Place-Based Learning Through a Proxy – Variations in the Perceived Benefits of a Virtual Tour

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***Abstract*—Place-based and fieldwork learning play a key role in higher education in environmental sciences and other geospatial disciplines. We report on a study in which we evaluated a web-based virtual tour application for teaching natural resource management in fire-prone western forests in two undergraduate classes. The virtual tour uses 360°-image-based virtual scenes and pre-recorded audio commentary by a domain expert to lead participants through the Stanislaus-Tuolumne Experimental Forest where forest treatments were implemented to reduce fire hazard. We present results from assessing students' overall perception of the virtual tour, their views towards its application in undergraduate education, and their feedback for improving the design of future virtual tours. Furthermore, we discuss the collected data from the perspective of gender differences and differences in familiarity with the topic of the tour.**

***Index Terms*—virtual tours, place-based learning, 360° imagery, forest and wildfire ecology, user studies, virtual reality**

I. Introduction

Virtual experiences of real-world places, ranging from 3D desktop applications to fully immersive XR experiences, hold enormous potential for communicating research and improving decision-making, education, and training in natural resource management. One particularly attractive aspect is their ability to scale-up access to important field-based research conducted in remote locations. A growing number of studies address the effectiveness of virtual experiences as proxies for actual field visits to research sites with the goal of gaining an understanding of natural processes and impacts of management strategies [1]–[5]. However, these empirical studies of immersive learning environments yield mixed results [6]–[8]. In addition, there is a lack of understanding on how virtual experiences that go beyond reality (e.g., simulations of temporal developments of environments, enhanced observation options via elevated viewpoints and drone footage) could improve the learning and training of the next generation of decision-makers.

To add to this important body of empirical research and evaluate specific design choices, we conducted a study on wildfire and forest management in California with students from two undergraduate classes in Geography and Forestry. Students participated in a virtual tour and filled out a pre- and post-tour questionnaire. We used a web-based desktop version of a VR tour we developed that describes an USFS study on the impacts of different forest thinning and prescribed fire treatments in the Stanislaus-Tuolumne Experimental Forest in California. The development of sustainable forest management practices is central to the education of resource management professionals and an informed public, particularly in states such as California where climate change and the hazard of severe wildfire are emerging socio-environmental concerns [9].

In our analysis of the questionnaire data collected in this study, we focus on assessing the general acceptance of the virtual tour application and feedback to inform an iterative design approach of virtual tour applications. Our results show an overall very positive assessment by the participants as well as multiple significant gender differences but no significant differences related to familiarity with the topic of the tour.

II. Background

A. The Stanislaus-Tuolumne Variable Density Thinning Study

The topic and location of the virtual tour is the approximately 100ha 'Variable Density Thinning' (VDT) study site at the Stanislaus-Tuolumne Experimental Forest in the central Sierra Nevada of California. The study was established in 2009 to test the effects of three stand structure treatments (High Variability Thin, Low Variability Thin, and an Unthinned Control), and two prescribed fire treatments (Prescribed Fire or No Prescribed Fire), on natural resource conditions (vegetation, wildlife, soils, water yield) and fire hazard [10]. The High Variability thinning treatment is a novel application of forest thinning with the goal of generating a heterogeneous environment more similar to what historical forests shaped by frequent fire once looked like. Forest thinning remains controversial within some stakeholder communities, but with recent large high severity wildfires [9] and bark-beetle outbreaks causing unprecedented tree mortality [11], there is also growing recognition of the need for management to improve forest resilience.

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Considerable interest exists in applying similar treatments at a landscape scale. Travel distance and seasonal limitations limit access and the potential for utilizing the site for active learning and engagement. The virtual tour application, available at any time to anyone with an internet connection, provides a means of delivering science findings to students, stakeholders and (future) decision-makers. The virtual content has the potential to facilitate a deeper understanding of complex interactions between forest conditions, fire effects, fire hazard, and forest resilience in fire-prone Sierra Nevada forests [12].

