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Knowing Your Student: Targeted Teaching Decision Support Through Asymmetric Mixed Reality Collaborative Learning

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ABSTRACT The Collaborative Virtual Environments (CVEs) created by Mixed Reality (MR) technologies have been classified as symmetric and asymmetric CVEs. The latter aim to provide different authorities for different collaborator roles utilizing heterogeneous techniques that cover the entire gamut of Milgram's Mixed Reality continuum. As a new type of MR display that generates an auto-stereoscopic viewing experience without head-mounted devices, the Light Field Display (LFD) has been incorporated with Augmented Reality (AR) and Virtual Reality (VR) headsets to create remote and co-located asymmetric collaborative environments. In previous asymmetric CVE research, LFDs were adapted to simultaneously render multi-contents for multiple students to lower average device costs for the MR vet training. However, multiple students sharing one LFD to interact with the teacher may weaken the teacher's understanding of individual students' current learning progress, making teaching decisions even harder. Therefore, this paper presents an enhanced solution that supports teaching decisions targeted at each student without increasing the device costs. The context-aware LFD student clients, which render a dynamic viewing zone for each student by face encoding tracking, are implemented and applied for anti-cheat quiz support. By synchronizing each student's tracking data with a Local Area Network (LAN) middleware, the AR teacher client can distinguish different students to in-situ superimpose the quiz progress and targeted-explainable teaching decision support over each corresponding student's head. Ten University vet/anatomy teachers participated in the remote expert review study to provide professional feedback. According to the questionnaire results, they think the designed collaborative learning tool will be helpful for both teachers and students.

INDEX TERMS Augmented reality, mixed reality, light field display, decision support, asymmetric collaborative virtual environments, anatomy education.

I. INTRODUCTION

The laboratory course is a crucial pedagogy for teaching Science, Technology, Engineering, and Mathematics (STEM). The conventional laboratory courses always require dedicated equipment, specimens, or facilities to assist lecturers in explaining the practical procedures for students. However, it is widely agreed that "situating learning tasks in authentic contexts" and "varying the diversity of context" [1] are essential for "visible thinking" pedagogy [2] and situated learning pedagogy [3], which encourage learners to actively apply in-class knowledge to solve real-world problems [1]. Such pedagogies inspired the emerging research into the creation of *virtual labs* [1] and teaching practice simulation [4] techniques to provide simulated virtual praxis environments for the learners. Such techniques are an absolute necessity for vet training and anatomy education, as these subjects require substantial practical operations and close observations of anatomies. This necessity comes with logical and financial implications as live tissues and anatomies are expensive to acquire and logistically challenging to store in large quantities. To bring high-fidelity simulations into virtual anatomy education labs, immersive visualization techniques, such as Augmented Reality (AR) and Virtual Reality (VR),

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are becoming increasingly popular solutions. Mixed Reality (MR) technologies have shown significant advantages in facilitating students' understanding of the 3D anatomy models [5], [6] and enhancing learning achievement [7] within the highly immersive [8], [9] or context-aware virtual learning environments. By combining the unique advantages of different technologies covering the full Milgram's Mixed Reality continuum [10], asymmetric Collaborative Virtual Environments (CVE) brought the new potential to the classroom by providing the teacher and students with different MR technologies according to their different requirements and roles [11], [12]. Light Field Displays have been incorporated with AR [6] and VR [5] teacher clients to provide students with headset-free auto-stereoscopic experiences in the remote and co-located vet training asymmetric CVEs [5], [6].

One of the first realizations that teachers have at the beginning of their careers is that they become aware that teaching all students in the same way is not a productive approach. One of the essential steps in teaching is to be able to aid the students in generating relevant connections between themselves and learning materials, which facilitates a personalized learning pedagogy [13] approach. Achieving such personalized learning requires accurate teaching decisions on the teaching methods and materials that are targeted at the individual learner's personal characteristics and level of knowledge [14]. Teaching decisions, described as ''complex cognitive processing of available information'' about the situation [15], is usually made based on not only the teacher's professional experiences but more importantly teacher's judgment about students [16]. Accurate judgments about students can potentially allow teachers to easily ''make changes to the teaching materials to accommodate student's needs or to accomplish instructional objectives'' [17], which requires the teacher to be immediately informed about students' learning behaviors, progress, obstacles, and outcomes in the classroom. However, it is sometimes impossible for a teacher to independently gauge where the students are on their learning journey even in small classes. Several exemplar pedagogy frameworks [14], [18], [19] applied traditional technologies to assist teaching decisions by providing learner analysis and progress tracking [17], based on which the teachers can provide individual learners with personalized teaching materials and praxis following the personalized and situated learning pedagogies. However, such personalized learning pedagogy and teaching decision support have been ignored by most prior research about CVEs, especially in anatomy education praxis. Additionally, most of such personalized pedagogy frameworks require long-term analysis to generate students' learning patterns for teaching plan adjustments, while teachers may need instant analysis of students' in-class learning outcomes and knowledge deficiencies for timely troubleshooting and personalized teaching plan adjustment.

