students' activities on viewing recorded videos [15]) from the students. For instance, Bremgartner and De Magalhães Netto [21] built a system collecting students' answers from class activities, searching for errors from collected errors, and matching students with other peers who can help with resolving those errors. Similarly, Arguedas et al. [26] proposed a model extracting students' emotional information from students' texts in the chat or forum debates and then visualizing assessed students' emotions as Word Clouds. The researchers found that their model helped students to improve their accomplishments by reflecting on their emotions and taking necessary actions to focus on completing given tasks in class. Lynda et al. [22] designed a system gathering student profiles, forming homogeneous groups of students, and distributing members of the homogeneous groups into separate groups to create heterogeneous groups. The heterogeneous groups allowed students to provide complementary feedback to each other. He et al. [15] developed a tool visualizing students' progress in viewing course videos and found that their tool helped students spend more time online and view more course videos.

On the other hand, researchers proposed a tool for helping students with their learning by collecting indirect inputs (e.g., non-verbal behaviors) during classes [27] and assessment activities such as quizzes [18]. Hwang and Yang [27] proposed an auto-detection mechanism for detecting elementary students' inattention or fatigue during online classes, giving alert reinforcement feedback to students who struggle to be attentive, and giving encouraging reinforcement feedback to attentive students. Shobana and Kumar [18] presented a system capturing learners' non-verbal behavior during assessment activities and providing insights regarding their level of knowledge acquisition by identifying specific areas that the learner struggles with so students know where to improve. Different from previous studies [15], [16], [18], [21], [22], [23], [24], [25], [26], [27], Walsh et al. [20] collected data (e.g., online resources regarding neuroscience) from external sources and let students access the collected data on an educational platform to improve students' knowledge gain in the asynchronous online learning environment. They developed a platform where students can access online resources about neuroscience available worldwide in an outline format that improved students' interest and knowledge in science. Nevertheless, less is known about tools instructors can utilize to ensure students' learning and build a collaborative learning environment in real-time online lectures. Therefore, in this paper, we aim to design a system that allows students to share their understanding of lectures with instructors in real-time and instructors to check students' understanding, allowing them to monitor students' learning status during synchronous online lectures.

2) DEVELOPED AND EVALUATED TOOLS FOR INSTRUCTORS

Prior studies proposed various tools to assist instructors' teaching in the asynchronous online environment [17], [28], [29], [30], [31], [32]. Four studies developed tools for managing students' learning by collecting direct inputs (e.g., students' activities in courses [29], [30], [33], questions regarding lectures [17], [32]) from the students. For example, Mazza and Dimitrova [30], Zapparolli and Stiubiener [29], and Kovanovic et al. [33] proposed systems showing a holistic view of students' activities in online courses, allowing instructors to perceive their activities and take appropriate measures to assist students. Moreover, Soh et al. [32] and Glassman et al. [17] developed systems allowing instructors to see students' questions about lectures. In particular, Glassman et al. developed a system allowing students to indicate muddy points (i.e., unclear parts) of lecture slides shown in recorded lectures, which helps teachers quickly check students' confusion. Different from previous studies [17], [28], [29], [30], [32], Wang and Hsu [31] study collected existing class materials (e.g., teaching templates, learning objects) from external sources and let instructors utilize the collected materials to create teaching content more suitable for their learners. These developments are practical for instructors with student management and class preparation. However, less emphasis was laid on their possible utilization in the synchronous online learning environment. Thus, we focus on managing students' learning in the synchronous online learning environment and propose a system that lets instructors check students' understanding of lectures in real-time.

B. TOOLS FOR SUPPORTING SYNCHRONOUS ONLINE LECTURES

Limited research has been done in studying ways of supporting synchronous online education involving video conferencing. One study presented timely implications to assist instructors' teaching in synchronous online education as many schools rapidly shifted from offline to online learning amid the COVID-19 pandemic [34]. Ma et al. created a system for grasping real-time student learning status by assessing students' non-verbal behaviors (e.g., state, emotion, head/facial behavior, and gaze behavior). They found that instructors considered the system effective when delivering synchronous online classes. However, Ma et al. noted that interpreting implicitly collected students' non-verbal behaviors could be inaccurate as they might have been missed or mistakenly detected due to factors such as video backgrounds, lighting conditions, or camera angles. Therefore, we aim to explicitly collect students' inputs in real-time and assess their learning status without being affected by external factors (e.g., video backgrounds, lighting conditions, and camera angles) by letting students notify whenever they struggle to understand lectures through a simple button click.

C. LIMITATIONS OF PREVIOUS STUDIES

Based on the previous studies, we found that the tools to support university instructors in synchronous online education are still under-examined. Prior studies analyzed existing tools and developed various tools to assist learners and educators in asynchronous and synchronous online learning environments. Nonetheless, most studies focused on developing tools that would support students' online learning and help students improve their learning outcomes. Discussion of tools for supporting university instructors in synchronous online lectures and investigating instructors' experience with those tools are still lacking. As critical stakeholders in education, educators should also be provided with tools that can assist their synchronous online teaching. Moreover, online education will likely continue after the pandemic [35], and instructors' difficulties staying engaged in online classes and interacting with students online are continuously reported [7]. Thus, further research is necessary to support instructors with technologies that incorporate methods built inside the pedagogical space and the human relationships between instructors and students [36]. Our study aims to extend the understanding of the tool's integration with synchronous online teaching and provide empirical findings on how the tool would shape university instructors' experience in real-time online teaching, along with prior studies on tools assisting online education.

$$\%\text{ of the students who understand the lecture} = 100 - \left(\frac{\#\text{ of students who clicked the button}}{\text{total }\#\text{ of students in the current lecture}}\right) * 100 \quad (1)$$

III. SETTING DESIGN GOALS

Our design goals were inspired by the systematic review literature that identified university instructors' challenges in synchronous online teaching [19]. Na & Jung suggested three design opportunities for designing tools for supporting instructors in online teaching: (1) Helping instructors gaining online teaching knowledge, (2) Creating a feature that provides learner feedback, and (3) Assisting instructors with technical issues. Even though the best-case scenario would be incorporating all three design opportunities, we selected one design opportunity and created a tool providing learner feedback after a thorough discussion. We chose students' understanding of synchronous online lectures as learner feedback, which would be delivered to instructors in real-time.

Multiple advantages exist in helping instructors check their studentsúnderstanding in real-time during online lectures. Checking students' understanding allows instructors to make instructional decisions immediately. For instance, if instructors perceive that their students struggle to follow their lessons, they are allowed to make necessary changes instantly (e.g., explaining the concept in more detail, slowing down the pace) to help students understand better. With revising teaching as a direct response to students' learning, instructors checking students' understanding would guarantee high student success in their classes [37]. However, if instructors fail to check their students' understanding during synchronous online lectures, it would be too late to modify instructions to help students achieve the desired learning outcomes. Also, checking students' understanding is especially critical when the instructors deliver new information to students. Since students tend to make errors while processing the construction of understanding new knowledge, instructors can play an essential role in preventing these errors by constantly assessing students' understanding while teaching [38]. Therefore, to design a tool that provides learner feedback to instructors in real-time during synchronous online lectures, we set two specific design goals (**RQ1**):

- **DG1:** Collect data on students' understanding of the lecture in real-time.
- **DG2:** Visualize the students' understanding data so instructors can quickly perceive it while conducting online lectures.