B. Virtual Tours in Place-Based Education

The idea behind place-based education [12]–[14] is to provide learners with a spatial, embodied, and contextual way of learning about natural and human environments allowing them to gain an experiential understanding of a topic [15], placing the method in the vicinity of pedagogical approaches such as experiential [16] and situated learning [17]. This kind of learning is prominent in many earth and environmental science disciplines and reflected by the role that fieldwork or field trips play in many undergraduate curricula. Virtual tours are considered an alternative or supplement to field trips or other forms of place-based learning activities, removing many of the financial, logistical, safety, inclusion related, or other challenges and limitations of these activities [18], [19]—and also as a way to facilitate remote online learning during the current Covid-19 pandemic. Virtual tours have been created and evaluated for several decades using various forms of media (websites, CD-ROMs, computer-based modules) [20], [21]. However, only with recent advancements in photogrammetry, 360° photography including very affordable 360° cameras, drones, and 3D modeling software, we are now coming close to realizing the vision of low-cost but highly realistic virtual tours that can be created by laymen, be it in the form of 3D desktop applications or of fully immersive tours delivered via head-mounted displays (HMDs) [22], [23]. A single 360° image can be used to create an entire virtual scene, enabling instructors or researchers to create the content for virtual tours of real-world fieldwork or research sites themselves with much lower costs, efforts, and expertise required than before.

Despite these encouraging developments, the application of 360°-image-based virtual tours in place-based higher education is still rare, and we are still lacking empirical studies to guide the design of such virtual tours and their application in the classroom on a larger scale. Design decisions can be expected to have a significant influence on learning experience, enjoyment, and acceptance by students, which in turn may impact the learning outcome. In addition, 360° images also come with a number of limitations (discussed in Section V). This study sheds some light on open design questions and potentially overlooked individual differences.

III. Empirical Study

The study was conducted during the Fall 2020 semester with a virtual tour application focusing on presenting the results of the VDT study created from 360° images taken in the Stanislaus-Tuolumne Experimental Forest and additional media such as photographs and forest stand visualization models.

A. Design

In this study, all participants experienced the same tour application. Our analysis focused on the overall perception of the virtual tour (see Section III-D on measures used) and a finer-grained investigation based on individual differences (familiarity with the topic of the tour and gender). We also utilized open-ended questions to collect additional feedback and to facilitate iterative design with the goal of creating improved versions of the tour application.

B. Participants

Participants were recruited from two undergraduate classes at PSU: (1) Forest Ecology, teaching basic concepts of forest ecology and silvics, that under normal circumstances would include a field component to observe the effects of various conditions or treatments on forest structure and growth; and (2) a Geography class on Global Parks and Sustainability, exploring topics of sustainability, conservation, and socio-ecological systems. In total, 121 students participated in the study (61 male, 50 female, 10 other; average age: 21.95 years, SD=5.1). Participating students were rewarded course credit.

C. Materials

The VDT study virtual tour application was originally created as an immersive VR application for standalone HMDs such as the Oculus Go/Quest/Quest 2. However, for the purpose of this study with students taking classes online during the Covid-19 pandemic, we created a WebGL adaptation of the tour that students could run in the browser on their personal computers. Fig. 1 shows several screenshots from the virtual tour. The tour starts with an overview map showing the Stanislaus-Tuolumne Experimental Forest, the different treatment areas of the VDT study, and the tour locations (the locations of the 360° images) as red dots (Fig. 1a). The tour is operated via keyboard shortcuts and using the mouse to rotate the camera. After starting, the tour moves through a sequence of 360° image-based scenes, in which the user can freely look around, while listening to the expert audio narration explaining the scene and its relevance to the study findings (Figs. 1b-f). The user can pause the audio at any moment as well as zoom in/out by moving the camera a fixed distance forward or backward. The 360° images were taken at different height levels: at 2 meters above the ground (Fig. 1c), at a height of approximately 8 meters to provide a within-canopy perspective (Fig. 1d), and via a drone at heights between 45 and 137 meters to provide a large-scale aerial view of the forest landscape (Fig. 1e). During the tour, different media resources such as maps, photographs, and forest stand visualizations are overlaid on top of the 360° image-based scenes to complement the narration (see Figs. 1b+f). At the end of the 33 minute tour, users can move back to the overview map where they now can select individual locations on the map to revisit the corresponding 360° images, this time without audio narration.