AR-based Decision Support System (DSS) has shown such potential to provide instant insight into the decision context at a glance by situated or in-situ embedding the decision-support data within the current contexts [20], [21], while it has been rarely applied to support teaching decisions. Moreover, very few AR-based DSS have provided accompanied decision explanations to increase user's trust [22] towards the given suggestions or recommendations. Therefore, based on the prior Mixed Reality collaborative learning system *METAL* [6], this paper further explores how in-situ AR data visualization and context-aware LFD visualization can be incorporated to strengthen the teacher's understanding of each student's current learning progress thus provide explainable teaching decision support (Fig. 4). An asymmetric CVE system is designed to allow teachers at a glance to know each student's current learning progress, so as to support instant teaching decisions for personalized-immersive learning in vet-training tutorials and labs.

The designed system framework aims to support a complete co-located vet tutorial/lab procedure: after the teacher shares different 3D anatomy models with students, the teacher can see each student's real-time manipulation of the assigned 3D model (Fig. 2) while walking through the classroom. Accordingly, the teacher can assign different quiz types by dropping a quiz upon a student's head in an AR environment. While students are working on the quiz using gesture control in front of the shared LFDs (Fig. 3), the teacher can see each student's quiz progress and quiz result analysis with a glance (Fig. 7), based on which brief teaching suggestions are provided to support the teacher's immediate decisions on targeted guidance and teaching plan/progress adjustments.

This co-located vet tutorial was chosen as the first application scenario as the proposed system is fundamentally a Collaborative Learning environment using a Problem-Based Learning (PBL) approach. The vet tutorial lesson takes a constructivist [23] approach where the teacher facilitates the understanding of the material, while the student can interact directly with the simulation. This educational pedagogy approach is influenced by Vygotsky's zone of proximal development where an ''enhanced professional practice and improved teaching in PBL'' [24] can be achieved through a learner's ability to experiment within the environment. Therefore, this proposed system was fitted into a Problem-Based Learning pedagogy to support vet training teaching decisions. We conducted a video-based remote expert review study to validate this proposed solution and evaluate the implemented system.

II. RELATED WORK

The usage of Mixed Reality (MR) technologies in education have been proved to increase student's learning motivation and knowledge gain when compared with other teaching methods such as paper-based materials and slides [25], among which the MR assessment system has been used to assess students' performance and knowledge [26] and achieved similar test outcomes compared with traditional physical assessment [27].

As Mixed Reality collaborative learning and immersive learning develop rapidly, multiple types of research also

FIGURE 1. System set up.

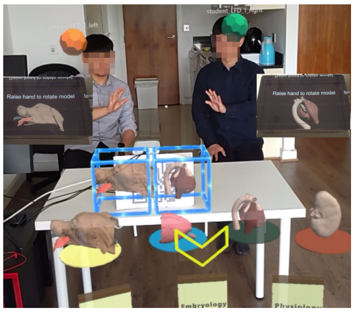

FIGURE 2. Drag-and-drop model sharing with individual students.

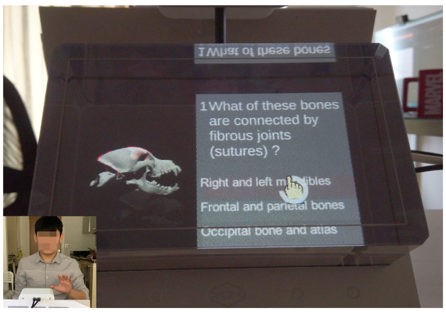

FIGURE 3. Student answering quiz with gestures.