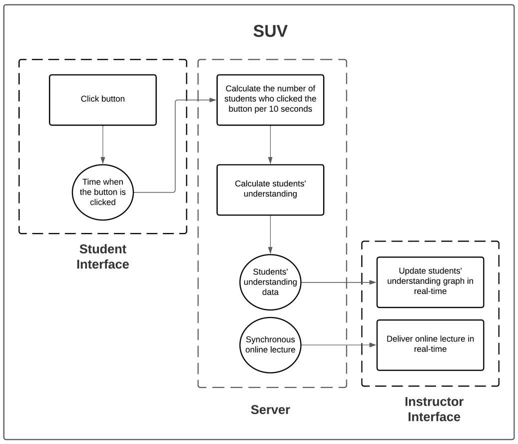

FIGURE 2. The framework of *SUV* comprises three parts: a student interface, a server, and an instructor interface. The student interface is a website that enables students to click the button when they struggle to understand the online lecture. As the students click the button, the timestamp data will be stored on the server, calculating the percentage of struggling students who understand the lecture. The system would visualize the percentage of struggling students as a graph. By accessing the instructor interface, a website for instructors, instructors can see the students' understanding graph.

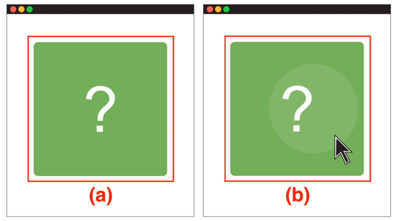

FIGURE 3. Screenshots of *SUV*'s button on the website for students. When accessing the student interface, students will see (a) a green button with a white question mark. The button lets students report that they struggle to understand the lecture with just a simple click. When students click the button, (b) a white circle spreads out from the center of the button to its outer part, showing that they successfully clicked it.

IV. SUV: STUDENTS' UNDERSTANDING VISUALIZER

To achieve design goals, we propose *SUV*, a system collecting data on students' understanding of synchronous online lectures and visualizing the collected students' understanding data to present to the instructors. *SUV* consists of three components (see Figure 2): a student interface, a server, and an instructor interface. The student interface (see Figure 3) takes inputs, the time of the lecture when students get confused, from the students and stores those inputs (i.e., timestamp data) in the server. Next, the server calculates the percentage of students who understand the lecture using Equation 1. Finally, the instructor interface (see Figure 4) visualizes the percentage of students who understand the lecture in a graph format on the instructor interface. *SUV* keeps updating how students' understanding of the lecture changes throughout the lecture so that instructors are allowed to check students' understanding in real-time whenever they want. We expect instructors to easily monitor if their students understand the lecture well in remote classrooms without seeing the students.

A. COLLECTING STUDENTS' UNDERSTANDING OF THE LECTURE

We built an interface collecting students' input (i.e., their understanding of the lecture) to create a students' understanding graph (**DG1**). First, students access the website, where they will find a green button with a question mark (see Figure 3). Also, once the synchronous online lecture begins, they click the button believing they are struggling to understand the lecture contents. To allow students to deliver their understanding of the lecture without being disrupted, we collected the data on students' understanding through clicks. When the students click the button (see Figure 3a), the exact time they clicked the button or the timestamp data are collected from their desktop/laptop and transferred to the server.

Once the system transfers the timestamp data to the server, the data are stored in the server that counts how many students clicked the button every 10 seconds. We set it to 10 seconds because the video lectures used in this study had their slide transitions every 10 seconds on average. Moreover, to prevent users from unnecessarily abusing the button by pressing it numerous times, the server counts the total number of clicks within 10 seconds as one for each user. The server then calculates the percentage of struggling students who understand the lecture (see Equation 1).

B. VISUALIZING STUDENTS' UNDERSTANDING DATA

We built an interface visualizing the students' understanding as a line chart for instructors (**DG2**). We first determined how to visualize students' understanding data. The instructor's interface contains a line chart (see Figure 4) that updates the percentage of current students understanding the lecture every 10 seconds. The graph's x-axis represents the elapsed time of the ongoing lecture (see Figure 4b). The y-axis represents the percentage of students who understand the lecture (see Figure 4a). Thus, the instructors are allowed to determine (1) what percentage of students understand their classes based on the lecture time and (2) when the percentage of students who understand the classes starts to decrease (see Figure 4c) or increase (see Figure 4d).

A viewer application was designed to enable instructors to view the line chart generated by the processed understanding data on a web page. We used React.js[1] and Node.js[2] to develop the web-based application. We used an open-source library provided by npm to update a graph smoothly in real-time. As illustrated in Figure 4, the application displays understanding data transmitted from each student who is currently taking the class as a graph.

V. USER EVALUATION

To explore **RQ2-RQ6**, we explore the instructors' experience with *SUV* and the usability of *SUV* through lab-based

[1]https://react.dev/
[2]http://www.nodejs.org/

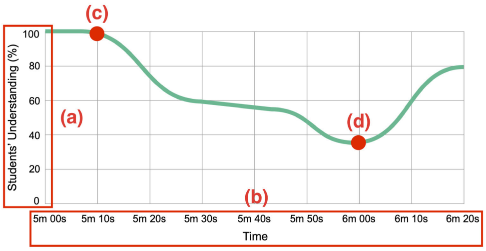

FIGURE 4. ***SUV*'s students' understanding graph. The graph consists of (a) the vertical axis indicating the percentage of the students who currently understand the lecture and (b) the horizontal axis indicating the elapsed time of the ongoing lecture. The green line of the graph indicates the percentage of students understanding the lecture based on the elapsed time of the ongoing lecture. Instructors can see that the percentage of students who understand the lecture started to decrease at (c) and increased at (d).**

usability sessions with university instructors, following the procedure shown in Figure 5. Since it was a lab-based usability session, we did not test *SUV* in an actual real-time online lecture where university instructors and students are in the same online space. Instead, we first showed the recruited instructors' recorded videos that were already posted on YouTube[3] to recruited students. We then asked the students to use the *SUV*'s button on the student's website while imagining that the video was a real-time online lecture. As students clicked the button, their input was stored in the server. We call these students' input *mock data* because they were not collected in actual synchronous online lectures. We used mock data in the system for evaluation as used in prior studies [39], [40], [41].

After the sessions with the students, we prepared the *SUV* instructor's website with the mock data and instructors' videos stored on the server. The instructor's website includes the instructor's own video (see Figure 6a) and the students' understanding graph being rendered as the video is played based on the stored mock data (see Figure 6b). We screen-recorded the instructor's website, capturing the graph rendered as the video was played. We decided to show the screen recording of the website instead of letting instructors access it, preventing situations where they cannot access it due to errors. During the usability sessions, each instructor watched the screen recording containing their own video and the graph reflecting students' understanding of their video. While they were watching the recordings, we asked the instructors to imagine monitoring the graph while teaching synchronous online lectures.