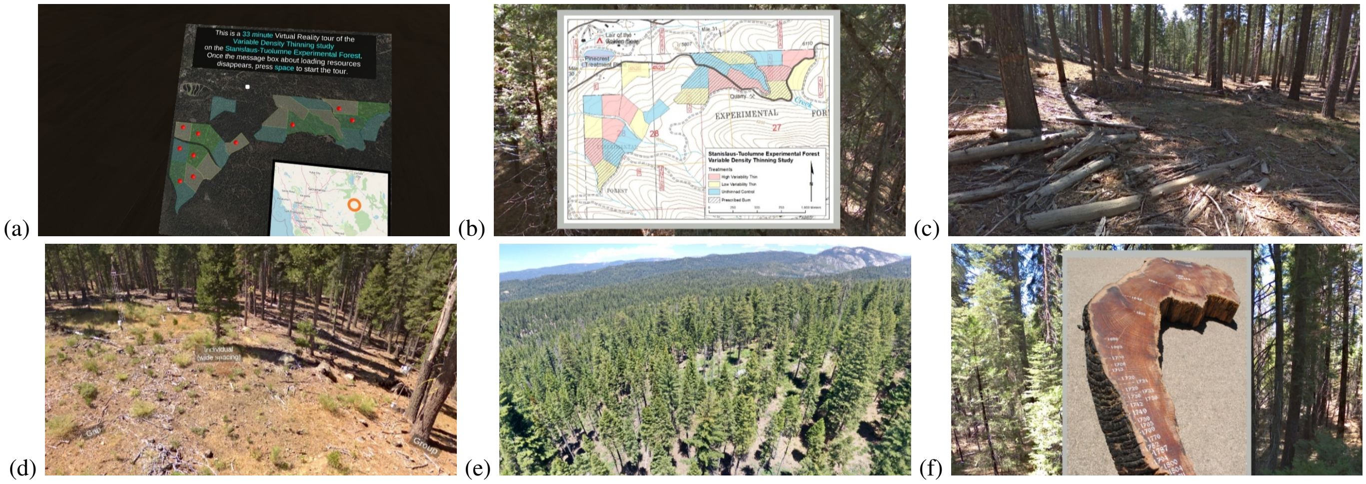

Fig. 1. Images from the virtual tour experience.

D. Procedure and Measures

Students were guided to the main web page for the study to read an introduction including the hardware and software requirements for participation. After consenting, they were moved to a pre-tour questionnaire. Next, participants received instructions on how to use the tour app. They then clicked a link that started the tour (33 minutes plus the time they spent revisiting individual locations after the end of the audio narration). After exiting the tour application, participants were sent to a post-tour questionnaire asking about their experience. The pre-tour questionnaire consisted of questions related to demographics and participants' level of familiarity and understanding of the topic of forest and fire management. In the post-tour questionnaire, we asked participants to rate the overall experience and used a larger number of established measures collected and described in [24] to assess different aspects (usefulness, ease of use, cognitive benefits, reflective thinking, learning effectiveness, overall satisfaction, improved understanding). Furthermore, we used the spatial-situation-model (SSM) part from the MEC-SPQ [25] as a measure of the user's ability to form a mental model of the tour environment. Finally, we used domain-specific questions to assess design choices and features of the tour, as well as to collect open-ended feedback. More details are provided in the next section.

IV. Analysis and Results

In this section, we summarize the results from analyzing the data collected in the study. We start with the statistical analysis of the Likert-scale and multiple-choice questions, followed by insights gained from the open-ended feedback.

A. Quantitative Results

We start with the overall assessment and then conduct comparisons based on familiarity with the topic and gender.

1) Overall Assessment: All Likert-scale question groups in the post-tour questionnaire were adapted from [24], except for the SSM group [25], and used scores from 1 (= very negative assessment) to 5 (= very positive assessment). The first group of questions asked about the "Perceived usefulness" of the tour in the context of undergraduate education. For this and all other question groups, individual question items were averaged to calculate the score for the corresponding metric for each participant. The mean score over all participants was 3.85 with a standard deviation of 0.88. The second category "Perceived ease of use" was concerned with the usability of the application. Overall, the tour is rather lightweight in terms of interactions and user interface, so the high scores (M=4.08, SD=0.82) in this category were what we expected. Next, for the SSM group about participants' self-reported ability to form a mental model of the environment, the mean score was 3.93, SD=0.74. The group "Cognitive benefits" asked specifically about to which degree the virtual learning environment promotes comprehension, knowledge gain, and memorization (M=4.03; SD=0.80), while the group "Reflective thinking" does the same for reflecting on the learning process and making connections to previous knowledge and experiences (M=3.81; SD=0.86). In the category "Perceived learning effectiveness", we focused on assessing to which degree the virtual tour was effective in conveying the learning content and obtained a mean score of 3.90 (SD=0.82). In the category "Satisfaction", we asked about the overall satisfaction with the virtual tour (M=3.81, SD=0.79). Lastly, in the category "Improved understanding" concerned with whether the participants felt they gained an improved understanding of the topic of fire and forest management and effects of different prescription strategies, the mean score was 4.09 (SD=0.85).