indicated certain issues brought by the usage of MR techniques in education while they bring numerous advantages. First, AR technology usability has been the most reported challenge that "AR is difficult for students to use" [7], [28], [29]. Similar usability issues also existed in VR headset [30], [31] usages in the classroom, which caused students much longer training time [32] and even motion sickness [33]. Moreover, the high costs of equipping each student with a VR/AR headset has impeded the large-scale application of these MR collaborative learning tools. Hereupon, *METAL* [6] has been proposed as a low-cost solution to allow for collaborative learning between the AR teacher client and the LFD student clients without sacrificing teachers' or students' user experience. In this prior work, LFD was indicated as a cheaper and handy alternative for its no-head-worn requirements and simpler interaction metaphors. Instead of getting all students trained for the AR headset usage, training the teacher to use the AR interface for teaching support may be more efficient. However, due to the interaction limitations of the LFD student clients, this prior research provided the teacher client with little or no information of individual students' learning behaviors and progress about the assigned teaching contents. Moreover, according to Feld's definition of asymmetric CVE [11] based on different authorities assigned to different collaborators' roles, in the educational asymmetric CVEs, the teacher should play the *primary* role to contribute the most to the teaching contents, and students should play the secondary *role* to mainly consume the teaching contents. While despite such an important role played by the teacher, very few MR CVE aimed to assist their teaching decisions by reinforcing the teacher and student roles in vet training praxis.

In the *METAL* [6] system, each LFD was divided into multiple static viewing zones to display different 3D contents for each student. This approach significantly reduced each student's Field of View (FOV) while also rendered redundant views that are invisible to any student. A rendering-pressure-relief algorithm has been proposed to turn off the unnecessary views by tracking the viewer's position [34]. Another prior work has further exploited this algorithm to allow for multi-content rendering for multiple observers by tracking multiple pairs of pupils using a webcam, which however left the potential issues of viewing-zone overlapping and even viewing-zone confusion when two observers move close or switch positions [35].

Also, in the prior *METAL* [6] system, 3D model manipulation was only supported for the teacher client while students were unable to interact with the LFD due to the device limitation. These limitations might diminish students' sense of engagement in the class and increase the teacher's workload.

This paper aims to solve the static-viewing-zone issue by distinguishing different observers with face encoding and tracking their dynamic positions, based on which the first anti-cheat LFD quiz support feature is illustrated. Additionally, LFD gesture control is also integrated with a depth camera [36], [37] to increase students' sense of engagement in the class.

Among all these prior MR collaborative learning CVEs, they have rarely focused on teaching decision support despite the challenges confronted by teachers in making timely-accurate decisions about teaching material and progress. While AR has been showing significant potential in decision support since recent decades [38] in multiple areas including shopping [39], medical treatment [40], Agriculture [41], and manufacture [42]. Therefore, this paper first utilizes the in-situ AR data visualization to provide instant teaching decision support with accompanying explanations to increase users' trust towards the system-generated decisions [43].

III. SYSTEM SETUP

The terminal device of the teacher client is a Microsoft Hololens 2 headset; each student client is powered by a high-performance desktop PC connected with an 8.9-inch

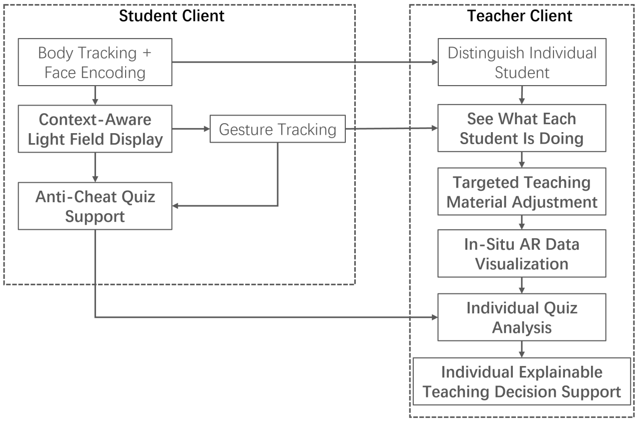

FIGURE 4. **Concepts behind the system design.**

Looking Glass LFD for displaying. A Microsoft Azure Kinect depth camera is attached to LFD to track the students (Fig.1). This whole system is developed using the Unity3D engine. For the student client, the latest version of Azure Kinect Unity Plugin[1] is applied for the gesture and position tracking; the Looking Glass rendering Unity SDK[2] is adapted to render dynamic viewing zones on the LFDs. MixedRealityToolkit[3] is applied to implement the interface of the HoloLens teacher client, and Vuforia Unity SDK[4] is applied to track the QR code attached to each LFD.