A. PARTICIPANTS

1) INSTRUCTOR PARTICIPANTS

We recruited instructor participants who uploaded YouTube videos so we could show their videos to the student participants to create mock data. To recruit instructor participants, we first identified videos and channels from YouTube. We queried YouTube videos and channels using combinations of keywords, such as "professors", "research videos", "introduction", or "research presentation". We were aware of the possible situation where the topics of the videos might affect collecting students' input during the study. For instance, when a lecture video on a particular field is shown, there is a high chance that some participants majoring in that field would not use our system as they completely understand the video. To ensure the collection of students' input for creating mock data, we aimed to find topics that would be equally unfamiliar to participants regardless of their majors. As a result, we found videos where university instructors introduce their research, as instructors do not generally teach about their research in undergraduate courses. The inclusion criteria for the videos were as follows: (1) in Korean; (2) longer than ten minutes; (3) aimed at graduate or undergraduate students; (4) introducing research studies; and (5) delivered by university instructors.

Finally, we identified three different channels containing videos that met the inclusion criteria above. We reached out to the instructors from the videos via email, and eight instructors showed interest in participating in the experiment. Then we confirmed with the instructors if they meet the following criteria: (1) between the ages of 18 and 64, (2) able to understand Korean, (3) have delivered at least one synchronous online lecture (for at least 50 minutes) in undergraduate courses since March 11th, 2020, (4) have participated in a real-time session at least once through Zoom,[4] and (5) have not participated in this study before. We recruited the participants who ideally have taught synchronous online lectures so that they had adequate teaching experiences to evaluate the usability of the instructor tool. We recruited instructors who have delivered at least one synchronous online lecture since March 11th, 2020, because most instructors would have experience teaching online as WHO declared COVID-19 a global pandemic on March 11th, 2020 [42], and schools rapidly moved from classrooms to online teaching. Also, we gathered the instructors who have prior experience with using Zoom, as our sessions would be conducted remotely through Zoom.

2) STUDENT PARTICIPANTS

In order to make mock data more realistic as possible, we recruited actual university students who would potentially use *SUV* to create inputs while watching the selected lecture videos. We created a pre-registration survey using Google Forms.[5] We posted the survey link and recruitment flyer on online communities for university students in the Republic of Korea, such as "Everytime"[6]. The eligibility criteria for the students were as follow: (1) must be between 18 and 64 years old, (2) must be able to understand Korean, (3) must be enrolled in undergraduate or graduate schools, (4) must have taken at least one synchronous online lecture (for at least

[3]https://www.youtube.com/

[4]https://zoom.us/
[5]https://www.google.com/forms/
[6]https://everytime.kr/

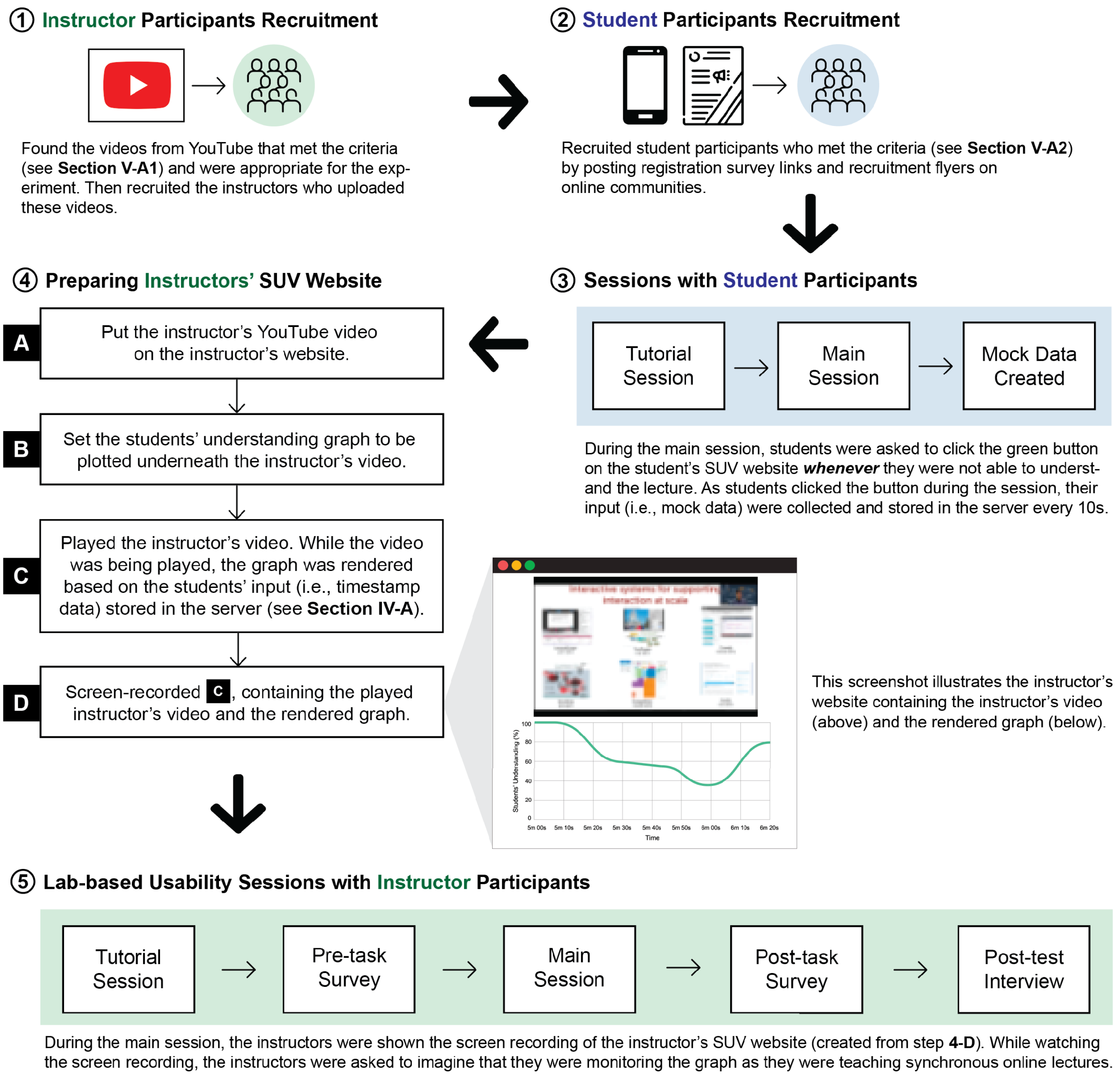

FIGURE 5. A step-by-step flow of the user study.

