



# Ubiquitous synchronised semi-immersive cycle training: A technical architecture development and user pilot study

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## Abstract

The application of virtual reality (VR) technology for immersive training shows promise in a variety of tasks, including cycling. However, methods that use head mounted displays (HMDs) are bulky, expensive and difficult to work with for larger groups of students. In this paper, we explore the utility of common and ubiquitous mobile devices in semi-immersive cycle training. We present the development of a technical architecture for synchronised semi-immersive training, featuring centralised 360° video playback controls for instructors. We conducted interviews with four groups of students aged 9-11 and three instructors. Furthermore, we collected survey data from 67 students across three different groups. We report that students and instructors alike, find this approach to be effective, immersive and highly accessible.

**Keywords** Bike · Cycling · Immersive · Pilot study · Virtual reality · 360-degree videos

## 1 Introduction

Immersive technology can greatly impact learning by providing the benefit of lifelike experiences without the dangers and variability associated with the real-world counterpart activities [1–3]. Practical skills such as safe on-road cycling and situation awareness when riding typically require learning in a real-world environment, and cannot be solely learnt in the classroom. However, immersive technology can provide a middle ground between

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the controlled and focused approach to learning in a classroom, and the dynamic experience of being out on roads [1, 4, 5]. Moreover, immersive experiences can improve learning by fostering a feeling of presence and a sense of agency [6, 7], as well as improving knowledge retention [3, 8, 9]. Furthermore, recent research suggests that the use of VR can effectively support young cyclists' learning when delivered alongside independent on-road riding with a Bikeability cycle instructor [10]; and very brief VR interventions can enhance adolescents' attitudes towards cycling on roads [11]. Providing immersive training simultaneously to a large number of students is logistically challenging, especially when the protocol requires comparatively expensive and unwieldy head mounted displays (HMDs), which limit the instructor's ability to monitor and control the learners' experience [12, 13]. This can be addressed by providing instructors with specialised tools for managing, assessing and supervising student experiences [14–16].

In this study we aim to present novel synchronised semi-immersive training achieved through our proposed architecture. This approach addresses the existing challenges whilst performing as an effective immersive training. Hence, we present a technical architecture for a pair of mobile applications designed to facilitate synchronised and semi-immersive viewing of 360° cyclist POV footage by entire classes of schoolchildren, using tablet devices. Following this, we present the findings of a pilot study in which we obtained instructor and student feedback regarding the effectiveness of these applications.

## 2 VR immersive training

Since its inception, digital media technology has seen applications in learning tasks. From flight simulation [17, 18], to serious games [19, 20] and educational experiences [21, 22], immersive technology can provide a safe and controlled learning environment. In the past decade, developments in head mounted displays (HMDs) have made immersive digital media more accessible than ever. With this, recent research has produced serious games and VR applications in engineering education [23, 24], arts and design training [25, 26], reading interventions [27], exposure therapy [28, 29], cultural heritage and decolonisation [30, 31]. The findings of these work have demonstrated measurable positive impact as well as increased engagement.

Beyond simple audiovisual experiences, the use of VR technology affords a large degree of interactionability. Not only can participants observe virtual scenarios, but they can interact and receive real-time feedback. Furthermore, when relying on real-world experiences and video recordings, training is limited to scenarios encountered in the moment. Naturally there will be scenarios that a student misses out on during training. One key benefit of dynamic simulations and serious games is that experiences can be tailored to individual students through the use of procedural content generation or AI [4, 32, 33]. So far, the use of HMD-based immersive cycle training has yielded promising results [10, 11]. However, there are some key limitations in the cost, distribution and reach of the HMD approach. To provide effective interventions at a scale larger than one-on-one, devices need to be portable and easy to setup [34]. While HMDs are more affordable than ever, their form-factor and setup make them difficult to deliver for multiple simultaneous learners. The serious game VRKeer [35], addresses this difficulty by opting for compact stand-alone HMD devices and a simple but effective use of controllers to emulate bicycle handlebars. As a result of

this, the app is limited to a specific device choice, and a proprietary handlebar mount. Furthermore, the added complexity of incorporating gamified elements can impose extrinsic burdens on users, which can negatively impact engagement [36]. Conversely, at the cost of reduced immersion, the use of more commonplace, compact devices, such as smartphones and tablets, would alleviate these factors and make interactive classroom based training more accessible.