Overall, the responses to these Likert-scale questions show a positive evaluation of the virtual tour and its application in the context of undergraduate ecology education. A more detailed picture of what aspects the participants appreciated or disliked most can be gained from the results of two multiple-choice questions from the post-tour questionnaire. In both questions, we provided options (11 for "most liked" and 10 for "least liked") chosen based on experiences from other studies with virtual tours [26]. Participants could select up to four

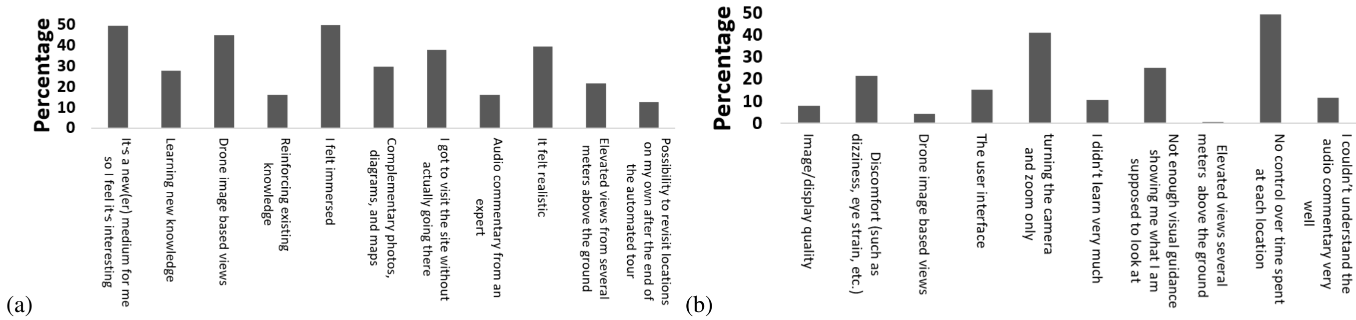

Fig. 2. Percentages of votes received for "What do you like most about the VR tour?" (a) and "What do you like least about the VR experience?" (b).

options. For "most liked", the percentages of participants that voted for each option is shown in Fig. 2a. We see 50.5% for "feeling immersed" (according to the participants' intuitive understanding of the notion of immersion), 49.6% for "new medium", and 45.1% for "drone image based views". "Feeling realistic" and "visiting the site without going there" are the two next highest options with 39.6% and 37.8%, respectively.

For the "least liked" multiple-choice question, the results are shown in Fig. 2b. The two options that stand out were "no control over time spent at each location" and "only able to turn and zoom the camera" with 49.6% and 41.4%, respectively. These are followed by "not enough visual guidance" referring to the fact that it is not always clear which part of the scene is currently explained in the audio commentary, and "discomfort" during the virtual tour (25.2% and 21.6%). The drone images and elevated perspectives, which may potentially cause discomfort in people with vertigo, were included in the options for "least liked" as well but were the two options that received the least amounts of votes with 4.5% and 0.9%.

2) Comparison by Familiarity: In the pre-tour questionnaire, we included one question asking "What is your level of familiarity with and understanding of forest and fire management issues?". To investigate the impact of previous knowledge and understanding of the topic on the experience, we split the participants into low and high-familiarity groups. Given that we only had the results of a single Likert-scale question to perform this categorization and that the distribution shows a strong maximum at the median value of 3, we decided to create the low-familiarity group from participants with scores of 1 and 2 in this question (38 students) and the high-familiarity group from those with scores of 4 and 5 (22 students).

We used Welch's t-tests to compare the results for the different question categories from Section IV-A1. Wilcoxon Rank Sum tests were used when the assumption of normality or homogeneity of variance was violated. We did not find any statistically significant differences between the groups for any of the question categories. The strongest indication of a difference between the groups was found in the "Improved understanding" category, where we asked whether the tour led to an improved understanding of the topic (t=-1.75, df=48.68, p=0.086, Cohen's d=0.45; with average scores of 4.02 (SD=0.87) for the low-familiarity group and 4.40 (SD=0.77) for the high-familiarity group). This provides some evidence that a previous understanding of the topic helps with gaining an improved understanding from the tour.

Answers to the questions of most/least liked features were similar between the low and high familiarity groups (see Figs. 3 and 4). However, there are also a couple of noteworthy differences: For "most liked", we found a much higher percentage of votes for "feeling immersed" (61% low, 36% high) and "feeling realistic" (50% low, 36% high) in the low-familiarity group. High-familiarity participants voted more for "reinforcing existing knowledge" (5% low, 18% high), which makes sense given the nature of the two groups. The high-familiarity group also appreciated the "elevated views" more than low-familiarity participants (13% low, 36% high).