50 minutes) since March 11th, 2020, (5) must have a desktop or laptop, and (6) must not have participated in this study before. We aimed to recruit undergraduate students enrolled in universities with experience taking synchronous online lectures and evaluate the student tool's usability. Moreover, we looked for students who had access to desktops or laptops since they had to use Zoom and access the *SUV* student's website simultaneously during the experiment. Overall, 126 students filled out the pre-registration survey and marked the possible time slots for their participation. We removed all duplicates before sending emails to students confirming their participation in the study. Moreover, we excluded people who did not fill out the survey appropriately (e.g., entering invalid email addresses such as "zzzzzz@zzz.com") from the pre-registration list. Out of 126 students, 81 were selected as potential study participants. We sent them emails to confirm their participation in the study.

B. PROCEDURE

We obtained data for experiment and evaluation through the following procedure. First, we asked student participants to watch the instructor's video and report their understanding using the *SUV* button. Then, we created the students' understanding graph based on the data from students. Lastly,

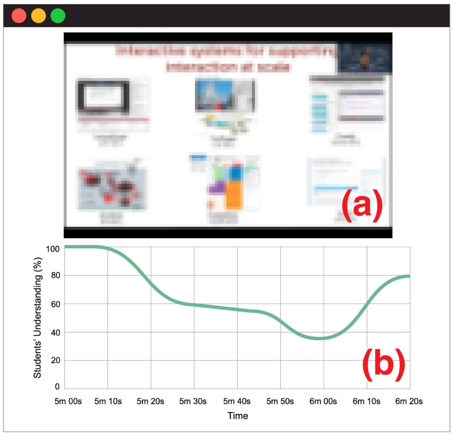

FIGURE 6. The instructor's website of *SUV*. The website consists of (a) the video of the instructor participant and (b) the students' understanding graph being rendered, matching the timing of the video above.

we asked instructors to use *SUV* with recorded lectures and the prepared students' understanding graph. We conducted pre-task surveys, post-task surveys, and post-test interviews to evaluate the usability of *SUV* with instructors.

1) CREATING THE MOCK DATA WITH STUDENTS

The session for students creating the mock data consisted of two parts: (1) a tutorial session and (2) a main session. We conducted a total of 21 sessions, and each student signed up for one session only (see Figure 5). Informed consent was obtained from each student participant prior to their participation in the session. At least two researchers were present throughout each session. One researcher took the role of an organizer and led the session. The rest of the researchers assisted the organizer and monitored the Zoom chat to see if the participants needed help. During the tutorial session, participants accessed the student interface of *SUV*, a website. The student's website has a green button that participants can click when they do not understand the lecture (see Figure 3a). Once all participants successfully accessed the website, we asked them to click the button to ensure it worked properly. The participants knew if the button was working as we explained that a white circle would spread from the center of the button to its outer part as they clicked it (see Figure 3b). If any participants encountered issues with the button, we asked them to reload the website.

After checking that all participants had working buttons, we explained that they would be using the button while watching a lecture video that we would share through screen sharing during the main session. Because the participants had their Zoom opened and the website with the button on it, they had to resize the window of Zoom and the website to use the button while watching the video through Zoom. The participants were told to click the button whenever they were under the following five different circumstances (1) I am unable to understand the meaning of a specific word; (2) I am unable to keep up with the pace of the lecture; (3) The content of the lecture is different from what I know; (4) I have questions regarding the lecture; (5) I am unable to understand the lecture due to other reasons. There was no penalty for not clicking the button during the lecture. We then asked participants to watch the lecture as if they were taking an actual synchronous online lecture.

For each session, randomly picked one of the videos and played it for seven minutes during the main session. We distributed the participants for each video equally as possible. Utilizing the between-subject design, we only showed one video per session instead of all eight videos, keeping the session duration short and preventing the participants' screen fatigue. We also played the video for seven minutes to keep the participants engaged while watching the video lecture [43] and using our system simultaneously. For each video, we set specific starting and ending times (made the duration of every video seven minutes), so the participants would view the same part of the assigned video. Upon completing the experiment, each student participant was given an eGift card worth $4.

2) EVALUATING THE USABILITY OF *SUV* WITH INSTRUCTORS

Each lab-based usability session with an instructor consisted of five parts: (1) pre-task survey, (2) tutorial session, (3) main session, (4) post-task survey, and (5) post-test interview. Informed consent was obtained from each instructor participant at the beginning of the session. At least two researchers were present in the session. One researcher took the role of an organizer and led the usability session. The rest of the researchers assisted the organizer and monitored the Zoom chat to see if the participant needed help. Before we began the tutorial session, we asked each participant to fill out the pre-task survey that aimed to collect their demographic information with the following questions : *How old are you?; How many synchronous classes have you delivered?; Have you ever tried to understand the students' understanding of lectures during synchronous online lectures?; What method do you use most frequently to check students' understanding?; How much are you satisfied with the method you use most frequently?*

Once all participants completed the pre-task survey, we moved on to the tutorial session. Through screen sharing, we showed them the instructor's tool (i.e., a website) and explained that it consists of his/her own recorded lecture video and students' understanding graph for the lecture (see Figure 4). Next, we clarified that the graph would decrease (see Figure 4c) if the students were under the following five different circumstances during the lecture mentioned in Section V-B1. On the other hand, the graph would increase (see Figure 4d) if the students were not in the five circumstances described above. Moreover, we explained that the participants would be watching the screen recording of the instructor's *SUV* website during the main session. Each screen recording contained the instructor's own lecture video and the rendered students' understanding graph that matched the timing of the video. Before the main session began, the participants were asked to imagine monitoring the graph while teaching synchronous online lectures.

After the main session, each participant was asked to fill out the post-task survey. We used a 5-point Likert scale to allow the participants to express how much they agree or disagree with the following statements to measure the usability of *SUV*'s students' understanding graph: (1) Benefits of using students' understanding graph: *What did you like about the graph and why?; What would be the benefits of using the graph if you use it while conducting synchronous online lectures*?; (2) Challenges of using students' understanding graph: *What did you not like about the graph and why? What would be challenging if you use the graph while conducting synchronous online lectures* and why?; (3) Potential features to be added to the graph: *If you were to use the graph in your actual lectures, are there any changes you would like to make or features you would like to add?* After gathering all of our quantitative results from the survey, we calculated averages and standard deviations. Finally, we conducted semi-structured post-test interviews with the participants to gain insights into their experience with the website. The post-test interview included the following topics: (1) Efficiency: *It was easy to check students' understanding using SUV's understanding graph*; (2) Effectiveness: *Compared to the method I usually use to check students' understanding in synchronous online lectures, SUV's students' understanding graph was easier to use*; (3) Satisfaction: *Checking SUV's students' understanding graph was not disturbing while conducting a synchronous online lecture*.

All of the interviews were conducted remotely over Zoom. Each interview lasted from 30 to 45 minutes. At the beginning of the interviews, the participants gave verbal consent to record their interviews and use their data anonymously for research purposes only. The participants who completed the experiment and interview received an eGift card worth $15. We removed every piece of information identifying individual participants and assigned new identifications (e.g., P1, P2). Once we finished analyzing the interview data, we deleted all the recordings.