IV. SYSTEM OVERVIEW

A. SYSTEM ARCHITECTURE

This system is developed based on prior *METAL* co-located content sharing system [6]; thus, this section only focuses on the extra features and innovations while omitting the existed *METAL* implementations. This system still maintains the high-level *METAL* setup for one AR teacher client and multiple LFD student clients. While instead of communicating both clients using a Wide Area Network (WAN), a Local Area Network (LAN) synchronization middleware is developed for speedy and secure network communication between the co-located teacher and student clients (Fig. 5). In addition, as Fig. 4 illustrates, to allow for teaching decisions targeted at each student, an LFD provides each student with a context-aware dynamic privacy viewing zone that follows their real-time movement. By doing so, the teacher client can distinguish different students and adjust the teaching materials targeted at each student. Exploiting such a dynamic privacy viewing zone, we integrated an anti-cheat quiz support to both clients, allowing for the in-situ visualization of the explainable teaching decision targeted at each student.

[1] https://assetstore.unity.com/packages/tools/integration/azure-kinect-examples-for-unity-149700

[2] https://lookingglassfactory.com/software

[3] https://github.com/microsoft/MixedRealityToolkit-Unity

[4] https://developer.vuforia.com/downloads/sdk

B. DYNAMIC PRIVACY LIGHT FIELD DISPLAY VIEWING ZONES FOR CONTEXT-AWARE VISUALIZATION

As Fig. 4 illustrates, the student client created a context-aware LFD visualization by dividing each LFD into multiple dynamic viewing zones according to students' real-time positions. To accurately track each student's face without violating their privacy, an Azure Kinect depth camera is attached to the LFD to real-time track each student's relative head position (p_{head}) and face encoding. Using these tracking data along with the LFD field of view (FOV fov) and its total number of views (n_{view}), the specific views that can be seen by each student ($V_{student}$) can be calculated from the Equation. 1. For every moment, a dynamic centering view is calculated from this equation to form a dynamic viewing zone along with its two adjacent views, which is always bound to the corresponding student's face encoding and therefore is never visible to any other students. Based on this mechanism, the anti-cheat feature is implemented for the quiz phase (Section IV-C). This dynamic viewing zone controls the 3D contents displayed for the bound student in the whole rendering procedure no matter how this student moves, hereupon supports different 3D content viewing with the entire FOV for each tracked student. Compared to the static viewing zones calculated by FOV divisions [6], such dynamic viewing zones allow more students to use one same LFD without FOV decreases simultaneously. In particular, if two or more students' viewing zones overlap, the rendering SDK will render nothing to prevent students from seeing overlapping scenes. Additionally, by tracking students' gestures using the depth camera, all students using the context-aware LFD are also allowed to manipulate the 3D model and answer the quiz with gesture controls.

$$V_{student} = \frac{n_{view} \times (\frac{fov}{2} - \arctan(|\frac{p_{head}.x}{p_{head}.z}|))}{fov} \tag{1}$$

As Fig. 5 illustrates, each student's real-time head position and gesture data are both sent to the teacher client for synchronization. Using each student's head position, we create an avatar following each student to allow the teacher to distinguish them from each other (Fig. 4). Therefore, the teacher can share a 3D anatomy model and quiz with the corresponding student by simply dropping the virtual contents to their head, as Fig. 6 shows. Simultaneously, the assigned anatomy model is also displayed in the corresponding LFD viewing zone box (Fig. 2) for the teacher to know what each student is viewing. Moreover, by synchronizing each student's gesture data to the teacher client, the 3D anatomy model in the corresponding viewing zone box will show the real-time rotation and scale changes made by this student (Fig. 2), which allows the teacher to see what each student is doing with their 3D model (Fig. 4).

C. ANTI-CHEAT QUIZ SUPPORT

As a critical strategy for the teacher to understand students' current learning outcomes, in-class quizzes usually take