For "least liked" we only saw differences in the percentages for "not enough visual guidance" (34% low, 14% high) and "couldn't understand the audio commentary well" (18% low, 0% high) as well as less pronounced differences for "only able to turn and zoom the camera" (32% low, 41% high) and "no control over time spent at locations" (47% low, 36% high). This provides some indication that people familiar with the topic were not as impressed by the immersion and realism provided by the 360° image-based approach and that much can be done to better support users with less previous knowledge on the topic, not only in terms of how the content itself is presented but also by providing additional features to better guide such users (e.g., visual guidance to indicate what is being described) and options to influence the pace of the tour.

3) Comparison by Gender: Comparison by gender, again using Welch's t-tests and Wilcoxon Rank Sum tests, yielded multiple statistically significant differences, with female participants consistently giving higher scores than males (see Table I). The results for "Perceived usefulness", "Cognitive benefits", "Reflective thinking", "Perceived learning effectiveness", "Overall satisfaction", and "Improved understanding" all show statistically significant differences. The evidence is particularly strong for "Reflective thinking", "Perceived learning effectiveness", and "Improved understanding", with p-values < 0.01. In the remaining two categories ("Perceived ease of use" and "Spatial situation model"), female participants also gave higher scores but the differences were not statistically significant (p-values of 0.16 and 0.11).

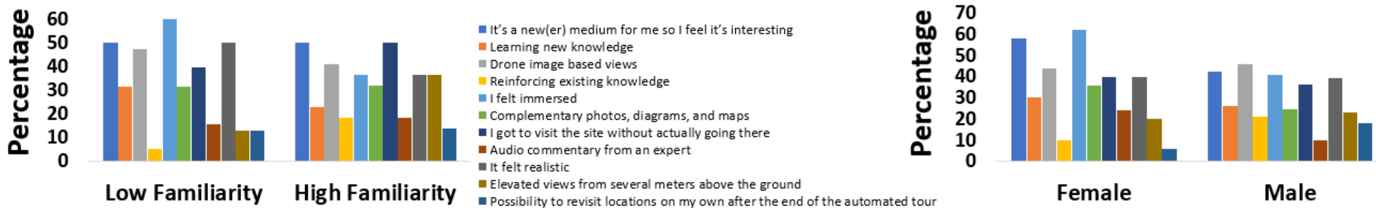

Fig. 3. "What do you like MOST about the VR experience?": Differences between high and low-familiarity participants (left) and females vs. males (right).

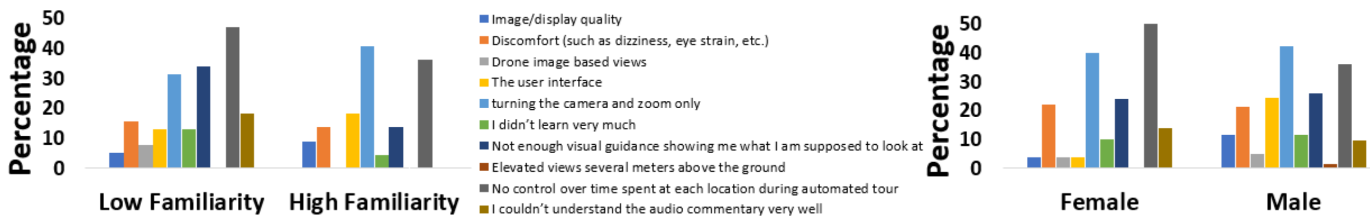

Fig. 4. "What do you like LEAST about the VR experience?": Differences between high and low-familiarity participants (left) and females vs. males (right).

TABLE I
RESULTS FROM COMPARING ASSESSMENT BY GENDER.

Metric	Female		Male		Test		
	M	*SD*	*M*	*SD*	*t/W*	*p*	*C d*
Usefulness	4.07	0.78	3.67	0.92	t(108.88)=2.47	.015*	.46
Ease of use	4.2	0.72	3.98	0.88	t(108.99)=1.42	.157	.27
SSM	4.05	0.68	3.83	0.77	t(108.39)=1.63	.106	.31
Cognitive benefits	4.2	0.66	3.9	0.89	t(107.87)=2.00	.048*	.37
Reflective thinking	4.04	0.73	3.62	0.91	t(108.99)=2.71	.008*	.51
Learn. effectiveness	4.16	0.62	3.69	0.9	t(106.09)=3.22	.002*	.60
Satisfaction	3.97	0.69	3.67	0.84	t(109.00)=2.06	.041*	.39
Impr. understanding	4.37	0.67	3.87	0.92	t(107.52)=3.25	.002*	.61

For the "most liked tour features" question (Fig. 3), we found noticeably higher percentages of votes by females for "new medium" (58% female, 43% male), "feeling immersed" (62% female, 41% male), "complementary photos, diagrams, maps" (36% female, 25% male), and "expert audio commentary" (24% female, 10% male). In contrast, a higher percentage of males voted for "reinforcing existing knowledge" (10% female, 21% male) and "possibility to revisit locations independently after the automated tour" (6% female, 18% male).