Many video playback applications support the viewing of 360° footage, and most current hand-held devices are capable of detecting device orientation through sensors such as gyroscopes, accelerometers and magnetometers. The usage of such devices for cycle training is already underway: with the support of nine Bikeability cycle training providers, Bishop and colleagues [37] used a commercially available VR app to provide semi-immersive cycle training to children in UK school classrooms, including children who had not undertaken any on-road training. The children viewed 360-degree cyclist-POV footage on tablets, guided by a Bikeability instructor, as shown in Fig. 1. Although their approach was highly effective, in several respects – not least the capacity to upskill the untrained children rapidly – manual synchronization of video footage across devices was clunky and reduced 'ride time.' In addition, applications such as the one used by Bishop and colleagues [37] typically comprise a host of functions that are superfluous for shared semi-immersive training experiences and can also be distracting for young *digital natives*, who inevitably explore the options these functions offer them [37].

In this paper, we present the design and implementation of a system for real-time synchronization of 360° footage, controlled by a single instructor, running on Android mobile devices connected over a Wi-Fi network. Our approach provides a ubiquitous solution which is still immersive but highly accessible, and reduces extrinsic burden of fully immersive or gamified approaches.



**Fig. 1** Students learning in a classroom setting using a commercially available 360° application

### 3 The Bikeability Trust VR Player: a local-network-synchronised 360° video player

Given the established benefit of immersive training experiences and the limitations of the existing approaches, we have developed a novel system for providing guided immersive experiences in classroom settings with the controllability of a HMD approach, but the ubiquity, affordability, and comfort of a handheld mobile approach.

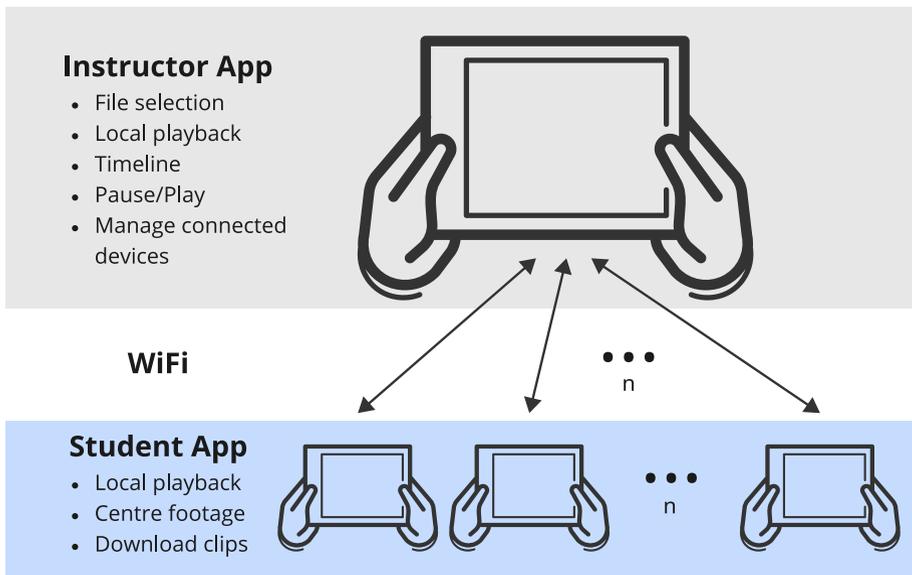
Figure 2 presents an overview of our system. The system involves a pair of mobile applications synchronised over a local area network (LAN), referred to as the *Instructor* app and the *Student* app. The *Instructor* app provides a single user with the capability to select and control the play state of 360° footage. When connected to the same network, the *Student* apps mirror the actions of the *Instructor* app, without any input from the student user. Thus, the user of the *Instructor* app has full control over the state of footage viewed by all *students* connected to the same network.

To incorporate accurate sensor reading, 360° viewing and real-time video control, these apps have been built using the Unity Engine [38]. Fast synchronicity over the network has been achieved via the open sound control (OSC) protocol [39].