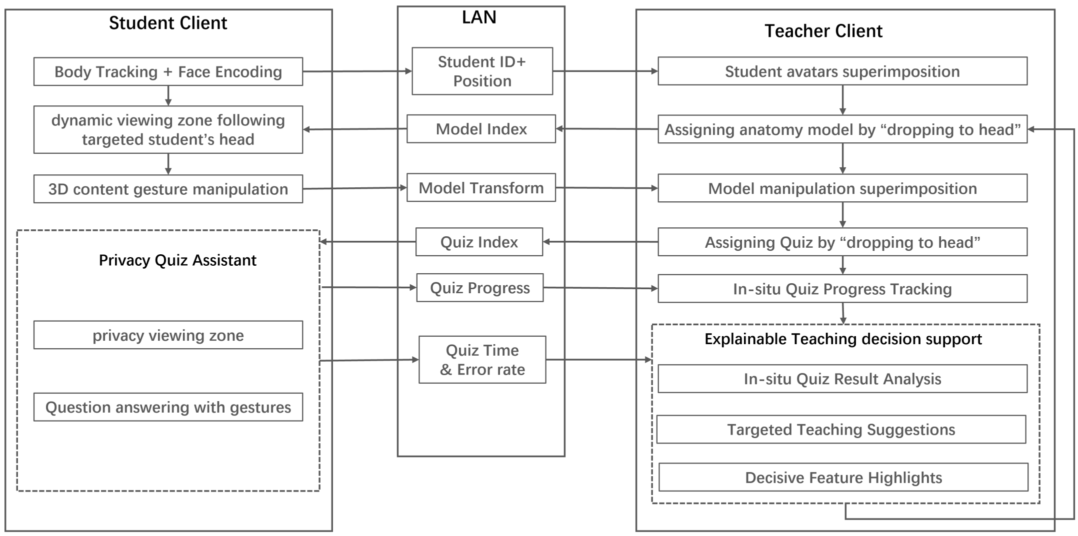

FIGURE 5. System architecture.

teachers or teaching assistants considerable effort and time to maintain quiz rules and mark the paper. To make this procedure more efficient, we integrated an anti-cheat quiz support into each student client, which is also simultaneously tracked by the teacher client. First, the teacher can select a quiz from the quiz pool and assign it to any student by dropping it to their avatar. Immediately when the quiz index is sent to the targeted student client, as Fig. 5 illustrates, the student may start answering the assigned quiz from their corresponding LFD viewing zone by simply hovering one cursor over an option for 2 seconds with gestures (Fig. 3). As is explained in subsection IV-B, each student is assigned a dynamic privacy viewing zone which is always and only visible to themselves. Therefore, students can never see others' quiz contents and answers even though they are sharing the same LFD. This mechanism prevents possible cheating behaviors during the quiz phase. Simultaneously, on the teacher client, a quiz progress bar is superimposed over each student in a quiz to show the teacher their quiz progress in real-time (Fig. 7).

D. TARGETED TEACHING DECISION SUPPORT WITH EXPLANATIONS

After any student finishes the quiz, their quiz result will be immediately sent to the teacher client to start a detailed quiz result analysis for this student (Fig. 4). As is shown in Fig. 7, the completion time and the error rates achieved in different quiz parts are both in-situ visualized over the corresponding student's head. However, drawing a conclusion based on these pie charts and histograms might be time-consuming for the teacher. Therefore, the AR teacher client directly highlights the weakest part and strongest part from all quiz parts by calculating the Rate of the Correct Scores (RCS) ([44]) for each quiz part, based on which the brief teaching suggestions can also be displayed. For example, according to the suggestions displayed in Fig. 8, the stomach components in the pie chart and the histogram are both highlighted in red, with the accompanying suggestion indicating more practice is needed for this part due to its lowest RCS. Additionally, a knowledge deficiency degree is also displayed at the end of the suggestion to indicate how much the RCS of this part is lower than the average level. Instead of simply providing suggestions about teaching plans, the student's knowledge deficiency and the deficiency degree are also highlighted as the decisive input values to explain the provided suggestion. Such decision explanation may not only increase the teacher's trust towards the given suggestion but more importantly, allow the teacher to provide detailed guidance targeted at each student's knowledge deficiencies. Compared to checking each student's quiz analysis from the computer or mobile phone, with quiz analysis in-situ superimposed over each student's head, the teacher is saved from searching for those students who may need more help among the whole class by calling their names. Instead, the teacher may quickly identify which students showed significant knowledge deficiency by a glance and directly walk to these students to provide personalized guidance.

E. LAN SYNCHRONIZATION MIDDLEWARE

As this system aims to support co-located teaching activities in labs and classrooms, this network middleware is designed to provide fast connection among the clients within a classroom. For such a co-located teaching system, any network latency will be significantly noticeable due to the mismatch between the user movement and virtual objects. Therefore, we chose to utilize a LAN-based network middleware to minimize the network latency. However, among the off-the-shelf network engines, no suitable solution can transmit customized information between Universal Windows Platform (UWP) applications and desktop applications via LAN. Thus, a dedicated socket-based LAN

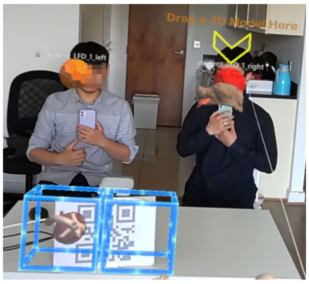

FIGURE 6. Targeted content sharing: dropping an anatomy model to a student's head avatar for content sharing.

