Virtual Reality, Real Pedagogy: A Contextual Inquiry of Instructor Practices with VR Video

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ABSTRACT

Virtual reality (VR) offers promise in education given its immersive and socially engaging nature, but it can pose challenges for educators when creating VR-specific content. VR videos can function as a new educational tool for VR content creation due to their creation affordability and user-friendliness. However, little empirical research exists on how educators utilize VR videos and associated pedagogy in real classes. Our research employed a contextual inquiry, through in-person interviews and online surveys with 11 instructors to gain actionable insights from envisioned teaching scenarios for VR videos that are informed by actual instructional practices. Our study aims to understand the factors that motivate instructors' adoption of VR videos, identify challenges educators face when incorporating VR videos into instructional units, and examine pedagogical adjustments when integrating VR videos into teaching. Through empirical evidence, we provide design implications for the development of VR-based learning experiences across diverse educational contexts. Our study also serves as a practical case of how VR can be adopted and integrated into education.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **Empirical studies in HCI**.

KEYWORDS

Virtual Reality, 360-degree videos, VR videos, educational VR, higher education

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1 INTRODUCTION

Virtual reality (VR) technology has gained widespread popularity in various fields, including education [42, 43, 46]. In particular, VR videos[1] have been used as a pedagogical tool to provide students with immersive and dynamic learning experiences. These videos can capture panoramic views of real-world or simulated environments, allowing learners to explore and interact with the content as if they were physically present.

While traditional video learning has long been a staple in education, the emergence of VR videos as an educational tool introduces new pedagogical practices. It has the potential to reshape how students engage with content, moving beyond the passive consumption of information associated with traditional video formats [75]. Prior work has reported positive effects on learning with VR videos, such as improved knowledge retention [5], motivation [18], and academic performance [41, 76, 96]. It also achieves technical advantages compared to other VR content given its ease of creation [45, 102], cost-effectiveness [41, 69], compatibility of a variety of devices [14, 44, 68, 88], and convenient employment without the need for extensive technical knowledge or training [75, 80].

Despite these promising affordances of VR videos, there is still limited research on how instructors use VR videos in their teaching practices and the effective pedagogical strategies associated with their use from a holistic view. A predominant portion of the existing research centers on specific subjects or content domains (e.g., [52, 70, 77, 84, 86]), often neglecting to initiate inquiries from an authentic pedagogical foundation building upon the instructors' real-world teaching materials and experiences. Ranieri et al. [74]

[1] In this paper, the term "VR videos" refers specifically to monoscopic 360-degree videos experienced within the VR headset. We selected this format due to its extensive range of uses and its prevalent adoption in the industry and education area [6, 63].

developed a more systematic approach to the understanding of the educational uses of VR videos in different educational contexts from a scoping literature review. However, this approach did not provide empirical insights and perspectives from the instructors — the actual strategies, real-world challenges, and expected outcomes remain areas of active exploration. Therefore, our research seeks to explore the pedagogy of how instructors may use VR videos as part of their pedagogical approach in-situ and identify the effective practices and challenges associated with their integration across diverse teaching contexts. Our exploration provides a comprehensive view of instructors' practices in integrating VR video in education, offering valuable insights into VR video's utility and perceived impact as a pedagogical tool. By grounding our study in authentic instructing materials and experiences, our research contributes empirical knowledge to VR video education, with a more nuanced and practical understanding of VR's role in contemporary teaching methodologies. Specifically, our research questions are as follows.

- **(RQ1)** What are the factors that impact the interest in VR video usage in classes?
- **(RQ2)** What challenges do instructors face and what facilitations are currently missing in the process of generating instructional units with VR videos?
- **(RQ3)** How do instructors adapt pedagogical approaches to instructional units with VR videos?

In order to answer these research questions, we used the contextual inquiry [8], which involves 1) an in-person contextual inquiry session including observing and interviewing instructors in their real workspace, and 2) an online interpretation session through a survey, helping validate and triangulate our results. Through this approach, we aimed to understand how instructors perceive VR video integration, the strategies or adjustments they consider for this integration, and the challenges and necessary support that arise during the instructional process. In summary, our contributions include the following:

- **Empirical insights into the potential incorporation of VR videos into instructors' teaching practices**, illustrated with target example scenarios provided by instructors. The selected integration scenarios are influenced by instructors' perceived educational values associated with VR videos.
- **Insights on necessary adjustments needed in the instructional processes and units for the integration of VR videos**, particularly during the stages of evaluating available video content resources, designing educational activities, and conducting pilot classes.
- **Challenges and missing facilitations in using VR videos across different teaching contexts**, such as limitations in content-related resources, the absence of collaborative communities and networks, and the need for tools to support class management and subject-specific learning activities.
- **Design implications and opportunities for future technology to support the adoption of VR technology in educational settings**, in light of our findings on VR videos' integration with current instructional practices.

2 RELATED WORK

Our work is inspired by the use of video as an educational tool, the incorporation of VR video technologies in educational settings, and the role of VR as a pedagogical medium.

2.1 Video as a Teaching Tool

Videos have proven to be a valuable educational tool across multiple disciplines for capturing rich multimedia records of the physical and social worlds [10, 100, 101]. The commonly used theoretical foundation for understanding the intrinsic motivation behind using video as a teaching tool is derived from the Cognitive Theory of Multimedia Learning [30, 54]. According to the theory, learners possess two channels for learning: visual and verbal (or auditory), deeper learning occurs when information is presented through both text and graphics than text alone [53].

Prior studies have shown that videos play a pivotal role in diverse class formats (e.g., online courses [49, 62] and blended learning [7]), which increases student's motivation [11], engaging students in active learning [10] and helping to illustrate abstract concepts to students in certain subjects [92], thus leading to positive learning outcomes [1]. Learning from videos also helps instructors maintain an affordable and sustainable teaching routine. Besides the vastly available resources online, instructors can also create their own videos to further facilitate teaching, such as recorded lectures [39].

However, video is only effective when it is embedded in appropriate instructional contexts and well-conceptualized learning environments [47, 83]. Little empirical research examines how specific instructional approaches might effectively exploit the potential of video with authentic context (one exception is using video for teacher education [9]). Recognizing this research gap, we initiated a contextual inquiry to explore which instructional strategies most effectively harness the potential of video, with a specific focus on VR video. This emphasis is rooted in the shared context of traditional and VR videos, as they both function as tools to visually and audibly convey information, fostering engagement and experiential learning. By gaining insights from real classrooms, our findings and implications provide guidance for future designs and research endeavors related to VR video-based learning.

2.2 VR Video Technologies in Education

VR videos provide a bridge connecting the traditional video-based learning experience with modern VR technology. Compared to creating other virtual graphic-based learning tools, such as simulated VR videos made from animated 3D models, VR videos are more cost-effective with the proliferation of affordable 360 video cameras and a ton of 360 video online resources [4, 15]. Prior literature review [46] has shown that VR videos can provide a more immersive and interactive experience that further helps improve students' learning outcomes, including an increased engagement in the learning activities [2, 59], higher satisfaction towards the learning process [87], yet the improvement in academic score still remains unsettled [40].

Many technologies have been developed to enhance the efficiency of VR video learning experiences, including annotation [95], view sharing [41, 63], shared video control [41] and interactive VR video [35, 35, 99]. For example, [41] presents a collaborative system that allows students to share notes, visual cues, and video control during joint VR video viewing. Their results showed that using collaboration tools in VR video can positively influence users' satisfaction, reduce cognitive load, and improve factual knowledge acquisition. Other studies introduce multi-sense in VR videos to support experience learning (e.g., spatial audio [63], olfaction and wind stimulation [60], and haptic sensation [36]). The enhanced multisense VR videos are proven to increase the sense of presence in the virtual environment, learning enjoyment, as well as provide novel interactions to further improve skills [22].

Despite the fruitful studies on VR video technologies in education, most studies focus on lab studies and specific educational scenarios. As highlighted in the previous section 2.1, effective video-based learning depends on contextualizing it within appropriate pedagogical approaches. We seek to identify empirically supported principles of VR video-based teaching and learning based on existing classes. This endeavor provides a holistic overview of instructors' insights into VR video-based class design, challenges, and areas requiring facilitation. It culminates in the formulation of design implications that aim to inform future research and provide guidance for educators' practices.

2.3 VR as a Pedagogical Medium

Learning in VR has a solid theoretical base (e.g., constructivism theory [27], social presence theory [33], cognitive theory[72] and embodied learning [89], etc.), which offers a strong rationale for the use of VR as a medium in educational contexts. Prior work also provides both quantitative [42, 81] and qualitative evidence [24, 34, 41] supporting its effectiveness. This validation has spurred educators and developers to design instructional technologies within the VR medium, with some focusing on enhancing class management and providing monitoring and creation tools for instructors. For example, Krekhov et al. [48] proposed a one-way mirror that allows the instructor to watch the student in VR from outside the virtual environment. ObserVAR [93] is a visual cue system that allows instructors to view in-VR students' gaze direction on a mixed-reality device. Their system provided a more flexible system to improve instructor-student interaction during class and can be scaled up to support larger classrooms. VRdeo [16] and EditAR [19] enable instructors to create and record the process when they're in the VR scene and can be exported as a traditional 2D video to view without a VR device. Several studies also target employing assessment in VR medium [13, 21, 67]. One comparison study [82] applies different machine learning models to automatically assess students' VR dental simulation performance based on their hand motion. There are also educational VR systems targeting between-students interaction [51, 94, 97]. Drey et al. [24] studied the impact of paired studying in VR and compared it with a VR-tablet pairing system. Their results showed a significant increase in the sense of immersion, satisfaction, and reduced cognitive load, which all contribute to learning outcome improvement.