For 360° viewing, a virtual camera is rotated based on device attitude. This is determined through a combination of gyroscope, accelerometer and magnetometer data where available. All users are able to re-centre the camera relative to the device attitude.

#### 3.1 Synchronisation architecture

A core aspect of this system is the ability to synchronize footage across a multitude of devices, based on the inputs of an individual *Instructor*. Importantly, this is done without streaming



**Fig. 2** An overview of The Bikeability Trust VR Player system

video footage over the network which would be increasingly unsustainable at higher device counts. In comparison, controlling locally stored footage via simple instructions is more scalable. We achieve this through a set of OSC messages, and corresponding response messages: commanding *Student* apps, then confirming their resulting status. These messages and the data they convey are presented in Tables 1 and 2.

The synchronisation architecture, presented in Fig. 3, shows the flow of communication between the two apps. Here, synchronisation messages from the *Instructor* app expect a corresponding response message from each connected *Student* app. The *Instructor* app compares these responses with its own status and indicates to the user whether or not the status matches. Naturally, there are a multitude of factors that can delay the synchronisation of footage between the apps, on top of the latency that occurs in network transmission. The time it takes for devices to seek a certain frame of a clip or load a new clip can vary, for example. Indicating to the *Instructor* app user that the status of a device does not yet match, suggests to them that they should wait for these devices before playing the footage.

On first launch of the *Student* app a unique identifier (UID) is generated and stored locally. This UID allows the *Instructor* app to differentiate between different *Student* app instances connected to it. The user of the *Instructor* app can give an alias to each device, which is associated with the UID. As a result, different *Instructor* app instances can refer to the same *Student* apps instances by different names.

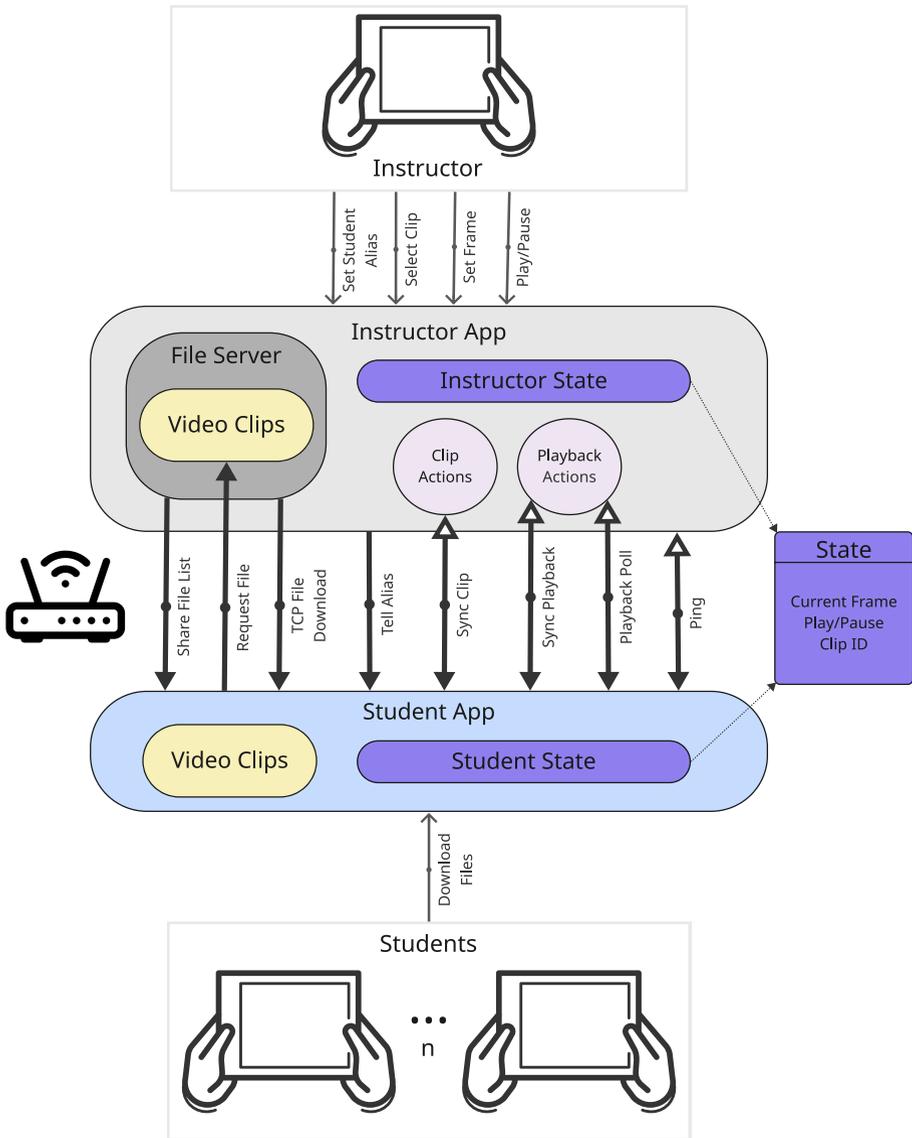
The *Instructor* app broadcasts a *ping* at 1 second intervals. When a *Student* app receives a *ping* it will store the IP address of the *Instructor* and respond with a *pong* message, containing its own IP address, UID and current viewing direction. When the *Instructor* app receives a message from a new device it creates a new entry to track its status. Once the *Instructor* app has the IP address of the *Student* app, and vice versa, further communication is conducted via unicast to ensure minimal latency.