We gathered statements from the interview transcripts to analyze the qualitative data from the interviews. Four researchers from our team conducted an affinity diagramming [44] session on Miro[7] to identify important insights, themes, and patterns that repeatedly occurred in the interview data. During this process, our team met regularly and constantly discussed with each other to resolve any discrepancies. We identified salient themes related to what benefits and challenges the *SUV* graph gives instructors while conducting synchronous online lectures and what features to be added to the graph for a better experience.

VI. RESULTS

We reported the quantitative data from the surveys with instructors regarding their previous experience with the experience of checking students' understanding in synchronous online lectures and the usability of *SUV*. We also classified our study findings on instructors' experience with *SUV* based on qualitative data from the interviews into three categories: benefits of using *SUV*, challenges of using *SUV*, and potential features to be added to *SUV*.

A. INSTRUCTORS SURVEY RESULTS

1) PARTICIPANT DEMOGRAPHICS

A total of eight participants completed the instructor experiment. The demographics of the instructor participants are illustrated in Table 2. The average age of the participants was 40 (SD=5.37), with four females and four males. The disciplines of participants varied: engineering (n=5), convergence technology (n=1), science (n=1), and art (n=1). The most used device for conducting their synchronous online lectures was a laptop (n=6), followed by a desktop (n=5). All participants used Zoom the most frequently for their synchronous online lectures (n=8). Since March 11th, 2020, four participants taught between 4 and 5 synchronous online courses, three participants taught between 2 and 3, and one participant taught more than 6.

2) PREVIOUS EXPERIENCE OF CHECKING STUDENTS' UNDERSTANDING IN SYNCHRONOUS ONLINE LECTURES

All participants answered that they tried to check students' understanding while giving synchronous online lectures. To check students' understanding, five participants replied that they check comments or questions on the chat in the video conferencing tool most frequently, whereas three participants said that they randomly select students to ask answers to the question verbally. Participants answered that they were satisfied with their current method for checking their students' understanding (M=3.625, SD=0.744).

3) USABILITY OF *SUV*

Participants agreed they were not interrupted by *SUV* while delivering the synchronous online lectures (M=3, SD=1.414). Also, participants replied that they felt it was easy to check students' understanding using the *SUV* (M=3.375, SD=1.06). Furthermore, participants responded that checking students' understanding through *SUV* is easier than the methods they usually use to check it in synchronous online lectures (M=3.375, SD=1.06).

B. INSTRUCTORS INTERVIEW RESULTS

1) BENEFITS OF USING *SUV*

We found two types of benefits that *SUV* offers to university instructors in synchronous online lectures. First, all participants said that *SUV* students' understanding graphs would help them conduct synchronous online lectures since the graph provided information on students' understanding in real-time. Six participants shared that *SUV*'s graph feature would allow them to check how their students were doing in class while conducting synchronous online lectures. For

[7]https://miro.com/

TABLE 2. The demographic characteristics of the instructor participants.

Participant	*Gender*	*Age*	*Primary Method of Checking for Students' Understanding*	*Mainly Used Device*	*# of Subjects Taught*
P1	M	50	Asking questions vocally to all students or students selected at random	Desktop, Laptop	4 – 5
P2	F	33	Checking students' comments or questions on the chat	Desktop, Laptop, Tablet PC	4 – 5
P3	M	43	Checking students' comments or questions on the chat	Desktop	2 – 3
P4	F	44	Asking questions vocally to all students or students selected at random	Laptop	2 – 3
P5	F	38	Checking students' comments or questions on the chat	Laptop	2 – 3
P6	M	38	Checking students' comments or questions on the chat	Laptop, Tablet PC	4 – 5
P7	M	38	Checking students' comments or questions on the chat	Desktop, Tablet PC	4 – 5
P8	F	36	Asking questions vocally to all students or students selected at random	Desktop, Laptop	6 or more

example, P1 stated that *SUV* would be beneficial because he could see if his students followed the class while teaching.

> *"It is not easy to check on your students if they are following and understanding my lecture while giving an actual lecture. But I guess it will be nice if SUV can help me with that… Students find it difficult to ask questions and intervene in the middle of lectures, so most of them just skip them. Of course, from the professor's perspective, I just hope students interrupt and say, 'Professor, I do not understand this part' or something like that."* (P1)

Similarly, P4 said it would be convenient to read students' reactions to her lecture using *SUV*'s graph. Both P3 and P6 stated that by showing students' understanding, the graph would tell the instructors how students react to the class and thus explain the current class atmosphere. The mentioned benefit of P3 and P6 regarding *SUV*'s graph indicates that the students' understanding graph could be utilized not only to check for students' understanding level but also to examine the classroom atmosphere quickly while conducting the class simultaneously.

Moreover, P7 said using *SUV* would be much easier for checking students' understanding of the lecture than reading students' comments from the chat box and guessing how well students comprehend the online lecture as the graph quantifies and shows students' understanding.

> *"I need to make additional guesses while reading the chats from the students in live online lectures. If I ask questions about the lecture and students type their answers in the chat, I need to infer my students' understanding by reading their comments. But this graph lets me check students' understanding right away. It becomes much easier."* (P7)

Three instructors mentioned that the graph allowing them to see the change in their students' understanding while conducting synchronous online classes would help them find the right moment to give their students adequate feedback. Specifically, P3 said it would be helpful to see the students' understanding graph in real-time because he could provide immediate feedback by asking students which part they were confused about when the graph went down.

> *"If I see the graph is going down, then I would wrap it [lecture] up and ask students which parts they didn't understand."* (P3)

P4 also stated that when the graph indicated the students were struggling to understand, she could give helpful feedback by adjusting the difficulty level of the content she was explaining.

> *"So it is easy to understand. It shows you the graph, not the numerical data. It [the graph] simply goes up and goes down. When it goes down, I would adjust the difficulty and explain it a little easier."* (P4)

Similarly, P5 said that by looking at the graph with students' understanding being updated, she could quickly catch the parts of the lecture where students struggle to understand and help them by addressing them. Thus, by observing *SUV*'s graph, the instructors would not only perceive the change in the students' understanding of the lecture but also consider those changes as indicators of their needing to check in with students instantly, especially when the graph started to decrease.

Three out of eight instructors said that students' understanding of the lecture provided by *SUV*'s graph could be important feedback on their lectures that help instructors prepare better lectures in the future. Two instructors mentioned that quantifying and showing students' understanding through a graph encourages instructors to set goals to increase students' understanding levels. Both P3 and P8 stated that the graph might motivate them to put more effort into successfully delivering synchronous online lectures to students to maintain a 100% understanding level. P6 also said that because the graph would help him identify why students do not understand specific parts of the lecture promptly, he would use that information for the rest of the semester or next semester to improve his remaining lectures.