However, most studies and available applications primarily concentrate on lab-based classes or provide support for purely VR-based classes. They may not fully capture the diversity of real-world teaching and learning experiences in classrooms, thus limiting the ability to capture the complexities of actual education [37]. Hence, there exists a gap in empirical research that provides a comprehensive understanding of educational VR technology from a pedagogical perspective, particularly concerning the use of VR as a supplementary tool within the teaching process, rather than as the exclusive medium for the entire class. Our study utilizes VR video as an illustrative technology within the VR medium to gain empirical insights into the strategies and challenges instructors might face when adapting their existing classes and instructional processes. We then used these insights to generate design implications for supporting VR technology in educational contexts.

3 METHODS

We employed Contextual Inquiry (CI) [8] to understand and construct the design space of VR-video-based classes for higher education. This approach advocates field interviews with participants in their actual workplace, which allows conversations to naturally evolve in the real-world context. We specifically chose CI over traditional interviews 1) to reveal the process, details, and motivations behind instructors' work, 2) to uncover factors in classroom environments or real settings of class preparation that could potentially influence the usage of VR videos, 3) to observe activities unfolding in their natural and rich context, and 4) to enable the recognition of subtle interaction cues and potential disparities between verbal expressions and actual actions. In this section, we provide a summary of our participants and their backgrounds, followed by a detailed description of our study procedure, data analysis process, and a discussion of our method limitations.

3.1 Recruitment and Participants

We recruited participants from a university in the Midwest area of the United States, through a comprehensive mailing list encompassing various subjects and departments of the university. A total of 11 instructors were selected to participate in this study to cover a range of academic field expertise. We stopped recruiting instructors when we reached data saturation when we started hearing repetitive themes from our participants. We also collected participants' background information including their area of expertise, VR familiarity, 360 video experiences, teaching experience, and video-based teaching experience. We screened potential participants based on their experience with using videos in teaching, and only selected ones who confirmed their previous use of video as a pedagogical tool in their classes. We did not require participants to have prior experience with VR or 360 video viewing and made the effort to include participants with a range of VR experiences in our recruitment because we wanted to explore how instructors with varying levels of familiarity with VR video would perceive and adapt to its educational applications.

Our participants' ages ranged from 29 to 56 years old (M = 38.5, SD = 10.48), with an average of 13.18 years of teaching experience (SD = 9.14), and the gender distribution included six females, four males, and one participant identifying as non-binary or third gender. Two participants had used VR in actual teaching, sharing 3D models (P2) or 360-degree images (P3), while two others (P1 and P6) experimented with at least one educational VR application. None of the instructors had used VR videos in their lectures; P3 had collaborated with a support team to record VR videos but had not utilized them for teaching. Before participating in our study, six participants had viewed 360-degree videos with or without VR headsets, three were familiar with the concept of 360-degree videos but had not watched any, while two participants had neither viewed 360-degree videos nor were clear about the concept. Table 1 provides background and demographic information about our participants.

Our study contained a contextual interview and an interpretation session (section 3.2). All participants completed both parts of the study. Each participant received a $50 gift card as study compensation. The study was conducted within the participants' workspace identified by themselves, with the setup including their own laptop/computer or teaching aids, a VR headset, and an audio recorder to capture the entire session.

3.2 Procedure

In order to understand practices and opportunities for VR videos to enhance instructing activities, we conducted a contextual inquiry and followed up with an interpretation session through an online survey (See Figure 1). In pre-study communication, we asked participants about their preferred location for the inquiry, which varied based on their class preparation needs (as shown in Table 1). Some instructors chose their office or home when instructing materials were accessible in their accustomed working environments, and not much consideration of the classroom environment was needed for their class preparations (i.e., regular lecture halls versus specialized laboratories). We also initiated correspondence with participants through email before the study, aligning with the guidelines outlined in [78]. Specifically, we followed the guidance that: 1) used the term *contextual interview* to distinguish it from a conventional interview, 2) elucidated the method's adaptable nature, devoid of predefined questions, and underscored the importance of observing their regular task execution, 3) presented an agenda of discussion topics and potential observational tasks, and 4) conducted an interpretation session to validate our results.

3.2.1 Contextual Inquiry. We conducted an in-depth, in-person contextual inquiry with instructors interested in integrating VR videos. During the contextual interview, a researcher from our team conducted interviews with the instructors while simultaneously observing their actions and writing memos for analysis. Our observations include instructors' interactions with digital and physical tools and materials as well as their workspaces. Researchers took observation notes and photos during the sessions for later analysis (see Appendix Table 2 for examples). The average time to complete this part was about 60 minutes (M = 60.9 minutes, SD = 5.15).

Introduction (~5 minutes). The contextual inquiry started with an introduction of the purpose of the study and method. After the consent process, we confirmed participants were clear about the differences between the contextual interview and traditional interview and encouraged participants to take a more active role in leading their sessions. Then, we explicitly communicate the following assumptions for this study to avoid leading the discussion on VR adoption due to our primary focus being on VR video. The assumptions are from an investigation about educational VR adoption [42], which anticipated that these issues can be resolved eventually with the wider public acceptance and availability of VR headsets.

- **Financial Consideration.** Assuming the course will not encounter financial constraints regarding VR headsets.
- **Health Concerns.** Operating under the assumption that students will not be significantly affected by cybersickness when using VR.
- **Technology Management.** Assuming that the university IT office will assist with headset distribution and troubleshoot both hardware and software issues.
- **Learning Curve.** Assuming that VR is no longer a nascent technology and has garnered familiarity, instructors can reasonably anticipate a widespread understanding of its operation.

It's important to note that although we made those assumptions, participants were still encouraged to raise their concerns, particularly those pertaining to the utilization of VR videos.

VR Video System Trial (~10 minutes). Next, we asked participants to explore an educational VR video system with a video of city tours. This session was intended to introduce our participants to the technical capabilities of VR video technology and assist them in broadening their approach to structure their classes. It was particularly beneficial for those participants who had limited prior experience with VR videos. We implemented an educational VR collaborative video system from an open resource. We chose this system because this system is specifically designed for collaborative educational settings and has demonstrated qualitative evidence about the potential usage in a real class for instructors [41]. With this system, instructors and students have individual video timelines and control. It has several class management and monitoring tools such as *view sharing* (peek students' views or synchronous instructor's view with students), *annotation* (speech-to-text notes, screenshots, and drawings), and *monitoring* (visualize students' current progress, views' focus and notes). Figure 2 shows a summary of all the functions of the system used in the trial. During the system trial, one researcher explained the functions and guided the instructor to explore all the features noted before.

Contextual Interview (~45 minutes). We collected instructors' detailed background and their prior experiences with video-based teaching methodologies and asked them to speculate suitable teaching scenarios based on VR video. While conducting the interview, the researcher also kept observation notes and took photos for further analysis. We structured our interviews based on the typical steps of preparing educational content for the classroom (e.g, ADDIE model [25]) as follows.

- **Select Teaching Scenarios**. We began by asking participants to reflect on their teaching experiences and recall details about their classes, especially those involving video technology (e.g., How did you use video in your class? How much of the course content is video-related? How do you view the role of video in your course?). Participants could share their existing class syllabus using their own laptops with researchers if available. Based on their class, participants can select the most suitable scenarios that could be adapted with VR video technology from the current class or potential class, and then explain why they believed VR videos would complement their class effectively. If they came

Table 1: Demographics and interview location of participated instructors.

Participant ID	Department	VR Familiarity	Have used VR for education?	Have Watched 360 Videos?	Interview location
P1	Molecular, Cellular and Biology	Passing Knowledge	Yes	No	Office
P2	Anthropology	Knowledgeable	Yes	Yes	Office
P3	Forestry	Passing Knowledge	Yes	Yes	Home
P4	Kinesiology	No Knowledge	No	Yes	Office
P5	Chemistry	Passing Knowledge	No	No	Laboratory
P6	Retail Merchandising	Knowledgeable	Yes	Yes	Office
P7	Chinese	Passing Knowledge	No	Yes	Home
P8	Dental Hygiene	No Knowledge	No	No	Classroom
P9	Music	No Knowledge	No	No	Piano room
P10	Fitness	Passing Knowledge	No	No	Gym
P11	Medicine and Surgery	Passing Knowledge	Yes	Yes	Office