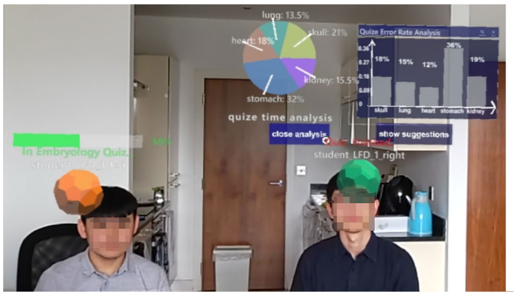

FIGURE 7. Quiz progress tracking & quiz result analysis.

FIGURE 8. Targeted teaching suggestions: highlighting weakest part and strongest part.

network synchronization middleware (Fig. 5) is implemented to satisfy these customized communication requirements. To ensure data security and network efficiency, only non-essential messages that are irrelevant to students' identities are transmitted via the LAN, which include the sender client type, client code, message type, the auto-generated student code and transform, as well as the 3D anatomy model/quiz code and transforms. Then the information is packaged using our customized application-layer protocol and transmitted to the destination using UDP to reduce the latency.

In a practice scenario, as soon as a student client boots, it will regularly broadcast its client code within the LAN to look for the teacher client. When the teacher client receives the message, including the student client code and its IP address, this message will be cached into the teacher client's address book. Consequently, a LAN connection is automatically established between the teacher client and this specific student client.

V. REMOTE EXPERT REVIEW STUDY

Due to the COVID-19 restrictions, an expert review study is conducted remotely with a 2-minute video demo and a five-point Likert scale questionnaire. Such video-based online survey has been applied in a new asymmetric CVE research [45] to collect first-round feedback of the demonstrated system.

TABLE 1. The questions in the online questionnaire.

No.	Question Content	Average Score
1	I think this system will help students learn the shared teaching materials better.	3.7
2	I think this system will help the teacher better understand each student's learning progress in the class.	3.8
3	I think this system will help teachers to make decisions about teaching progress and materials easily.	3.6
4	If given all these devices, I would like to try this system in my class.	4.2
5	I think displaying each student's quiz progress over their head looks intuitive	3.5
6	I think sharing 3D anatomy models and quizzes by gesture manipulation looks intuitive.	3.9
7	I think directly displaying each student's quiz analysis over their head looks better than displaying them on paper or computer.	3.2
8	I think the suggestion showing a student's weakest and strongest part is helpful for me to provide targeted guidance.	4
9	I think showing the students 3D anatomy models using the auto-stereoscopic display will be helpful for their understanding about the anatomy.	4.1
10	I think allowing students to rotate and scale the shared 3D model using gestures will be helpful for their 3D structure understanding.	4.4
11	I think the feature that students cannot see the content and quiz shared with other students will be helpful.	4.2

As this collaborative learning system is mainly designed to support teachers' in-class teaching decisions in the context of vet/anatomy training/teaching, the expert review study focuses on the vet/anatomy teachers' preliminary feedback about the system features. Therefore, the questionnaire was designed to collect these teachers' professional opinions about the demonstrated features based on their prior teaching experiences. Due to the hard requirements of participants' professional experience, only 10 anatomy teachers from local universities have been recruited to anonymously answer the online questionnaires. These participants are all experienced teachers with 5 to 25 years of teaching experience in anatomy areas. They either are veterinarians or hold Ph.D. degrees in genetic or comparative anatomy. The majority of participants were familiar with AR/VR, but one participant had limited prior experience in AR/VR and had previously only viewed the medium as an entertainment medium rather than the possibility of its use in education.

In the first section of our online questionnaire, a short video is inserted to show the whole application scenario using the designed system by combining a HoloLens screen record and two LFD screen records. This questionnaire contains 13 questions in 4 sections to collect these expert participants' opinions about overall system design, teacher client features, student client features, and the most/least attractive features of the system according to their professional experiences (Table 1). Additionally, one final optional section asks the participants for subjective suggestions.