> *"I think it is important to know where the students were lost in synchronous online lectures so I can work on those parts. So I think the graph not just shows the students' understanding of the graph but also gives us a chance to reflect on our own lectures."* (P6)

P6's perceived benefit of *SUV*'s graph reveals that delivering students' understanding level in real-time could help instructors grasp the parts students struggle to understand. Moreover, allowing instructors to assess their lectures and take corrective measures swiftly by showing the status of students' understanding would lead to improved future lectures.

2) CHALLENGES OF USING *SUV* GRAPH

We identified four main challenges that participants would have while using the graph. First, five instructors shared that it would be challenging to use the graph because it would interfere with conducting their synchronous online lectures. Three instructors said monitoring the graph while conducting lectures would be difficult. P1 shared that taking turns looking at students, lecture slides, and the graph on his multiple screens would be inconvenient.

> *"I kept watching the graph. But when considering that I was conducting a synchronous online lecture, I imagined looking at my lecture materials, my students through the camera, and then the graph. As I kept doing that, I thought, 'Wow, this is inconvenient.' "* (P1)

Similarly, both P5 and P7 said it would be difficult to keep paying attention to the graph to see if the students' understanding of the lecture decreased while conducting the online lecture. Moreover, two other instructors said they felt they would be interrupted by the graph due to the emotional distress that the graph gives. For instance, P8 shared that the graph looked like evaluating his teaching skills, so he felt pressured about delivering lectures. P3 said that when he first saw the level of students' understanding decreasing, he started to panic.

> *"...when I saw the level of students' understanding started to decrease, I was a little bit panicking, I think. And started to wonder what just happened and why students are struggling to understand."* (P3)

These instructors' concerns reveal the negative influence of showing students' understanding level while teaching instead of supporting the instructor in synchronous online teaching.

Half of the instructors said they would have difficulty using the graph because it did not explain why students did not understand their lectures. For example, P2 stated that the graph did not explain why their students struggled to understand the lecture. Similarly, P3 talked about how utilizing the graph in his synchronous online lecture was difficult and explained that he would ask his students the reasons for not understanding to solve the issue.

> *"So when the graph started to go down, I could recognize that students were having trouble understanding the lecture. But the graph does not tell me why. So I would ask my students why they struggled to understand my lecture."* (P3)

Furthermore, P7 and P8 both said it would be challenging to take the right actions to help their students without knowing why they struggle to understand the lecture. P8 stated that without knowing why his students are struggling, P8 would not be able to provide specific guidelines or suggestions to support students' learning. Moreover, P7 mentioned that even though she would know that students struggle to understand the lecture due to one of the five different circumstances introduced in Section V-B1, she would not know exactly which circumstances students are in.

Moreover, P7 mentioned that even though she would know that students struggle to understand the lecture due to one of the five different circumstances introduced in SectionV-B1, she would not know exactly which students are in which circumstances.

> *"I thought why students would have been confused about the lecture, but I could not figure out the reasons. It wasn't easy. Yeah, so without knowing the exact reasons why students did not understand the lecture, there was nothing really I could do to help them."* (P7)

The concerns of P7 and P8 indicate the need for a detailed explanation of decreasing students' understanding levels, as that information is necessary for instructors to provide constructive feedback to students.

Next, four instructors shared that they would encounter challenges when using the graph for synchronous online lectures since they will not either catch or memorize the parts of the graph where students' understanding levels start to decrease. Both P3 and P5 pointed out that they will not be able to immediately see the graph sometimes falling while they conduct the lecture. P2 and P8 said that even if they realized that the graph had decreased, it would still be challenging to remember what they were explaining to students. For example, P8 stated that it would be difficult to remember where the students' understanding started falling and going up as he also needs to pay attention to the content he is teaching. P2 also mentioned that she would not exactly remember what she was talking about when the graph started to graph.

> *"Let's say the graph dropped precisely at five minutes and 40 seconds. It is just so challenging to think back and remember what I had said and shared which specific slide at that exact time."* (P2)

The concern of P2 and P8 shows the possible distraction in teaching synchronous online lectures that *SUV*'s graph could cause, as instructors would already focus on delivering lecture content to students in real-time.

Lastly, two instructors mentioned they would struggle with trusting the data provided by *SUV* as it does not explain how it gathered the data regarding students' understanding of the lecture. P7 also stated that she would hesitate to use the graph until she knows how the graph is drawn and the system collects the necessary data for creating the graph. Furthermore, P1 also mentioned that he would be unsure if he could trust the *SUV* graph's data because it does not tell how exactly it gathers and visualizes the students' understanding.

> *"I don't know what this, the graph, is based on, so I have a question about whether this graph of students' understanding is something that I can refer to as I keep paying attention to the lecture. If it is based on reliable and reasonable data, I would actively use it in my lectures."* (P1)

This struggle with using the *SUV*'s graph presents the need for a sufficient explanation of how *SUV* collected data from the students and what data are used to portray students' understanding of the lecture.

3) POTENTIAL FEATURES TO BE ADDED TO *SUV*

We found that participants were interested in various features that would enhance their experience with using *SUV*. More than half of the participants wanted *SUV* to show the changes in students' understanding with better visual elements. Three participants suggested the changes in graph color to show the changes in students' understanding. While P1 and P3 recommended the changes in graph color based on students' level of understanding, P2 preferred the changes in graph color based on why students' level of understanding decreased.

> *"For instance, if the understanding level goes below 80%, the graph color changes, and when it goes below 50%, the graph color changes into red. The change in graph color directly shows the changes in students' understanding, meaning I don't have to look at the graph to see whether it's at 100% or 80%. This will allow me to focus better on the lecture."* (P3)

On the other hand, P5 and P8 proposed a different format to show the changes in students' understanding. Instead of a graph, they suggested using pop-up alerts telling the students' understanding drops below a certain level (e.g., below 50% of total students' understanding) and notifying the instructors to take action. The participants' desired changes in the visual representation of *SUV*'s students' understanding reveal instructors' need for an eye-catching presentation of students' understanding of the lecture so that instructors can perceive it at a glance while conducting online lectures simultaneously.

Some participants wanted *SUV* to have a feature indicating which part of the lecture students did not understand. P7 suggested a feature that allows the graph to show students' questions along with their understanding levels. Likewise, P2 and P3 recommended a feature that allows instructors to see which part of the lecture students did not understand. P2 suggested a feature enabling instructors to see the slide students struggle to understand when they put a cursor on the part of the graph that goes down. P3 proposed connecting the graph and lecture slides so that students could mark the part of the slides they have difficulty understanding.

> *"If I can check the lecture I was teaching [when the graph goes down], for example, a screenshot [of the lecture slides] will pop up when I put the cursor on the graph."* (P2)

Some participants also wanted additional information on the students' understanding of the lecture. For instance, P4 wanted to view each student's understanding while delivering synchronous online lectures.

> *"For the same course but different sections, instructors can compare the students' understanding of different sections and why their understanding differed. I think once the instructors can analyze the difference between the students' understanding of different sections, it will help them to prepare about teaching methods in the same course for the next semester."* (P4)

P6 wanted to compare students' understanding levels from multiple lecture sections of the same course. By comparing each section's students' understanding, P6 stated that he might see the difference in students' understanding based on the time or day of the week the lecture is held, which could uncover some factors causing the difference in students' understanding from different sections.