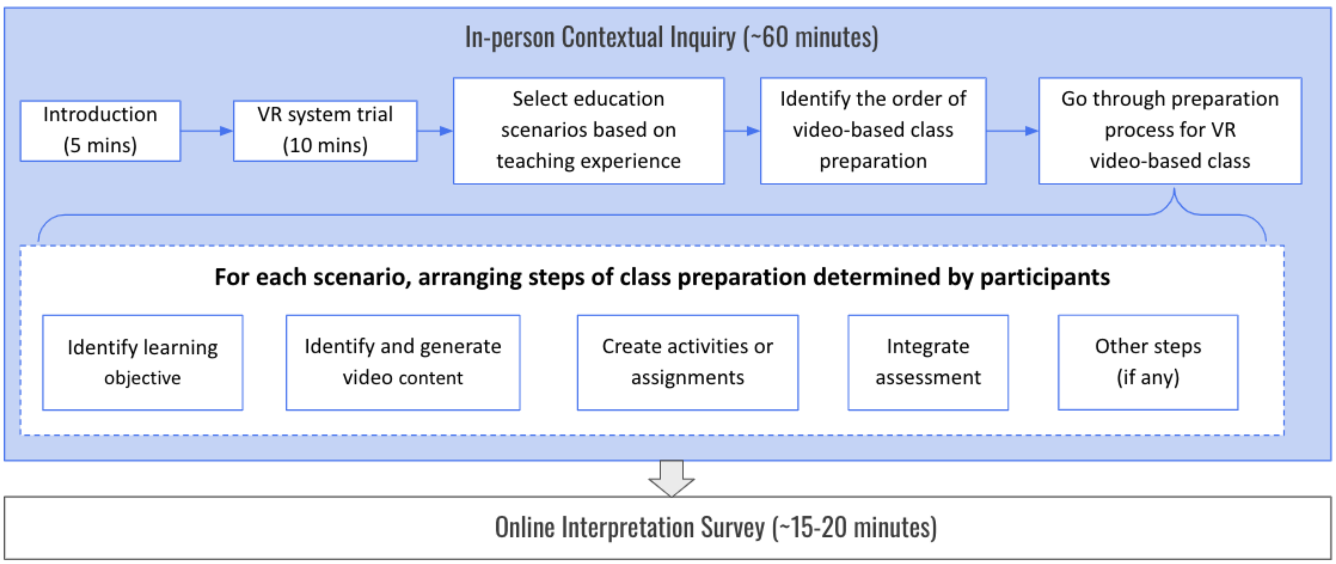

Figure 1: Overview of the study procedure.

up with two scenarios, they would follow the same process to go through the rest of the steps.

Next, we provided instructional units as cards and allowed participants to rearrange the order to match their teaching behaviors and habits. If there were additional steps they considered important but not included on the cards, they could add them on blank cards. The order of the next four stages was determined based on the order participants established during this process. Participants were allowed to draw connections between steps even if a linear process didn't apply. For each stage (including the stages the instructor proposed), we asked participants about potential changes, challenges, and missing facilitations if using VR videos and related concerns.

- **Identify Learning Objectives.** During this stage, we engaged participants in reflecting on the learning objective within the selected education scenario.
- **Create Activities with Class Constraints and Learning Goals.** Participants adjusted their activity designs to incorporate VR videos in this stage. By sharing their teaching materials with us, participants made changes to existing activities and were prompted to consider the VR video tool in VR Video System Trail session.
- **Identify or Generate Video Content.** Instructors started this stage by reflecting on their prior experiences with video generation — whether self-generated or sourced from online resources. Then they discussed how they might adapt VR video content and started a think-aloud activity [98] of searching for appropriate videos online to locate a VR video that matches their teaching scenario. If a specific video is unavailable, they were encouraged to extract elements from other VR videos (or 2D videos), use VR videos as motivational introductions rather than course-specific content, or think about cameras' positioning for creating VR videos.

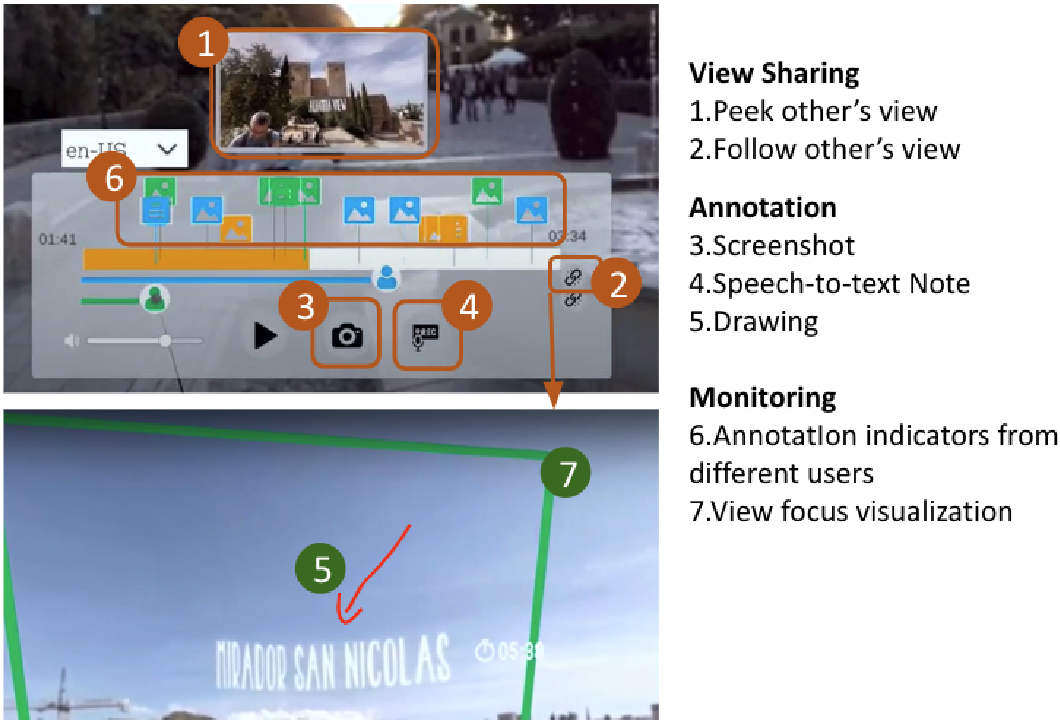

Figure 2: Overview of features of collaborative VR video system used in the study.

Researchers observed the process, noting any challenges encountered during VR video searches as well as providing assistance when needed, such as suggesting 360 video keywords or websites. Once a video was identified (or a potential video was generated), participants were asked to share additional resources used in video preparation (e.g., video editing tools). They elaborated on their usage and reflected on their concerns and the support they needed in the content generation process.

- **Integrate Assessment of Learning Outcomes.** In this stage, instructors retrieved the assessments previously utilized (if applicable) within the chosen educational scenarios.

Finally, we asked participants to discuss the support they would require from external sources (e.g., department, video player developer, video producer) during the creation of this activity/video and the challenges or unexpected situations that might arise in a real class.

3.2.2 Online Interpretation. To validate and refine the outcomes derived from our contextual inquiries, an interpretation session served as member checking [17] was conducted through an online survey format with open-ended questions. Member checking allows for participants' intentions to be assessed by providing them with the opportunity to rectify errors, offer additional information, and contribute insights. Instructors who participated in the contextual inquiry were contacted to partake in this follow-up online survey. This survey included qualitative insights from the contextual inquiry sessions. The survey took approximately 15-20 minutes for participants to complete.

3.3 Qualitative Content Analysis

For qualitative data analysis, we adopted a data-driven thematic analysis approach, drawing inspiration from the Grounded Theory Method [58]. Our process commenced by transcribing the recorded contextual inquiry interviews into textual data. Subsequently, the transcriptions were subjected to open coding by the first three authors who had actively participated in the interview process and possessed training in the Glaser method [31]. All observation notes and memos from the contextual inquiry were converted into textual data and analyzed through the same process. Photographs taken during the inquiries were included in the analysis as supplemental materials to textual data, to provide a visual context for analysis.

This procedure generated a substantial collection of over 1300 open codes, from 11 individual interview sessions. The next phase involved a comprehensive review and clustering of the open codes, led by the first two authors. We iteratively clustered all codes using a constant comparison approach, which was operationalized through the creation of an affinity map. During the clustering process, a third author was involved in the discussion to resolve any difference between the two lead authors. All authors also engaged in regular discussions about the clusters during the analysis process. The final clusters generated five themes (see Appendix Table 3), which we presented to our participants in an open-ended questionnaire format. This follow-up questionnaire was created for member checking, to further engage our target group of users and enhance the credibility of qualitative research. We analyzed the collected interpretation survey using a similar qualitative approach and combined it with previously generated themes, which we report in our findings.

3.4 Method Limitations

We recruited participants from a single university in the Midwest area of the United States and reached data saturation with a relatively small size of participants (N = 11). Although we took measures to ensure diversity within this small group of participants, the limited scale and single-site nature of our research might restrict the generalizability of our findings, particularly to educational contexts beyond university-level instruction, such as elementary, middle, or high school settings. A larger and more varied group, possibly from multiple geographical locations and educational levels, would likely have yielded a more comprehensive understanding of VR video applications in broader educational environments, which is open for future investigations. Furthermore, although two instructors had previously employed VR technology for displaying 3D models and 360-degree images, none of these instructors in our study had directly utilized VR videos in their classrooms. Our findings are thus speculative in nature. Future research that deploying VR videos in actual classrooms, is essential to validate and expand upon our insights. Despite these constraints, we strived to offer in-depth and valuable insights into the integration of VR videos in higher education, serving as a foundation for further research and exploration in this evolving field. In addition, qualitative analysis inherently involves subjective judgments during coding and interpretation, which could introduce a degree of interpretation bias. Finally, the technology tutorial on the collaborative VR video system during the contextual inquiries could have introduced a certain level of bias, as participants' responses may have been influenced by the system we presented to them.

4 RESULTS

In this section, we begin by summarizing participant-identified teaching contexts and then present five salient themes through our data analysis. For each theme, we present a rich description of how educators adapt their pedagogical strategies and instructional units to accommodate changes when integrating VR videos into their classes, and what are the challenges and missing facilitations during this process. Throughout this section, we present boldfaced pain points that we believe can be mitigated through technological and research innovations, thereby enhancing efficiency and educational outcomes.