According to the average scores achieved in the three rating sections, participants highly rated the demonstrated system (overall design 3.83, teacher client 3.65, student client 4.2). 9 out of 10 participants agreed or strongly agreed that they would like to try this system in my class, which showed the potential of applying the demonstrated system into practical teaching activities.

As Table 1 shows, among all statements listed in these three rating sections, three statements achieved a relatively high average rating of 4.2 (between *agree* and *strongly agree*): *"I think allowing students to rotate and scale the shared 3D model using gestures will be helpful for their 3D structure understanding."*, *"If given all these devices, I would like to try this system in my class."*, *"I think the feature that students cannot see the content and quiz shared with other students will be helpful."*. Participants' high ratings in these statements potentially showed the teachers' approval of the asymmetric CVE framework that combines the AR headset teacher client and LFD student clients. Other high ratings highlighted the usefulness of anti-cheat quiz support from the teachers' perspectives, which is one important novelty illustrated in this paper.

Unlike the generally high ratings achieved from these three rating sections, the fourth section that votes for the most and least preferred features showed some interesting diversities. First, 7 out of 10 participants indicated that dropping a 3D model to a student's head for content sharing was a feature that attracted them the most. Additionally, over half of participants voted for the targeted quiz assigning, and voted explainable teaching suggestions as the most attractive features. However, the targeted quiz assigning (3 votes) and teaching suggestions (2 votes) were also voted by other participants as the least attractive features. These opposite opinions might have indicated that the targeted quiz assigning and teaching suggestions are sometimes unnecessary for some teaching activities. Particularly, the suggestion models [46] that directly provide suggestions or recommendations have always been tricky in terms of user satisfaction, as users' personal preferences significantly determine the amount of decision support they want. Although neither of these features is mandatory operation to use the designed system, these opposite preferences still show the necessities to provide user preference settings in the future teaching decision support systems.

In the last questionnaire section, 7 out of 10 participants gave their subjective suggestions. Among all comments, the most referred question is the scalability issue. Four participants asked how to manage larger-scale classrooms using such a targeted teaching system as they found it was *"difficult for a teacher to keep track of results that are all in different places in the classroom"*. Similarly, one participant expressed their worry about the information overload issue for larger-scale classrooms, which is an important challenge confronted by situated and in-situ AR data visualization. Although the teacher can close the quiz analysis display at any time, a more efficient and context-aware metaphor to automatically filter and hide unwanted information is worthy of further exploration. Additionally, this concern also indicates that such a targeted teaching approach should be applied as an optional-additional step of the common teaching mode to make sure the teaching activity works in different class scales. Another participant asked about some existing features illustrated by previous *METAL* which were therefore not demonstrated in this system, such as allowing the teacher to manipulate the models to explain details for all students. Although these existing features have not been integrated into this system, the future integration of teacher clients' global manipulation and teaching material adjustments may increase the system user experience in the classroom. One participant suggested using 3D scanned real specimens, and another participant expressed their surprised feeling towards the demonstrated system *"the future is here just now"* and encouraged the team to *"continue working in this field"*.

Despite the overall high ratings gained by this expert review, as a first-round small-scale online expert review, there are several limitations that deserve attention.

First, as this online expert review focus on experts' feedback, the participants are strictly limited to experienced teachers in relevant areas from local universities. This high requirement of participants' professional experience significantly limited the sample size. Therefore, this small-scale expert review only provides a preliminary set of expert feedback of this framework, which aims to provide early validation of this framework and inspire future work in this area with the lessons learned. However, due to the small sample size, this preliminary expert review does not aim to indicate a firm conclusion about the usability of the actual system. However, it does give us the confidence to explore system usability by conducting a larger-scale in-class study with a larger sample size when the pandemic has abated. Though this technology is only in its infancy, further large-scale experiments would be needed with mid-scale (50) and large-scale (100+) classrooms. If those experiments are proved fruitful, in the long term, a longitudinal study would be needed to finally confirm this pedagogy approach, e.g., tracking students who used this system throughout their medical or veterinary studies and comparing it with others that did not use the system.