> *"I mean, I teach multiple sections in a single course, and the only difference between those sections is like time and on which day of the week the section is held. But the content that I deliver during my synchronous online lectures is consistent. So if the understanding level of each section is different, we might be able to see if those factors, [time and day of the week], or uncover other unknown factors are manipulating students' understanding of the lecture or not."* (P6)

This shows the need for a potential feature allowing instructors to select the target (e.g., individual students, students in a single lecture, multiple classes in one multi-section course) that they would like to monitor its understanding freely.

Lastly, P6 and P7 wanted to know which data the system uses and how it processes the data to generate the student's understanding graph.

> *"I think instructors will gain more trust [of students' understanding graph] if they know what kind of students' signals are used, how many students' responses are used, or if any AI model being used to generate [this graph]."* (P7)

Not revealing how data regarding students' understanding was collected and how it was processed into a graph could prevent instructors from using *SUV* in their synchronous online teaching with trust. Thus, transparency on the gathered data for the graph and an explanation of how the system renders the graph in real-time based on the collected data are critical potential qualities to be applied to *SUV*.

VII. DISCUSSION

Our findings reflect university instructors' experience and thoughts on using *SUV*'s students' understanding graph for synchronous online lectures. The instructors shared the benefits of our system and the challenges they would encounter while using *SUV*. Moreover, the instructors shared the additional features they would like to add to *SUV* for a better experience. However, the findings of this study revealed instructors' perception of *SUV* and their specific needs for enhancing their experience with the system. In this section, we first discuss our findings related to the instructors' experience with the students' understanding graph of *SUV* and then propose the design opportunities for improving the system's usability.

A. USING SUV TO IMPROVE LECTURES

The findings of this study revealed that besides allowing instructors to see students' understanding of the lecture in real-time, *SUV* would also provide them opportunities to improve their lectures right away or future lectures by working as a medium that delivers students' feedback on lectures. Prior studies showed the effect of getting student feedback regarding the lectures. Glassman et al. [17] developed a tool called *Mudslide*, allowing students to double-click on the exact parts on the lecture slides that they felt confused about and type in why. Mudslide was found helpful for assessing lecture videos' clarity. The teachers considered the muddy points as weaknesses of the lectures and indicated a strong desire to change their lectures. Therefore, the feedback can work as important cues indicating students need help comprehending the lecture and encourage instructors to improve their lectures, leading to an effective learning environment.

Additionally, multiple studies analyzed the use of clickers in physical classrooms [45], [46], and flipped classrooms [47]. Clickers provide immediate feedback to instructors, allowing instructors to quickly monitor students' learning and understanding of the class materials [45], [47] and to clarify the lectures when students are shown to struggle to understand [46]. Other studies [48], [49] on the effect of clickers in classrooms also reported that clickers could help students understand concepts in classes and acquire learning skills. Thus, clickers providing immediate feedback from the students to instructors make instructors act promptly, correct misconceptions, and improve students' understanding, especially when students need help comprehending the lectures.

Like Mudslide and clickers, *SUV* assists instructors with checking their students' understanding of online lectures in real-time. As other studies reported, knowing how students are doing in class gives instructors various opportunities to improve their lectures. Instructors can take the right action to maximize their class learning and plan more effective lectures by adjusting and incorporating students' feedback. Thus, *SUV* would not just display how the percentage of students understanding changes over time but also could contribute to building a better learning environment as it supports and encourages instructors to devise their lectures to help students understand better.

B. MAKING SUV LESS DISRUPTIVE IN CONDUCTING SYNCHRONOUS ONLINE CLASS

We identified a few potential features that instructors wanted *SUV* to have. One of the most common features was informing the changes in students' understanding graph more noticeably. Three instructors shared that they would like to see *SUV* utilizing colors to make the changes in students' understanding graph more eye-catching. The other two instructors suggested using different types of cues other than visual ones to let instructors know the ongoing changes in students' understanding during the lecture. All of these instructors wanted *SUV* to notify the change in students' understanding because they could not keep staring at the graph while teaching. When instructors conduct synchronous online lectures, they have various things to do, such as conducting the lecture, screen sharing the lecture slides, and checking the chat box constantly to see if their students have comments or questions. At this point, it is evident that instructors cannot monitor the students' understanding graph that *SUV* provides. Thus, by making the changes in showing students' understanding of the lecture more notable, the instructors do not need to keep looking at the graph.

Maglio and Campbell [50] examined different scrolling text displays, including peripheral information such as announcements, sports scores, stock prices, or other news. The researchers aimed to discover how to design those peripheral displays to provide the most information while not distracting users working on their main task. The researchers investigated three different types of displays: continuous scrolling text, discrete scrolling text, and serial presentation. After several experiments comparing those different scrolling texts, the researchers found that the continuous scrolling display is the most distracting display among other displays. In addition, the researchers suggested five different guidelines for designing peripheral displays based on their findings. As a graph that continuously moves, students' understanding graph of *SUV* might be an evident source of distraction to instructors who conduct synchronous online lectures. Thus, we might need to improve the graph by adjusting its existing features following those guidelines produced by Maglio and Campbell so it does not distract instructors from their main task, teaching.

C. INSTRUCTORS WANTING TO CHECK INDIVIDUAL STUDENT'S UNDERSTANDING

We found that instructors might want to check the individual level of students' understanding from *SUV*'s graph besides checking students' understanding as a whole class. When asked for potential features to add to *SUV*, P4 specifically mentioned that she would also like to see each student's understanding. P4 said it is better to monitor students' understanding of a lecture in a group if it is a large lecture, but monitoring the individual level of students' understanding would be preferable in a small-sized lecture.

Previous studies have studied the difference between individual and group feedback and what types of feedback can play a role in students' learning. Archer-Kath et al. [51] compared each impact that individual and group feedback can have on the achievement, attitudes, and behavior of the students working in a group setting. The researchers found that the feedback needs to be focused on the individuals' actions rather than the whole group's to maximize its impact. Moreover, the researchers showed that individual feedback is more effective than group feedback as individual feedback increases students' motivation to achieve and helps them achieve an actual achievement. Race [52] highlighted the qualities that feedback should have to help students effectively. One of the feedback qualities that Race mentioned is ''intimate and individual.'' The researcher claimed that to match the feedback with students' traits, such as achievement, individual nature, and personality, it should address students individually rather than as a whole. Also, Race presented the pros and cons of different types of feedback. Individual feedback could be less efficient in large classes since it takes more time than giving feedback to a group. When giving individual feedback, students might feel threatened and stressed as it solely addresses them. However, individual feedback allows instructors to address each student's needs, strengths, and weaknesses, improving students' learning.

The students' understanding graph of *SUV* provides data about students' understanding in synchronous online lectures, and instructors can utilize the data to support the feedback they give to their students. However, since *SUV*'s graph reflects students' understanding as a whole class, it might be difficult for instructors to give specific feedback to individuals to improve their learning. Therefore, the students' understanding graph might need a feature that allows instructors to see each student's understanding of the lecture during synchronous online lectures to provide adequate feedback for enhancing each student's learning.