4.1 Overview of Participant-Identified Teaching Scenarios

Our participants had various backgrounds in teaching methodologies, instructing setups, and disciplines that might shape their experience with VR video. They were asked to concentrate on one or two specific classes, relying on their actual teaching experiences, to speculate on how VR videos could significantly enhance the learning process in those contexts. In the following, we summarized the scenarios envisaged by participants varied on several dimensions (details are shown in Appendix Table 4).

Teaching Scenarios. A total of 14 teaching scenarios that participants described cover a wide range of subjects and disciplines. We categorized these scenarios based on the work by Parker et al. [71], which describes different immersive learning scenarios found in the literature by using VR videos. The categories identified include *virtual tours* (N = 3)[2], *recorded processes and procedures* (N = 3), *recorded situations* (N = 1), *recorded experiences and recording processes for learning through replay (self-reflection)* (N = 3). We added additional categories (e.g., *simulated situation* (N = 1), *simulated processes* for spatial knowledge representation (N = 4)) to differentiate simulated video from recorded video.

Class Capacity. The described scenarios varied in class sizes, spanning from large lectures with more than 100 students to 1-1 instructional interactions. In these scenarios of larger lectures (N = 12), classes utilizing VR videos in an asynchronous setup had an average student capacity of around 65, while those integrating VR videos to facilitate synchronous settings had an average of around 25 students. The two 1-1 scenarios include both asynchronous and synchronous setups.

Real World Captures vs. Simulations. Participants envisioned scenarios involving videos from real-world captures (N = 9), simulations (N = 3), or both (N = 2). Real-world scenarios often encompassed virtual tours and recorded experiences or processes, offering students access to experiences that are otherwise inaccessible in the real world. Simulated scenarios included safety training and virtual animations or models that serve to demonstrate complex spatial or temporal concepts or mimic situations which is hard to capture in real-world environments. Most of the simulated VR video scenarios from our participants regard spatial knowledge representation processes.

Timing. Participants explored the temporal aspect of VR video that could play in different teaching materials when describing scenarios. Participants considered the incorporation of VR videos into in-class activities (N = 6), allowing both instructors and students to engage with the content simultaneously. Alternatively, VR videos were utilized as pre or post-class resources (N = 10), accommodating diverse learning paces and economizing time, particularly for longer videos.

VR Video Duration. The video duration in the described scenarios ranges from 2 minutes to 30 minutes, with the exception of one scenario with the video that lasts for 2 hours. This extended video described by P5 covered half of the class duration and was dedicated to demonstrating an experiential laboratory process. Typically, VR videos in the scenarios provided only occupied a small fraction of the class time.

However, we did find that most participants envisioned utilizing VR videos at a foundational level (i.e., understanding rather than applying or analyzing concepts), and explored scenarios using short demonstration stream videos to introduce fundamental ideas. Such applications often aim to motivate and engage students at the beginning of their learning process. Only one scenario (P11) focused on VR in a higher level of context of applying and practicing learning, for training fellows to become acquainted with surgical processes and the operation of complex medical devices.

[2]The number represents the number of scenarios related to the specified categories. The count of scenarios may be multiplied when a single scenario can be classified into more than one categories.

4.2 A Varying Interest in VR Video Adoption based on Perceived Value and Received Support

As shown in section 4.1, all participants identified teaching scenarios where they believe integrating VR videos might yield positive outcomes. However, their ultimate adoption decision was closely tied to their perceptions of the educational value of VR videos and the availability of a supportive community for resources and assistance.

4.2.1 Perceived Learning and Instructing Values. Instructors' decisions on VR video adoption depended on their perception of the learning and instructing values associated with VR videos. Our participants identified several benefits of VR video usage when compared to other visual aids such as images, 3D models, and traditional 2D videos, which aligned with benefits identified by prior work [71]. Specifically, VR video can provide an immersive and natural environment that students don't normally experience with traditional visual aids (P1, P2). P6 further commented on the learning environment with minimal distractions provided VR video's immersive experience. VR video can also effectively convey spatial dimensions and dynamic attributes of locales or objects, even if "*it's flattened to a video*" (P1, P2, P5, P6, P10, P11). And it has the capability to elicit emotional responses from students and enhance empathy (P8). Both P1 and P9 commented on VR video's ability to support students' understanding and memory retention through moving demonstrations. P3 felt VR video can facilitate student collaboration and information sharing through a panoramic view of informational content, as well as accommodating individualized interests.

Regarding the learning objectives, the consensus among our instructors was that the class objectives would remain unchanged when integrating VR videos into their classes, with minor modifications depending on the actual video content. The predominant role of VR videos, as perceived by our participants, would be enhancing learning efficiency and teaching effectiveness during the processes, to provide students with a deeper understanding and opportunities for experiential learning related to the existing learning objectives. As shown in Appendix Table 4, most scenarios identified by our instructors focused on the introductory level. Instructors were more likely to be interested in adopting VR videos if they perceive them as an introducing tool that enhances student engagement, motivation, and active participation in the learning process:

> I would play VR videos before class starts just to get students to wake up a little bit because it's an 8 a.m. class. So I'd love to find like some cool biology videos. That kind of helps to wake them up. (P1)

During the interpretation session, instructors concurred with this theme regarding their VR video adoption. Two instructors (P1 and P9) emphasized that the presence of evidence regarding the impact of VR videos on students' learning outcomes (i.e., the effectiveness of VR video in teaching) might influence their inclination toward integration. As the music instructor P9 stated,

> I might not use VR videos if there is evidence demonstrating only a slight improvement in student engagement compared to 2D videos. It wouldn't be worth it to invest that much effort just to experiment with a new technology. (P9)

This statement was also echoed our observation of P9's arrangement of instructional units, which is reflected in Figure 3. The process of identifying learning objectives is captured by revisiting the analysis stage, ensuring that the perceived instructing value can justify the decision to incorporate VR videos. Although perceived educational value holds significance to instructors, **it is challenging for instructors to identify strong evidence that can demonstrate such perceived values in their teaching scenarios**.

4.2.2 Available Community Resources and Support. Community support is another crucial factor that influences instructors' interest in VR video adoption. From our contextual interviews, we found three types of community support that can reduce the time and effort required for instructors when integrating VR videos into their practices, and enhance instructors' confidence in using VR video as a new teaching tool: *1) the support from related learning community and training programs* which can reduce the time and effort in learning and navigating content when integrating VR videos into instruction; *2) adequate technical support* which helps with setup, troubleshooting, and maintenance for instruction, and *3) general VR related resources*, such as existing practical guidelines, VR video content and platforms.

In the interpretation sessions, instructors expressed different opinions on the types of community support needed. They agreed that technical support is very important when using VR headsets and they will "*have more confidence and are more willing to try it when they know that colleagues have been successful in implementing it in their own classrooms*" (P1). However, with the assumption of the negligible learning curve associated with VR usage, extensive training isn't deemed essential for VR video integration. As emphasized by P6:

> VR videos, if already live online, are very easy to use, at least for me. I don't feel the need for much tech support or training. (P6)

P2 shared a similar sentiment that in spite of the limited resources and support, instructors were still able to achieve their goals if they "*really want to find a way*".

Overall, community resources and support serve as a foundation for instructors interested in VR video as a new technology. However, instructors may not be able to get adequate support or opportunities for related training in VR as a prerequisite before using VR videos (P1, P5, P7, P9, P11). **There is also a notable absence of a mature community that provides resources on VR video-based learning and teaching**, as P3 mentioned in her comment.

4.3 The Importance of Class Piloting and Refinement in Successful Teaching

Class piloting allows instructors to experiment, refine, and evaluate their instructional units with VR videos before implementation on a full scale. Our investigation into rearranging instructional units revealed that the instructional units often are not arranged in a linear sequence but can be iterative or grouped to align with instructors' objectives (see Figure 3). Piloting classes emerged as a critical step advocated by instructors, an aspect that had not been previously covered in our initial instructional unit framework but has an impact on every unit. Instructors identified two types of piloting, with different goals, practicing technology and testing the contents' effectiveness.

4.3.1 Practicing VR Technology. Instructors express concerns regarding the technical aspects of VR video integration, such as equipment setup, troubleshooting, and ensuring seamless integration with instructional activities (especially for pre-video and after-video activities), which can be challenging for both instructors and students (P3). They also mentioned that piloting the technology is more about practicing VR usage than practicing the logistics of VR video in teaching. Instructors might also come up with more ideas on VR video integration after piloting (P1).

4.3.2 Evaluating the Effectiveness of VR Video. Instructors also hoped to evaluate the effectiveness of VR videos through piloting before formally teaching the class. To understand the effectiveness of VR videos, instructors wanted to evaluate the impact on students' engagement and learning outcomes, including measurable skills, abilities, knowledge, as well as values they expected from students completing a VR video-based course (P1, P2, P3, P4, P5, P6, P7, P9, P11). The piloting session can involve only a small group of 2-3 students for initial feedback, including their preferences (P6) and a comparison between VR and other visual aids (P3), or expand to a larger class to ensure the "*VR videos have educational value in the class*" (P7).