**Table 1** Contents of OSC messages sent by the *Instructor* app

Instructor Message				
Ping	Clip Sync	Playback Sync	Playback Poll	Tell Alias
IP address	Current clip	Current frame Is playing	Current frame Is playing	Alias

**Table 2** Contents of OSC messages sent by the *Student* app

Student Message			
Pong	Clip Sync Response	Playback Sync Response	Playback Poll Response
UID	UID	UIP	UID
Viewing direction	Current clip	Current frame	Current frame
IP address		Is playing	Is playing



**Fig. 3** The architecture for synchronisation between *Instructor* and *Student* apps. Two-way arrows indicate messages initiated by the *Instructor* app that have an expected response from *Student* apps

**Algorithm 1** File list comparison

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```

procedure GENERATESYNCSTATUSGUI( $IF[]$ ,  $SF[]$ ) ▷ INPUT: instructor files (name, frame count), student files
(name, frame count)
  for all  $f_i \in IF$  do
    CreateGUIElement( $f_i$ , unsynced)
  end for
  for all  $s_j \in SF$  do
    if  $\exists f_i \in IF$  such that  $s_j.name = f_i.name$  and  $s_j.frames = f_i.frames$  then
      SetGUIElementStatus( $f_i$ , synced)
    else
      CreateGUIElement( $s_j$ , unneeded)
    end if
  end for
end procedure

```

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To synchronise files between the devices, the *Student* app first requests a list of value pairs from the *Instructor* app containing the names and corresponding frame count of each file in its clip folder. The *Student* app then compares this list with the names and frame counts of the files in its own local clip folder. Any files in the *Instructor* app's list that the *Student* app does not have is listed in amber on the UI. Algorithm 3.1 shows how this is achieved given the file lists. The user may then initiate a download process for all un-synced files. This download process occurs over HTTP.

**Algorithm 2** Comparison of *Student* app states with *Instructor* state, with visual indication

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```

procedure UPDATESSTATUSINDICATORS( $agg$ ,  $D$ ,  $i$ ) ▷ INPUT: aggregate device, connected devices, instructor
device
   $aggMatch \leftarrow true$ 
  for all  $d \in D$  do
     $match \leftarrow StatusMatch(S_d, S_i)$ 
    SETSTATUSINDICATOR( $d$ ,  $match$ )
    if  $match = false$  then
       $aggMatch \leftarrow false$ 
    end if
  end for
  SETSTATUSINDICATOR( $agg$ ,  $aggMatch$ )
end procedure

function SETSTATUSINDICATOR( $d$ ,  $match$ ) ▷ INPUT: device, match
  if  $match$  then
     $d.indicator \leftarrow "green"$ 
  else
     $d.indicator \leftarrow "amber"$ 
  end if
end function

function STATUSMATCH( $S_s$ ,  $S_i$ ) ▷ INPUT: student (device) status, instructor status
  return  $(|S_s.frame - S_i.frame| \leq 5) \wedge (S_s.playing = S_i.playing)$ 
end function