D. DESIGN OPPORTUNITIES

Based on the findings of our study, we propose three design opportunities for creating and designing tools to help instructors to monitor students' understanding of online lectures in real-time while teaching. We propose showing students' understanding more noticeably using colors. The instructors indicated they needed help to keep looking at the graph while conducting synchronous online lectures. As a result, the graph should notify the change in students' understanding levels more noticeably, so the instructors do not always need to look at the graph while teaching. For example, the graph could turn red as it goes down and blue as it goes up for more evident visual cues. Besides using visual cues to update instructors on the students' understanding level, sounds can be used. For instance, the instructors will get alarmed whenever the graph decreases since that is the right time for instructors to step in to help students.

Moreover, we propose a feature in the graph that allows instructors to view individuals' understanding of the lecture and the whole class's understanding of the lecture. Letting instructors check on each student's understanding of the class will allow them to provide students with more intimate and personalized feedback that would help enhance students' learning in class. For instance, a filtering feature could be utilized. With filtering, the instructors could see the whole class' understanding, like in the graph of *SUV*, and narrow down the data to an individual's understanding of the lecture.

Lastly, we suggest a feature explaining to instructors why and which parts of the lecture students struggle to understand. We found that university instructors struggled with utilizing the *SUV*'s graph because it did not explain why their students did not understand the lecture. Our instructor participants mentioned that if the instructors have no information on which parts and why students are having difficulty understanding the lecture, they cannot take appropriate actions to help students. Therefore, providing instructors with detailed information (e.g., on which parts of the online lecture students struggle to understand and why) in real-time is necessary so the instructors can provide constructive feedback.

E. LIMITATIONS AND FUTURE WORK

Our study still has remaining limitations that need to be addressed in future work. First, our study only focused on a few university instructors in South Korea. We evaluated our system with eight university instructors from universities in South Korea. Thus, our study sample may not represent the large target population (i.e., university instructors conducting synchronous online lectures). Next, our pilot study evaluated the usability of *SUV* in a lab-based setting. Thus, the questions about the feasibility, validity, and effectiveness of *SUV* in a real-life setting remain. Furthermore, we only evaluated *SUV* from the instructors' perspective, while it is important to evaluate the usability of *SUV* with university students in actual synchronous online lectures. For instance, we do not know if asking students to report their understanding in real-time while watching ongoing online lectures would help or disrupt students' learning.

Moreover, our current system updates students' understanding every 10 seconds discretely. We should incorporate the sliding window technique into *SUV* to continuously collect and visualize students' understanding. Also, the current version of *SUV* is only usable on desktops or laptops. Suppose the instructors have only one desktop or laptop available. In that case, utilizing *SUV* during class might be difficult since our system cannot display the students' understanding graph once the instructor starts to share their screen. Showing class materials through screen sharing is crucial in online lectures because it helps students to understand the lesson easily [53]. Thus, *SUV* would need to allow instructors to see the students' understanding graph while sharing their screens or be accessible through various devices such as smartphones or tablet PCs other than the primary devices instructors use for online lectures.

Lastly, our system only shows the percentage of students who understand during the lecture through a graph to instructors. Our system does not show the instructors exactly which part of the lecture students struggle to understand and why. Without knowing which parts of the lecture students have trouble understanding and why, it would be difficult for instructors to take action while teaching immediately (e.g., clarifying the parts where students struggle to understand by giving more examples) to support students' learning. This could be more challenging and time-consuming, especially in large-scale lectures, as instructors would need to check in with more students to see why students are struggling to understand. Therefore, not just the percentage of students who understand the lecture, *SUV* would also need to show instructors exactly which part of the ongoing lecture students are finding difficult to understand and for what reasons. Besides these, there could be more unveiled limitations of SUV and unknown potential challenges to be explored when implementing the system in actual synchronous online lectures and different settings such as large-scale lectures or mixed-mode (i.e., hybrid learning) classes.

Future studies will look at more instructors with diverse backgrounds from different cultures and education levels, such as elementary schools or high schools. In addition, we need to measure the system's feasibility, validity, and effectiveness through a long-term deployment study in a real-life setting. Further exploration of the user experience and possible improvements could be beneficial for enhancing the usability of *SUV*. For instance, since the students are also our system's direct stakeholders, we need to evaluate the usability of *SUV* with students. We also need to ensure our system includes students not paying attention in class. Even if students are not physically clicking the *SUV*'s button, we might be able to assess their understanding of the lecture by detecting their engagement in class with other methods, such as eye-tracking or facial detection [34]. Additionally, by incorporating the sliding window technique into our system, collecting and plotting the moving average of students' understanding data, *SUV* could show a more accurate understanding. In addition, we need to make our system accessible and usable on various devices (e.g., smartphones, tablets, etc.) besides desktops or laptops instructors use for lectures, so our system does not interfere with other activities necessary for instructors' teaching. Also, we need to modify *SUV* and let it shows the instructors exactly which parts students cannot understand and why so instructors can take specific actions to guide students through the online lecture in real-time. Further work is required to evaluate the modified *SUV* in actual synchronous online lectures with both students and instructors.

VIII. CONCLUSION

This paper explores visualizing students' understanding in a graph format to improve the interaction between instructors and students in synchronous online lectures. We developed *SUV*, a system that takes students' input by allowing them to click the button whenever they do not understand the online lecture, visualizes their inputs as a graph, and presents their understanding graph to instructors. We conducted surveys and semi-structured interviews with eight university instructors to evaluate our system and learn about their experience with *SUV*. We found that instructors perceived *SUV* as helpful for conducting synchronous online lectures as they can see if their students understand the lectures and give adequate feedback to the class depending on students' understanding. We also identified the key challenges experienced by university instructors in using *SUV* and incorporating the system in their synchronous online lectures. Moreover, we found that instructors were interested in various potential features enabling them to recognize the change in students' understanding more quickly, obtain reasons why students struggle to understand the lecture and apply the system in different circumstances. Based on our study's findings, we presented design implications for improving the instructors' experience with *SUV* and increasing the practicality of the system. Prior studies have reported on evaluating systems that support students and instructors in facilitating asynchronous and synchronous online lectures. To further extend these studies, our evaluation study highlights the usefulness of *SUV* in assisting instructors in checking students' understanding of their lectures while teaching synchronous online lectures. *SUV* presents possibilities for researchers in the online learning community to conduct further studies on enriching instructors' experiences in synchronous online lectures.

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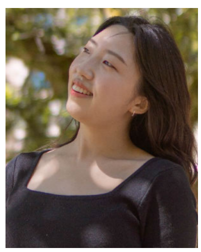

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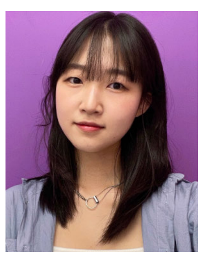

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