During the interpretation session, P1, P3, and P4 raised concerns about the pilot's potential costs for both practicing technology and testing its effectiveness. They suggested addressing these concerns by tapping into community support (section 4.2.2), through sharing experiences and guidelines with instructors teaching in similar contexts to potentially avoid the need for a large-scale pilot. Therefore, **piloting classes is crucial for VR video-based educational success**. This step can be accelerated through the collective wisdom of the educational community by sharing experiences and guidelines with instructors in similar teaching contexts, thus avoiding the unnecessary duplication of efforts.

4.4 Constraints on Experience Diversity Due to Video Generation Capabilities

The intended learning experience is often affected by the quality of VR video content used for the instruction. We observed that participants often struggled to find a good amount of video content from online resources, as well as generating their own content.

4.4.1 Online Video Resources Limitations. In the video generation unit, we observed instructors' content preparation procedures for the 14 teaching scenarios they proposed, and identified their challenges with finding suitable and quality resources on existing video content platforms. Participants commonly searched for content on Youtube [3] and Google [4]. They found some 360-degree/VR video searching platforms such as AirPano [5], DeoVR [6] and 360cities [7]. Despite the widespread availability of video content online, often tagged with descriptors such as *360°*, featuring 360° icon, or VR headset images on the video covers, we observed that some instructors still held misconceptions about 360-degree/VR videos. Some of the video content selected by instructors also turned out to be 2D videos, although they were labeled with keywords or hashtags like *VR*, *Point of View (POV)* [8], *3D* videos.

Among the 14 scenarios, only five were able to locate appropriate VR video content without the need for significant edits. These videos consisted of recorded processes and virtual tours, with minimal adjustments such as time shortening. For seven scenarios, suitable VR video content was not readily available, but instructors could extract relevant elements from existing videos online or their prior teaching materials (whether VR or 2D video) for their classroom activity. These videos were mostly in the category of simulated processes or experiences. Three scenarios involve letting students generate their own reflection videos. One scenario, which was about simulating heart disease training procedure named MitraClip [9], encountered difficulties in finding relevant information but managed to pick elements from existing images.

Instructors were concerned about whether the quantity and quality of VR videos from current online resources can serve their educational purpose or not. For example, P6 commented that the VR video "*is still in the developmental stage... It's not pervasive like everywhere, and you still need to make lots of effort to look for them.*" Notably, instructors explored alternative VR tools as substitutes for VR videos during the video search process. For instance, P6 initially found *360-degree images* in search results and became interested in this content because it could also create an immersive real scene in merchandising design to meet her teaching goal. She also expressed a willingness to explore simpler VR tools as potential VR video alternatives if feasible. Additionally, P4 came across a video recording of a VR volleyball game and saw it as a valuable supplement for beginners to pique their learning interests, which could serve a similar role as VR videos.

During the interpretation session, instructors highlighted the significance of user-friendly capturing and editing tools for authoring VR videos. They also stressed the need for substantial support from the community in terms of content discovery and adaptation to align with their teaching objectives. P3 provided insights about her thoughts on deciding between self-made videos or existing video resources:

> We have helped with the creation of some Google Cardboard 360 apps for other departments (e.g., Forestry), which have included 2D images and annotations. I think our lab is one of the few places on campus that can do this. For most folks, I would recommend starting with existing resources vs. making their own experiences. (P3)

[3]https://www.youtube.com/
[4]https://www.google.com/
[5]https://www.airpano.com/360video_list.php
[6]https://deovr.com/
[7]https://www.360cities.net/video_gallery
[8]POV video is meant to be watched as if the viewer were present or the viewer is in a specific situation
[9]MitraClip is a procedure to fix the mitral valve. During the procedure, doctors access the mitral valve with a catheter that is guided through a vein in the leg to reach the heart.

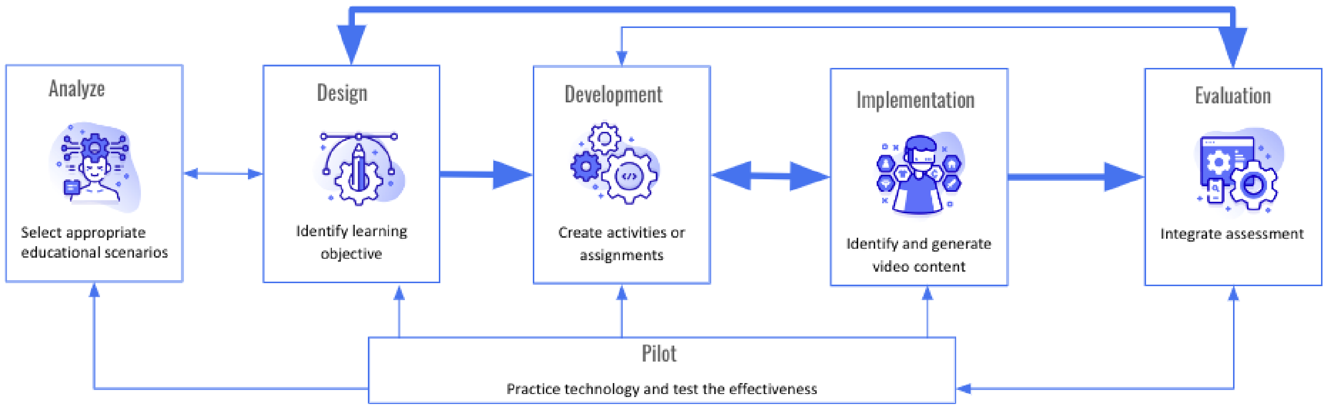

Figure 3: Class design procedure of instructional units when integrating VR Video. This procedure was adapted to ADDIE model [25], which is a structured framework for instructional design that includes Analysis, Design, Development, Implementation, and Evaluation stages. The thickness of the line represents the number of people who have chosen this sequence, with thicker lines indicating a higher number of selections.

Hence, **there still exists a gap in building a resourceful library for educational VR video and helping instructors easily navigate these resources for their needs**. VR content in other formats can also be provided to instructors to supplement their teaching materials as alternative options.

4.4.2 Video Authoring Limitations. We rarely observed instructors show interest in creating VR video content themselves. Only one instructor, P3, mentioned her collaboration with a video generation team, providing her with the capacity to create custom VR video content. The majority of instructors opted to utilize online VR videos as they lacked the resources and support to capture videos themselves, particularly for the 360-degree videos generated through computer simulations. In scenarios where students were tasked with creating their own VR videos, instructors also raised concerns about the availability of capturing tools. P4 suggested a potential solution, which involves "*creating the 360 videos in groups*" to lower the need for capturing tools.

When instructors identified VR video content suitable for their classes, we inquired about the specific editing requirements they envisioned. The editing tasks mentioned most frequently included shortening the video duration or specifying a starting timestamp (P1, P3), adding captions and annotations (P4, P9, P10, P11), or incorporating background voice (P9, P10). Although these tasks mostly concerned with fundamental video editing skills (which instructors were familiar with editing 2D videos), we observed that instructors encountered significant challenges in completing them. For instance, P11 attempted to download the 360-degree videos onto his laptop and import them into the video editing software he usually employs to add annotations. However, there was a dramatic disparity emerged between the downloaded version on his laptop (presented as an equirectangular projection[10]) and the original content experience on the website, where viewers could only see a portion of the video and had to actively determine their viewing direction. P11 conducted online research and explored a few VR video editing tools, and was surprised by the large amount of projection methods in 360-degree videos (e.g., equirectangular, monoscopic[11], stereoscopic[12], and cubemap[13]):

> I didn't realize there were so many formats for 360-degree videos, and I don't know which one could be compatible with VR headset... It seems like the video is distorted at the edges (shown in the video editor), so I'm uncertain how I can place annotations accurately. (P11)

Instructors also brought up additional capturing or editing needs they might have, such as creating interactive videos capable of responding to students' input (P7), having multi-sensorial capturing capabilities (e.g., smell) and adding them to VR videos (P3). The ability to navigate 360 video with depth information in the tool is also important (P5, P8, P11). This tool would be particularly valuable for subjects requiring observations from multiple angles, as exemplified by P5's scenario involving a chemical lab experiment. In such cases, it is essential to observe operations conducted at a fixed point from different directions.

This limitation in authoring tools was also re-iterated during interpretation sessions. P9 contributed additional points regarding future VR video editing and creation tools. These points included the need for tools capable of automatically generating 360-degree videos, potentially utilizing multiple phone cameras, video clips, or converting 2D images into VR videos with animation effects, emphasizing the necessity of an AI-based video editing tool. Furthermore, they stressed the need for tools that simplify the process of downloading/uploading 360-degree videos to VR and editing

[10]Equirectangular projection maps the globe onto a rectangle, maintaining equal spacing of meridians and parallels.

[11]Monoscopic projection involves a single image or video projected onto a sphere around the viewer.

[12]Stereoscopic projection provides a 3D viewing experience by delivering separate images to each eye.

[13]Cubemap projects the video onto the six faces of a cube that surrounds the viewer, with each face representing a different direction.

software, without the need for format conversions (P9). Thus, current technological options for VR video authoring often require professional skills and training, which makes **it challenging for instructors to utilize without a professional team's help to support instructional needs**. Capturing and editing tools should place a strong emphasis on being user-friendly, reducing the requirement for specialized technical knowledge or training.