For "least liked tour features" (see Fig. 4), "no control over time spent at locations" received far more votes from female participants (66% female, 36% male). In contrast, the options "user interface" (4% females, 25% male) and to a lesser degree "image/display quality" (4% female, 12% male) received noticeably more votes by males.

B. Open-Ended Feedback

To analyze the responses from the open-ended questions, we used inductive content analysis [27]. Two coders coded the responses and intercoder reliability was tested using Cohen's Kappa and Krippendorff's Alpha statistics. The values for these statistics were above 0.8 for all coding categories with averages of 0.91 for both of them across all categories and questions. We included open-ended questions asking about most/least liked aspects of the tour because, while not suitable for a rigorous statistical analysis as the corresponding multiple-choice discussed above, this form of feedback in our experience allows for evoking further details and insights, and for assessing additional aspects that participants come up with while reflecting deeper on the experience. Due to space limitations, we can only summarize the main results here.

For the open-ended question "Describe which things you liked the MOST about the virtual tour experience and why", the coding results are largely consistent with those of the corresponding multiple-choice questions discussed in Section IV-A with a strong focus on the visual impression from the 360° imagery (mentioned by 41% of the participants), on feeling immersed (25%), and on the experience feeling realistic and detailed (13%). The ability to freely look around in the scenes (16%) and the two categories for multiple-elevation views (7%) and usage of drone images (10%) are also mentioned frequently. Besides these visually-focused aspects, the presented content itself received positive feedback for being informative and leading to new insights and knowledge gain (22%). We also found specific mentions of other features of the tour, namely the labels overlaid on some of the scenes to provide visual guidance (5%) and the complementary media used in form of photos, plots, and maps (5%). Due to the gender differences we found in the previous analyses, we also calculated the percentages of the categories for males and females separately. The most noteworthy differences were found for visual realism, details, and the use of complementary media. In all three categories, a larger percentage of female participants mentioned these categories than male participants (55 vs. 30%, 21% vs. 8%, and 8% vs 3%, respectively).

More important for future tour applications are the results for "Describe which things you liked the LEAST about the virtual tour experience and why". Results in the first two categories were similar to findings from the corresponding multiple-choice question (Section IV-A), namely a preference for a more flexible, less restricting format compared to the fully automated tour used, providing more control over the tour order, the time spent at different locations, the pace of the narration (20%), and allowing for free movement at each location (12%). New aspects in this version relate to performance issues (12%) and non-professional audio narration (10%). While the majority of participants were able to run the application without problems, using a large number of high-resolution 360° images in a WebGL browser-based application caused long loading times, crashes, or other performance issues for some users. The audio commentary recorded by a domain expert rather than a professional narrator faced criticism that we believe may have been further boosted by the discrepancy between perceived professionalism of the visual aspects and of the auditory ones. The overall length of the tour and amount of information provided (7%), lack of visual guidance (7%), lack of clarity of the presented content (6%), and an interest in captions or subtitles (7%) were other points of criticism. Regarding gender differences, we found larger differences for performance issues (6% females vs. 17% males) and for lack of captions and subtitles (11% females vs. 3% males).

For the question "What are the functionalities you would like to see in future developments of this application?", requests for more control over the tour (27%) and the ability to move around in each location (22%) were the most common responses, followed by requests for more interactive elements (20%). In addition to requests for captions and subtitles (8%), visual or other forms of guidance (7%), and more supplementary media and content (7%), we also found multiple requests for a more flexible zoom function (4%) and embedded tests as a means of self-assessment (3%). We observed a higher percentage of females interested in more control over the tour (40% vs 17%). We also found a higher percentage of votes for captions and subtitles among females (15% vs 3%).