Second, although this paper presents an MR collaborative learning system, this expert review study mainly focuses on teachers' opinions of teaching decision support features; thus, the expert review results are limited to the user experience from the teachers' perspectives. The reason why student participants were not invited to rate the student client features mainly resides in the special visualization methods of Light Field Displays. Compared to the AR teacher client, the LFD student clients require more situated interaction including free head movement and binocular experience to perceive the dynamic stereoscopic viewing zones of targeted 3D contents with binocular motion parallax, which is impossible to achieve through an online remote experiment. Additionally, as an important feature of the student client, the anti-cheat quiz support may not be clearly demonstrated and explained with videos. Therefore, the online expert review with merely videos and questionnaires may not make student participants fully understand how the system works in a real lab scenario. Physical in-class user studies are necessary as this is the only way that allows student participants to fully experience the LFD student client features.

Finally, due to the HoloLens screen record limitations, the resolutions and frame rates of the demo video looked much more lagging and unstable than actual normal experiences, which might have made some features in the teacher client look unclear, especially in such a short video. A participant asked whether the teacher can see how a student has turned the 3D model, which, however, has been demonstrated in the video. One possible reason might be the low frame rates that have made the model manipulation synchronization look less noticeable. Also, demonstrating the one-to-multiple CVE with one teacher and only two students in an apartment is not compelling enough. One participant questioned about the information overload issue for larger-scale classes. Therefore, in the future, when COVID-19 restrictions allow in-class study, demonstrating the system in a middle-scale class by showing how the teacher freely activates and closes information may facilitate participants' understanding of the actual amount of information visualized for the teacher client.

VI. FUTURE WORK

Future work would require exploring student client interaction enhancement and including formal in-class user studies. As this work mainly focuses on teaching decision support, the student-client interactions are limited to quiz answering and 3D model manipulations. To enhance the whole system to thoroughly support more in-class activities for both the teacher and students, more student-client interactions can be integrated by exploiting the Kinect camera face and gesture tracking. By tracking the student's expression, gaze, and postures, the system may analyze each student's concentration levels and how well each student has understood the demonstrated content. By reporting students' concentration and comprehension levels to the teacher client, the teacher can instantly adjust their teaching. Also, to increase the scalability of this system, universal teaching content assignment and quiz result analysis should be added as one optional mode to deal with large-scale classes. In this case, the teacher may firstly assign all students the same teaching materials, and further adjust the teaching contents for any individual students based on their quiz analysis.

A larger-scale in-person user study will be a valuable future work. Based on the expert feedback and lessons learned from the preliminary online expert review, this research will enter its next evaluation phase within a physical classroom setup. Both teacher and student participants of a larger sample size will be recruited to have a vet class and conduct in-class quizzes using the presented MR system and a desktop-based collaborative learning system. By comparing the quantitative and qualitative results of the user experience from the vet teachers and students, more research questions can be answered. Chiefly among them is to explore if there are real-world advantages in the use of an MR teaching decision support system in the education area as the expert users' feedback from this research suggests.

This paper uses small-size LFDs to demonstrate the system framework with limited costs. However, large-size LFDs[5] have been commercialized but have yet been widely applied due to the current high prices. In the future, when the large-size LFDs are widely applied, this presented system will allow even more students to share one large LFD, resulting in a superior user experience to the current generation. Similarly, although the current technical limitation of the Microsoft Azure Kinect camera is not the main focus of this work, the student client user experience may still be affected by the unstable gesture tracking, especially for sophisticated 3D manipulations. However, this hardware limitation can be mitigated as the emerging development of modern head and gesture tracking techniques, which will further allow for a more stable and smoother student client user experience.

VII. CONCLUSION

This paper is the first to report on the incorporation of context-aware Light Field Displays and the in-situ Augmented Reality data visualization to support targeted teaching decisions in a vet tutorial/lab collaborative learning embodiment. By illustrating the dynamic privacy LFD viewing zone and its application in anti-cheat quiz support, this paper aims to inspire future explorations towards diverse combinations of Mixed Reality devices including context-aware LFDs. They offer the ability to create ubiquitous applications in people's daily life beyond the use case of immersive learning outlined in this paper. Moreover, this paper not only demonstrated the first in-situ AR teaching decision support system, but more importantly, presented an example of decisive-input-value-based explanations as an important part of the AR DSS to bridge the gap that existed in previous AR DSS research. Despite the limitations of the remote video-based expert review study, expert participants still gave high ratings to the demonstrator system based on their past teaching experiences. The expert review highlighted the abilities to create intuitive-targeted teaching materials, quiz progress analysis, and targeted teaching suggestions.

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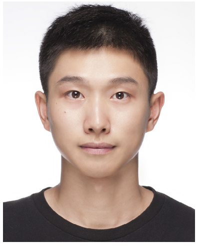

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