4.5 Missing Management, Monitoring, and Assessment Tools in VR Context

4.5.1 Disconnection between the Video and Related Activities. Instructors discussed the concerns in moving between platforms and formats for VR video content and other supporting activities related to the video content. When instructors discussed their teaching activities involving VR videos, we observed the presence of both pre- and post-video activities in most teaching scenarios. For instance, prior to commencing the VR video session, P1 designed guiding questions to prepare students for the video content. After watching the video, P9 and P11 emphasized the importance of subsequent discussions, often utilizing notes from the video. A few instructors, such as P5, incorporated a brief quiz to further deepen students' understanding and enhance learning outcomes in a chemical experimental class. Several class management issues arose during this process. P11 commented on the management's effort in distributing the video to students. P9 talked more about the disconnection as students move from VR platform to other education tools:

> It appears that we'll need to remove and put on the headset frequently during multiple video sessions for class discussion or other stuff...which can diminish the immersive benefits that VR offers. (P9)

Instructors highlighted the importance of improving facilitation for pre- and post-video activities, whether conducted within VR or outside of it. Certain instructional facilitations, such as guiding questions, a brief introduction, or discussions, can be seamlessly integrated into the video experience, allowing for a more immersive learning process without the need to remove VR headsets. For example, smoothly exporting the notes students made during the video for their reference after the video is good for them to recall memories and elicit meaningful discussion (P5).

In the interpretation sessions, instructors confirmed that pre- and after-activities should be tied to the VR video. **A smooth transition between in-VR video and non-VR activities is essential to maintain a consistent learning experience as well as a sense of immersion during VR-integrated teaching**.

4.5.2 Disconnection between student/instructor and student/student. Instructors expressed their need to establish stronger connections with students or encourage connections among students while playing VR videos. These personal connections included facilitating team collaboration (P1, P3, P5, P7, P8), keeping awareness of all students' statuses and processes (P7), and assessing students' performance inside VR (P1, P6, P8). For example, P8 walked around the classroom, explaining her usual group separation methods, and expressed interest in using VR videos for similar student grouping. She noted the challenge of interacting with groups in a VR setting, as she typically moves between them to give guidance physically. It is also important for instructors to control the pace of a class when using the VR tools, because compared to in-person classes, "*it is very difficult to make sure that every student is concentrating on the video in VR*" (P7) and *"students may not stay on task while using VR, such as chatting*" (P1).

Several instructors provided insights to address this issue based on their experiences from collaborative VR system trial. They provided suggestions for features such as view-sharing and monitoring tools. For instance, one instructor recommended that the system should have "*a more effective visualization method that illustrates students' focus areas such as the hot areas*" (P8). Furthermore, P9 expressed an interest in enhanced capabilities for managing team discussions, such as the ability to set up VR video rooms for smaller team interactions, along with the option for instructors to transfer between different rooms.

During the interpretation phase, all instructors agreed that tools for building connections are essential and important considerations for VR videos to be effectively integrated into classes. **It is important to provide class management, monitoring, and assessment tools that establish the connection between instructors and students during VR video for its adoption**.

4.6 Missing Subject-specific Learning Aids for Experiential Learning

Although we set out to identify the common needs across different teaching contexts, we find that some educational subjects still require specific learning aids to facilitate their learning process. In the scenarios described in Appendix A, four instructors believed that the general VR video system was sufficient for their scenarios, while over half of the instructors mentioned the need for subject-specific aids.

To illustrate this need, P11 provided a concrete example of his expectations regarding the integration of the existing 2D dynamic ultrasound image with VR video to enhance the training process for MitraClip. In this scenario, the VR video serves the purpose of enhancing students' spatial perception and aligning it with the ultrasound image, which will be used in real-world practice. Similarly, P3 expressed the need for a measuring tool that is proportional to the scale of objects within the video for geography students to perform measurement studies on a virtual field trip. Other examples of the aids included incorporating specific 3D models (P1, P2, P5, P10) and adjusting video playback speed (P4).

In the interpretation session, all instructors agreed that having subject-specific learning aids will improve the efficiency of VR in learning. While some instructors expressed an understanding of the constraint with cost in developing VR applications, they indicated that subject-specific aids could be "*largely beneficial and possibly mandatory for instruction to be successful*" (P4). Existing VR video tools often neglect the customization requirements for each subject, hence **missing the opportunity to offer specific educational support**. However, addressing this gap would require additional development efforts and associated costs, leading to the discussion on the potential trade-off between cost and the expected educational value.

5 DISCUSSION

Our findings provided insights into the present and prospective utilization of VR video within higher education. In this section, we first summarize our results in alignment with the research questions posed, then translate the results to four key design implications aimed at enhancing the development of VR educational technologies (with a focus on VR video) for the future. Next, we reflect on the theoretical framework and model related to educational technology integration and methods.

5.1 Principal Results

We started our inquiry by examining teaching scenarios in which instructors express interest in incorporating VR videos into their real classes. After identifying specific scenarios, instructors revealed related instructional units that leverage VR videos effectively from a practical perspective. We qualitatively analyzed the data from contextual interviews and interpretation surveys to understand the factors that influence instructors' decisions to integrate VR videos in practical educational settings. For our RQ1 regarding the **factors that impact the interest in VR video usage in classes**, instructors proposed 14 teaching scenarios based on their teaching experiences and we found that:

- Instructors' interests in integration are often influenced by how well VR videos align with the learning objectives and the perceived educational benefits of VR videos, such as increasing students' engagement and providing in-depth learning experiences.
- The availability of community support and resources can encourage instructors' VR video adoption. Such support can include the available related learning communities, VR technical support, as well as relevant resources, such as practical guidelines, video content, and platforms.

Our exploration of RQ2 revealed the **challenges that instructors face and the missing facilitations** when instructors generate instructional units with VR videos. Our findings highlighted that:

- Instructors' video generation capabilities are constrained by the limited quality of online videos, as well as the availability of subject-specific VR platforms and user-friendly editing tools for educational purposes.
- The absence of tools for class management, student engagement monitoring, guidance provision, and assessment facilitation in VR learning contexts can diminish instructional effectiveness.
- Missing subject-specific learning aids in VR-facilitated learning can hinder experiential learning.

For RQ3, we sought to understand the **potential adaptation in teaching strategies and methods** resulting from the incorporation of VR videos in the classroom setting. These insights include:

- An iterative process for constructing instructional units, rather than a linear process, which highlights the importance of community support within the process.
- The pivotal role of piloting classes in the success of VR video-based instruction, serving the dual purpose of evaluating the effectiveness of VR videos for achieving learning objectives and providing instructors with hands-on experience with VR technology.
- An understanding that VR videos are not intended to modify learning objectives but instead enhance existing objectives by offering students opportunities for in-depth and experiential learning. To achieve such enhancement, adaptations are required in the stages of discovering suitable video content and designing appropriate teaching activities.

Based on our findings, we have identified four design implications for the utilization of educational VR technology context with an emphasis on VR video technology, as outlined in the next section.

5.2 Design Implications for Supporting Educational VR Technology Adoption

While this paper primarily delves into the utilization of VR videos as a pedagogical tool, it also serves as an exemplary illustration of how VR technology can swiftly adapt to the actual classroom. For each implication, we begin by translating our findings into implications for VR videos and then extend them to support a broader adoption of educational VR technology.

5.2.1 Facilitating the Validation of Educational Effectiveness and Community Collaboration. Our results show that educators' interest in VR videos depends on perceived educational value and the level of support they can receive from related communities. Instructors found it challenging to determine whether the perceived educational benefits were substantial enough to outweigh the integration costs they incurred. Hence, the results promote the necessity for technology capable of assessing the performance of VR video in learning outcomes, which can further empower instructors to better understand the benefits and encourage instructors to integrate it in classes. Moreover, these findings also call for a supporting knowledge-sharing and collaboration ecosystem designed to streamline the integration of VR videos. The collaborative effort of a community can thereby reduce entry barriers, minimize the costs of pilot studies, and alleviate individual workloads.

We suggest the following design implications for new technologies to enhance the supporting ecosystem for VR video adoption and increase instructors' confidence in adopting it for achieving learning objectives. These implications also work for the educational VR context, enabling researchers to evaluate, analyze and share the learning outcome, experiences, content, and pedagogical approaches. First, **developing assessment, analytics, and sharing tools for educational VR activity** can help instructors validate its educational outcomes and foster a knowledge-sharing community. Technologies should facilitate and tailor for assessment and analytics within VR environments, and also support knowledge sharing. There are two possible solutions to uncover data-driven insights that can offer evidence of the educational advantages offered by VR technologies [90]: 1) Integration of VR capabilities into existing assessment and analysis workflows situated outside VR environments. Educators can augment traditional desktop applications with 3D visualization and data collection features (e.g., a simple way is casting or exporting log data from VR), enabling the utilization of established desktop data analysis and assessment capabilities for VR-enabled applications. 2) Incorporation of assessment and analysis functionalities directly into VR applications. For instance, the tool [26] can capture and record immersive VR sessions within explorative virtual environments, yielding valuable insights into user behavior, scene saliency, and spatial affordance. Additionally, MRAT [61] is available to streamline the entire data collection and visualization process for analysis. Within the context of video content, prior research offers a video analysis tool to scrutinize gesture performance [61] and assess view similarity during viewing experience [63].

Second, **developing a comprehensive educational VR supporting ecosystem** for content and knowledge sharing is essential. Technology should complement and assist educators with essential VR training and educational VR resources that cater to various VR equipment options, such as massive open online courses and online communities. These platforms can serve as repositories of best practices for different types of VR technologies (e.g., VR video, 360-degree images, VR games), enabling instructors to exchange experiences and mentor one another in the effective integration of VR technology.