The final open-ended question asked "If any, did this current method of instruction have advantages over classical methods of teaching used in classrooms?". The most prominent category is comprised of statements that indicate that the visual elements of the tour better support learning and spatial understanding compared to classical methods such as textbook, lectures, or videos (30%). 17% of students described the tour as more engaging, captivating, interesting or simply more fun than traditional teaching. 13% mentioned immersion and realism as elements that better promoted understanding of the content. Among the less specific responses, 7% indicated that they agree that there are advantages. 7% said that they disagreed. 7% expressed the belief that virtual tours are a useful complement to more traditional methods but not a complete replacement. Compared to the other open-ended questions, we found fewer gender-based differences. Nevertheless, there was a difference for the "visual and spatial aspects" category, mentioned by 38% of females compared to 23% by males.

V. Discussion

The overall assessment and feedback to our virtual tour application have been largely positive. Students reported an improved understanding of the topic of fire and forest management and indicated a positive attitude towards more usage of these kinds of virtual tours as part of their university education. The large majority of participants described advantages they see in using these kinds of virtual tours over traditional teaching methods or at least believe that they are well suited to supplement other methods. Even though we were limited to conducting the study with a desktop application rather than a fully immersive VR application, "feeling immersed" was among the positive aspects mentioned most frequently. Many statements indicated that students were impressed or even surprised by the realism and ability of the 360°-image-based tour to create a feeling of immersion. The image quality did not receive much criticism, in contrast to previous studies with low-cost VR HMDs [5], [26], in which image and display quality have been main concerns. The use of elevated views and drone images was another aspect that received positive feedback as we expected (see [5], [26]). Even though the virtual tour used in this study can be improved in many ways, this overall evaluation is an encouraging indication of a positive learning experience that could have the potential to strengthen learners' engagement and learning outcome.

It is noteworthy that we did not find any significant differences based on familiarity with the topic of the tour. Both high and low familiarity groups seem to assess their learning experience and the tour as a whole in an equally positive manner. However, in the open-ended feedback, we noted several suggestions that would particularly benefit low-familiarity earners, such as more visual guidance, the ability to control the pace of the tour, ability to rewind and repeat the audio narration, supporting captions or subtitles showing import key terms, or links to access additional information or explanations of key concepts. The request for more visual guidance that indicates which part of the scene is currently described is something we expected based on previous studies in other domains [26]. We previously compared different guidance mechanisms in the context of 360° image-based tour applications [28] but decided on the label approach because of the entities existing multiple times in the scene (e.g., groups of trees, gaps in the tree structure). The request for more supporting text could be an indication that such features would have value for users least familiar with the tour topic.

In the list of least liked features and suggested improvements that have the potential to inform the design of future virtual tours, aspects related to more freedom, more control, and more interaction were very prominent. Clearly, the strictly automated tour format in which participants only control the view direction of the camera while listening to the audio narration is not the format that most students prefer. There are many indications in the feedback that students believe improvements in these regards can not only make the virtual tour experience more enjoyable, but also make it more engaging and motivating and, as a result, improve the learning. Some such aspects are relatively easy to implement but the 360°-image-based low-cost approach also presents technical limitations. The requests for more control over the order of locations, over the pace of the tour including the time spent at each location, the ability to rewind and repeat parts of the narration, as well as a general request of more interactions and embedding tests to assess the understanding of key concepts are relatively easy to incorporate. However, they raise pedagogical questions on how to best design and combine these elements in a virtual tour application. The also highly prominent request for the ability to not only rotate the camera but move around in each 360°-image-based location as in a 3D video game, on the other hand, cannot fully be realized in a 360° based approach: In contrast to an actual 3D model of the environment, a single 360° image does not allow for moving between objects, and even just moving the camera out of the center of the 360° image sphere (as possible via the zoom functionality we provided) will result in visual distortions that get stronger the further the camera moves away from the center. While many students seem to be aware of the fact that the scenes in the tour are created from 360° images, our impression from the feedback is that many of them are not fully aware of these limitations. Nevertheless, the appreciation of completely free movement raises the question to which degree the 360° approach with its inherent limitations can be justified. The decision to base the tour on 360° images was made in the light of the trade-off that exists between the richness and sophistication of a virtual tour experience and the costs and efforts required to create it, as we previously discussed in the context of fully immersive VR tour experiences [26]. 360°-image-based tours are firmly established as a method that even allows laymen to produce virtual tours with the help of an affordable 360° camera, enabling in particular instructors to become content authors and tour creators. In contrast, creating tours consisting of 3D models that allow for free movement in the scenes is a much more involved process even with photogrammetry and other techniques available today, in particular for natural landscapes such as forests. For applications in education on a broader scale, low-cost and low-requirement 360°-image-based tours still seem to be the most suitable approach. However, there are options to go beyond the basic approach used in our tour, such as using a relatively dense set of multiple 360° images for each tour location to emulate free motion. Evaluating these approaches in terms of benefits vs. additional costs and efforts required is a task for future research.