5.2.2 Lowering Barriers for Content Search, Creation and Authoring Tools. Our results showed that most instructors chose to directly get video content online. However, there are limitations in online resources and accessible tools to adapt video content for pedagogical purposes. Our results echoed the prior VR investigations [42], which showed that the major barrier to VR adoption is the content creation barrier. Thus, reducing barriers to content search, creation, and modification is crucial to enable educators to save time and exert less effort in leveraging VR technology.

The first suggested action is **facilitating accessible means of searching for VR resources**. The VR Resources platform should include clear indicators of format types (and can be searched by), as various 3D projections and display methods used [32] may not be directly compatible with their intended educational applications. For example, in the context of VR video, YouTube distinguishes VR videos from other videos by using a "360" tag, which helps participants quickly identify the video format. This could be optimized by technologies such as AI-powered language-searching chatbots or advanced recommendation systems [23, 55] for easier navigation.

Second, **scaffolding easy-enough content creation and editing** to accommodate instructors' content-building process. Automatic templating tools and AI-generated content hold promise for scaffolding instructors in the creation of suitable VR content. In VR video context, prior works explored various strategies and techniques to improve audio and video editing in authoring tools (e.g., [12, 85]). One approach involves text-based video and audio editing, introducing an additional interaction modality that allows users to navigate and edit content using transcriptions generated from media sources [38, 50, 79]. Another method is developing an integrated software solution that supports the intuitive and native handling of 360-degree video formats within VR environments such as Vremiere [64].

Third, participants in our study also expressed the need to **customize subject-specific learning aids** within VR. Technology should be adaptable to accommodate specialized teaching aids and functionalities that facilitate the instructional process. Some specific requirements could be integrated as pre-added common functions; for instance, some instructors expressed a desire to integrate subject-related models, suggesting a need for self-model integration functions. Some subjects might benefit from multisensory authoring tools (e.g., haptic feedback [20], scent and wind [22]). However, certain requirements may incur additional costs on hardware equipment and development efforts for implementation. Recognizing that creating bespoke tools for each subject would escalate development costs, in line with our initial implication concerning community support and learning, technologies should **simplify the sharing and connection for educators and content creators**.

5.2.3 Developing Cohesive Classroom Management, Monitoring and Assessment Mechanisms. From section 4.5, we gained insights into the critical role of classroom management and assessment tools in ensuring effective instruction. These tools enable instructors to grasp students' progress, adapt the learning pace based on assessment results and ensure seamless transitions between in-VR and out-VR activities.

In response to this, we have outlined the following design implications. First, **providing instructional toolkit for class management, monitoring and assessment**. Prior research employed both symmetric designs [42], involving instructors and students within VR, and asymmetric designs, enabling instructors to manage teaching activities and track student progress outside of VR [48]. For instance, one study delves into evaluating student performance in VR using gaze data [82], providing tools for instructors to gain insights into how students interact with VR content and to measure their comprehension and engagement levels. Integration visualization techniques (e.g., [28, 73]) and measurement tools (e.g., simulator sickness questionnaire [29]) with VR could also help the teacher to better interpret what happens during the learning session.

Second, **facilitating instructor-student and student-student interactions** via novel collaborative techniques. Instructors emphasize the importance of collaborative activities, such as group study and discussion within VR, to optimize learning experiences (e.g., "*When watching VR videos, group members could observe different aspects and collectively synthesize their findings*" (P8)). Technology should provide new modes of interaction between instructors and students or among students that enable instructors to manage team activities or exchange information rapidly. This could involve tools for team formation and collaboration to enhance collaboration among students with special consideration in VR environments.

Third, **enabling post-VR revisitation** to deepen students' understanding. This can be achieved through features like "Note Transactions," where students can take screenshots and add 3D annotations for note-taking during VR experiences. Instructors expect these notes to be exportable for further discussion or performance evaluation (P1). Additionally, incorporating "Video Recording" functionality would allow students to revisit their VR activities outside of VR, aiding in review and comprehension, similar to the growing trend of recording traditional classroom sessions on platforms like Zoom (P6). Future VR technologies should include playback options for revisiting and re-examining VR experiences (e.g., VRdeo [16] and EditAR [19]), catering to diverse accessibility needs.

5.3 Theoretical Reflections on Instructional Process for Educational Technology Integration

Technology was identified as a significant player in the learning and teaching process for contemporary education reform. Previous research has pointed out the lack of theoretical and conceptual frameworks to guide research and prepare teachers for technology integration in education [3]. As noted in [56], understanding "what the teachers need to know in order to appropriately incorporate technology into their teaching" as well as "how they might develop it" is important to ensure the smooth involvement of educational technology in the classroom. Our study contributes to these questions by offering practical examples and empirical evidence on how to adapt new technology (e.g., VR videos) to the class, thereby supplementing existing frameworks and models. In this section, we reflect on two theoretical frameworks that are closely related to this work that can serve as a roadmap for educators, offering strategies for managing the instructional process to integrate new educational technology.

First, the **Technological Pedagogical Content Knowledge (TPACK) framework** [66] describes the kinds of knowledge required by teachers for the successful integration of technology in teaching. It suggests that teachers need to know about the intersections of technology, pedagogy, and content. However, this framework is not accompanied by specific recommendations or strategies for how to help develop this body of knowledge for teachers [65, 91]. In this study, we explored how the integration of new technology might interact with and influence pedagogy and content, giving practical examples and implications for researchers and educators.

Second, our unit creation process is similar to the existing **ADDIE model** [25] (shown in figure 3). This model is often used to design learning and training programs in organizations. This model provides a streamlined, structured framework that can help instructors create effective classes. There are five stages of the learning development process: analysis, design, development, implementation and evaluation. A significant challenge of the ADDIE model is its linear process [57], which lacks the flexibility and creativity required to envision the integration of new technology into the class. To address this challenge, we modified the ADDIE model by allowing participants to rearrange the order of the last four stages during the analysis phase. We incorporated a pilot phase into the model, aimed at gathering valuable feedback to refine each step. Our findings suggest an iterative pathway for educators to have a pilot phase in technology integration, involving not only instructors but also capitalizing on community knowledge sharing.

5.4 Method Reflection

We employed contextual inquiry to investigate our research questions. This approach immerses both participants and researchers in an actual teaching preparation process and environment, offering first-hand insights into how instructors conduct the given tasks with considerations of contextual factors, such as classroom setup, technological infrastructure, available resources, and institutional support. For instance, when designing the teaching activity, P8 demonstrated how she would organize student groups in the classroom. Additionally, she utilized a dental teeth model within the classroom to illustrate her approach to positioning the 360-degree camera for creating an ideal VR video. Another example pertains to the video-searching task. During our observation, we witnessed instructors searching and editing for video content and noted their confusion and struggles during this process. More examples can be found in Appendix Table 4. These insights might be challenging to accurately glean through traditional interviews.

We used multiple data sources and methods, such as interviews, observations, and surveys to investigate our research questions through iterations. We included member checking and soliciting feedback from participants, which contributes to the overall credibility of our interpretations from the analysis and our study's outcomes. For instance, we initially identified that a multi-sensory VR video authoring system was a general need for instructors, and after the interpretation, we discovered that instructors actually prefer a straightforward video editing tool that includes only essential features and requirements. In addition, since novel technology can be challenging to conceptualize and investigate for practical guidelines and use cases, employing multiple methods of investigation with iteration can effectively assist users in eliciting their needs. We encourage other researchers, especially those involved in the design of innovative educational technologies, to consider using similar strategies when carrying on formative investigations with novel educational technologies to enhance the credibility of their results.

6 CONCLUSION

This research has explored the integration of VR videos as a transformative VR tool in higher education. Our investigation has elucidated the instructional strategies employed by educators when integrating VR videos into their teaching practices. Through a contextual inquiry, we have unveiled the determinants influencing instructors' interest in utilizing VR videos, pinpointed pertinent challenges, and highlighted essential pedagogical adaptations. These findings offer invaluable design implications for the development of VR video-based learning experiences and a broader educational VR technology context across diverse educational settings. Finally, we reflected on the existing theoretical framework and our study methods. As educators, instructional designers, and technologists continue to explore the transformative possibilities of novel technologies in education, the lessons drawn from our examination of VR videos offer a starting point for expressing the full educational potential.

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A APPENDIX

Table 2: Observation types and examples of observation notes (with label [*Note*]) and related photos (with label [*Photo*]) from the collected data. All photos captured during the session are converted to a textual description for analysis.

Type	Description	Examples
Interaction with digital technology and materials	Observes how instructors engage with digital technologies and contents, focusing on activities like navigating interfaces, interacting with videos and editing tools, using existing teaching materials, and responding to digital stimuli.	• P10 searched for videos for volleyball class on YouTube but mistakenly clicked on videos of a recorded VR volleyball game instead of 360-degree videos [*Note*]. The photo captures YouTube search results of query "volleyball VR video." The results include videos capturing real-life volleyball matches and recordings from VR volleyball games [*Photo*]. • P1 presented a class slide showing a 2D video followed by a quiz with questions related to the video [*Note*]. • After displaying a 3D skeleton model on the computer, P2 searched for tools to record her manipulation of the model into a VR video. Despite exploring numerous webpages, she was unable to find a suitable method for recording [*Note*]. • P10 used an AR application to showcase a 3D human muscle anatomy and showed interest in using VR video for animated demonstrations [*Note*]. The photo shows a person holding a phone that displays an AR view of a human skeleton with various muscles labeled [*Photo*].
Interaction with physical tools and materials	Examines how instructors interact with physical tools and tangible materials, such as the arrangement of instructional units and engagement with physical teaching aids.	• While organizing instructional unit cards, P1 switched the sequence between "Create Activities" and "Identify or Generate Video Content" several times and eventually added a bidirectional arrow between these two cards [*Note*]. The photo captures P1's final arrangement of the instructional unit cards, showing several bidirectional arrows drawn between the cards [*Photo*]. • P8 found a physical teeth model in the classroom and used it to explain her idea of positioning a 360 camera inside the mouth to capture all teeth for her own video creation [*Note*]. The photo captures a person holding a dental model featuring an upper and lower set of teeth, and pointing to where the two halves connect [*Photo*]. • P5 utilized a chemistry molecular model kit on his desk to explain the complexities of molecular structures, and noted how VR videos could enhance students' understanding of spatial information [*Note*]. The photo shows a hand holding a molecular model, representing a chemical compound's structure. The model consists of colored balls connected by rods, representing atoms and bonds respectively [*Photo*].
Teaching environments	examines the physical setting of VR use, including classroom layout and atmosphere, to understand how it affects the VR educational experience.	• P9 pointed to the mirror and explained its importance for students to observe their mouth and body movements [*Note*]. The photo shows a piano practice room with a black piano, wall-mounted mirror, chairs, and a music stand [*Photo*]. • P8 moved through the classroom, showing her approach to forming and circulating among various student groups to provide guidance [*Note*]. The photo shows the classroom with grouped tables and chairs, whiteboard, electronic lectern, side cabinet with tooth models and dental appliances [*Photo*].

Table 3: Preliminary results and interpretation adjustments

<table>
<tr><th>Theme</th><th>Preliminary Results of Contextual Interviews</th><th>Post-Interpretation Adjustments and Supplements</th></tr>
<tr><td>A Varying Interest in VR Video Adoption Based on Perceived Value and Received Support</td><td>This theme underscores the significance of both the perceived educational value of VR videos and the impact of community support in shaping instructors' interests. It specifically necessitates:
(1) Instructors' interest is influenced by how well VR videos align with their learning objectives and their belief in the educational benefits, such as increased student engagement and deeper learning experiences.
(2) Community support includes several essential aspects:
• Availability of related learning communities, training programs, or workshops reduces the time and effort needed to integrate VR videos into instruction.
• Adequate technical support positively influences instructors' interest, including help with setup, troubleshooting, and maintenance.
• Availability of relevant resources, such as existing practical guidelines, VR video content and platforms.</td><td>• Instructors' willingness to apply VR video in classes will also depend on whether there exists strong positive evidence for improving students' learning outcomes, which may be challenging to find;
• Technical support is crucial for VR training but may not be as essential for using VR videos;
• Instructors may still attain learning objectives with limited resources if they are sufficiently motivated.</td></tr>
<tr><td>The Importance of Class Piloting and Refinement in Successful Teaching</td><td>Piloting allows for experimentation, refinement, and evaluation of instructional units incorporating VR videos. It includes:
(1) Testing the effectiveness of using VR video to their learning objectives.
(2) Practicing technology for class management, such as equipment setup, troubleshooting, and ensuring seamless integration with instructional activities.</td><td>• Piloting class, despite its importance, may be costly to instructors and is suggested to be offloaded to the supporting community;</td></tr>
<tr><td>Constraints on Experience Diversity Due to Video Generation Capabilities</td><td>It highlights the need for high-quality videos (including computer-generated simulation videos), concerns include:
(1) Limitations of search engines and the quality and quantity of online videos, e.g., an AI-supported VR video searching tool that helps to get the appropriate video.
(2) Lacking VR video capturing tools, e.g., somatosensory/spatial audio/smell capture, and advanced video creation/format conversion tools for 360-degree 3D simulation videos.
(3) Lacking VR video editing tools, e.g., creating interactive videos, integration of 3D models, 2D images, annotations, and assessments within the video.
(4) Lacking financial support to purchase high-quality videos, or capturing tools.</td><td>• Video capture tools are suggested to include functions such as automated video generation, phone camera integration, etc;
• A simplified tool to facilitate the process of downloading VR video and uploading to VR devices is suggested;</td></tr>
</table>

Theme	Preliminary Results of Contextual Interviews	Post-Interpretation Adjustments and Supplements
Missing Management, Monitoring, and Assessment Tools in VR Context	This theme recognizes the need for tools that support class management, monitor student engagement, provide guidance, and facilitate assessments within the VR learning environment. More specifically, it requires: (1) Tools for managing, monitoring, and assessing students' engagement and learning outcomes in VR experiences. E.g., AI assistant for teamwork facilitation and evaluation. (2) Support for multiple device displays in case of VR malfunctions or limited hardware availability. (3) Natural transitions between traditional teaching methods and VR video content. (4) Facilitations for pre-video introductions or priming activities to prepare learners for the upcoming content. (5) Facilitations for post-video discussions or reflections to deepen understanding. E.g., tools for exporting notes or annotations made during the video.	• No significant adjustment with this theme; all instructors highlighted the need for easier VR management and connection tools to facilitate class activities;
Missing Subject-specific Learning Aids for Experiential Learning	This theme emphasizes the need for tools and resources that are subject-specific that allow for the visualization of complex concepts, procedures, structures, and measurements during watching the VR video. E.g., Incorporation of measurement tools for a VR field trip; Incorporation of 3D human models for a fitness class.	• The integration of subject-specific tools may increase the efforts and cost of developing VR applications, but can largely benefit the learning process.

Table 4: Participant-identified teaching scenarios and class information. Domains of scenarios are adapted from the literature review of [71].

P ID	Scenario Category	Scenario Description	Type of video	Class Size	VR Video Usage	Timing
P1	Simulated processes for spatial knowledge representation	In the introductory biology course, VR videos are employed to showcase the stages of mitosis and meiosis, aiding in the comprehension of the DNA replication process.	Simulations	100	Small proportion of the class; Video about 5 minutes long.	Both
P2	Virtual tour for archaeological site	In the introductory anthropology course, VR videos are employed to immerse students in archaeological sites for the study of societies and cultures.	Real world capture	50	Roughly 30 minutes of class-related video shown every two weeks.	Async
P3	Virtual tour for outside recreation	In the course of managing recreational lands, VR videos are utilized for engaging in outdoor recreation, aiming to comprehend and apply management tools designed to mitigate recreation-related impacts and conflicts.	Real world capture	40-50	Less than 10%; Usually 2-10 minutes.	Sync
P4	Recorded processes and procedures for sports training; recorded processes for learning through replay (self-reflection)	In the introductory volleyball course, VR videos are employed as illustrative examples to facilitate learning of volleyball skills, concepts, and team play strategies.	Real world capture	35	Not significant amount, 10-15 mins for each video.	Async
P5	Simulated processes for spatial knowledge representation	In the general chemistry class, VR videos are utilized to demonstrate the structure and function of proteins or molecules.	Simulation	100-130	Small amount; 5 mins for each video	Async
	Recorded processes and procedures for laboratory course	In the experimental class, VR videos are employed to depict the physical occurrences within experiments before or after their actual execution.	Real world capture	20	About 50% of lab time (4 hours).	Sync
P6	Recorded experiences for merchandising	In the virtual reality retailing course and retail merchandising class, VR videos are utilized to teach visual merchandising aspects of the store.	Real world capture	40-70	Videos used during class are mostly short, 2-3 minutes.	Both
P7	Recorded situations for language practice	In the beginning level Chinese class, using VR videos to contextualize a cultural environment and practice the language.	Real world capture	20	About 15 videos each week, each video is 2 3 mins long.	Sync
P8	Simulated processes for spatial knowledge representation	In the introductory level of dental and oral health class, VR videos are employed to demonstrate the anatomy and development of the mouth and teeth.	Simulations	20	Not a significant amount, 5 mins for each video.	Sync
P9	Virtual tour for culture and music	In the introductory music course, VR videos are utilized to provide a survey of musical styles and forms within specific cultural or situational contexts.	Real world capture	40	Roughly 10-15 mins for each video.	Async
	Recorded processes for learning through replay (self-reflection)	In 1-1 vocal music class, VR videos are employed to offer music context, address stage fright, self-assess performances, and prove particularly valuable for novice learners.	Real world capture	1	Approximately 5 minutes per video, depending on the song's duration.	Sync
P10	Recorded processes and procedures for fitness training; recorded processes for learning through replay (self-reflection)	In 1-1 fitness class, VR videos are utilized to exemplify correct fitness actions, introduce body anatomy, and assess students' home training, particularly beneficial for novice learners.	Real world capture	1	Might employed only at the beginning of the entire class, approximately 20 minutes based on learners' comprehension.	Sync
P11	Recorded or Simulated situations for emergency training	In cardiac surgery patient emergency training, VR videos are employed to enhance decision-making, preparedness, and response.	Both	3-5	Training through video takes about 15-20 minutes.	Sync
	Simulated processes for spatial knowledge representation; Recorded processes for surgery training	In structural heart disease fellow training, utilizing VR videos to enhance knowledge and procedural skills.	Both	3-5	Training through video takes about 15-20 minutes.	Sync