Other feedback and suggestions were concerned with the level of professionalism, mainly of non-visual aspects of the tour such as the audio narration, content presentation, and performance. In particular, the first two are relatively easy to address but will lead to increased costs and time efforts needed to produce the tour (e.g., for hiring a professional narrator) and, in particular in the case of content presentation, need to be considered in the light of pedagogically adequate approaches suitable for virtual tour applications. As we mentioned, the tour was originally intended to be an immersive experience using HMDs. One downside of moving to a desktop experience was that this removed the control over hardware and software that students would use to run the tour, leading to some technical difficulties. This is an aspect that certainly can be improved; however, in the context of a 360° based tour delivered over the web, there again exists a certain tension between detail and complexity of the tour (e.g., image resolution and the number of locations) and requirements (e.g., hardware and internet connection) to be able to smoothly run the tour. Related to this last point, the received feedback also raises the question of the adequate length and amount of content for a virtual tour. We do not think there is a general answer to this question but it is interesting to note that while the larger number of participants found the tour too long and partially even exhausting, there were also requests for more content and detail. This makes for a good argument for deviating from the automated tour format by adding elements that allow students to tailor the content and experience to their needs, while at the same time making the tour more interactive.

While not designed as a study to investigate gender differences, the analysis of the collected data unexpectedly showed an even more positive assessment of the overall experience by females, and specifically for usefulness, cognitive benefits, reflective thinking, learning effectiveness, and improved understanding gained. While we do not think that the collected data is conclusive, the responses suggest a higher level of appreciation by females for the visual features, level of immersion, and the actual content of the tour. Female participants also expressed more interest in having control of the time spent at each location. For male participants, performance issues, and to a much lesser degree visual quality were more prominent in the negative feedback. One interpretation of these numbers could be that males have higher demands when it comes to technical aspects of the application (maybe from more exposure to state-of-the-art video games and other 3D applications), while for females there is stronger novelty factor and a tendency to be more concerned with the conveyed content. Including more detailed questions on background and previous experience with virtual tour applications or other types of software should be able to shed more light on these gender differences in future studies. Another interesting question is whether these differences affect the actual learning outcome, not just the self-reported learning experience.

VI. Conclusions and Outlook

1) Technological Perspectives and Limitations: Virtual tour applications that re-create place-based experiences have been around for several decades but have still seen limited use in education in many disciplines, largely due to the costs and effort required to create them, as well as the logistical challenges of employing them. With the availability of affordable 360° cameras allowing the creation of low-cost tour experiences, this picture is slowly changing but applications of such experiences in higher education on a larger scale, as desktop applications and even more so as fully immersive VR experiences, are still limited. While we do not argue that virtual tours can or should replace actual excursions and fieldwork, they do offer several advantages including reduced costs, unlimited repeatability, availability to distance learners or learners with certain disabilities, and reduced logistical challenges. However, using virtual tours in education comes with a number of challenges, in particular in times of social distancing and online classes. At the moment, the availability of VR headsets is still not wide-spread enough to expect that every student owns such a device. As a result, in the study we reported on in this article, students were asked to run a browser-based virtual tour application rather than experiencing a fully immersive VR version. Nevertheless, our results show that students not only assessed the tour as a positive experience with the potential to significantly enrich and improve teaching, but they also rated the experience as realistic and immersive, with much fewer complaints about image and display quality compared to what we found for similar tours delivered via low-cost VR HMDs [26]. These results raise challenging questions for future research on the benefits that fully immersive tours delivered via HMDs can provide in the context of low-cost tours of real-world research sites [29].

2) Future Work: Other aspects for future research will be the evaluation of improved designs based on the feedback we obtained in the reported study, including the investigation of different means to emulate free movement in a primarily 360°-image-based tour. In addition, our plan is to move from *perceived* learning effectiveness to quantitative assessments of learning outcome via knowledge tests during and after the tour. This will also allow us to investigate to which degree students misjudge the learning effectiveness of the virtual tour. We further intend to extend the pre-tour questions to obtain more information on background and previous experience with virtual tours and other types of 3D software to allow for a more thorough analysis of gender and other individual differences with the goal of providing optimal and potentially individualized support to different users. Lastly, we have already started to move from purely educational contexts to other areas to assess the application of the Stanislaus-Tuolumne virtual tour to communicate research results to different groups of forest and fire management stakeholders and decision makers.

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