```

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To synchronise footage, the *Instructor* app sends *clip* or *playback* instructions whenever the clip is changed or the play-head is set to a different time, or footage is set to play or pause. When *Student* apps receive these instructions, they adjust their own state and respond with a confirmation message containing their current *clip* or *playback* status. Until

the *Instructor* app has received a response for a particular *Student* app, it will repeatedly send the last instruction to it until the response is received. The synchronisation status for each connected *Student* device is indicated to the *Instructor* device user with an amber (awaiting response) or green (synchronised) circle via Algorithm 2.

While footage is playing, the *Instructor* app polls the *Student* devices every 1/30th of a second. This ensures that the *Instructor* app can report an up-to-date synchronicity status while footage is playing. When there is a difference in the frame being shown by the *Instructor* and *Student* apps, the *Student* app must adjust to match the *Instructor*. A seek operation would need to be either instantaneous or take a pre-determined amount of time for the two apps to achieve a frame delta of zero. To address this, the *Student* app instead compares the current frame of the *Instructor* app to its own current frame using an algorithm inspired by dead reckoning approaches, and modulates its playback speed to minimise the difference, as shown in Algorithm 3.

To handle cases where *Student* apps connect during footage playback, the *Instructor* app sends it the full status, using which, the *Student* app loads the correct clip, seeks the correct frame and begins playing.

**Algorithm 3** Modulation of *Student* app playrate based on the frame delta between the local footage and the *Instructor* app

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```

procedure MODULATEPLAYRATE( $\Delta_f, t_p, t_c, FPS, r_{min}, r_{max}$ ) ▷ INPUT: frame delta, packet time of creation
(seconds), current time (seconds), frames per second, min playrate multiplier and max playrate multiplier.
   $\Delta_f \leftarrow \Delta_f + FPS \cdot (t_c - t_p)$  ▷ Synchronisation.
  if  $\Delta_f \neq 0$  then
     $r \leftarrow \text{Clamp}(1 + \frac{\Delta_f}{FPS}, r_{min}, r_{max})$ 
    SETPLAYRATE( $r$ )
  else
    SETPLAYRATE(1)
  end if
end procedure

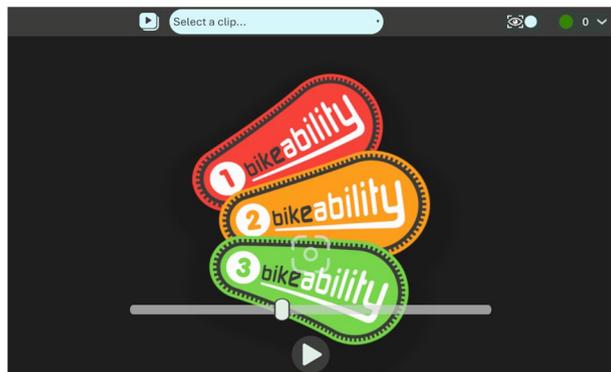
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### 3.2 Final implementation

The user interfaces for the *Instructor* and *Student* apps are shown in Figs. 4 and 6 respectively. The *Instructor* app presents typical video player controls including a time

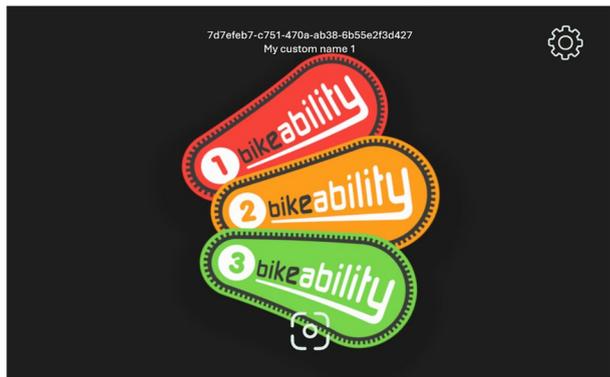
**Fig. 4** *Instructor* app UI



**Fig. 5** *Instructor* app UI with expanded *Student* list



**Fig. 6** *Student* app UI

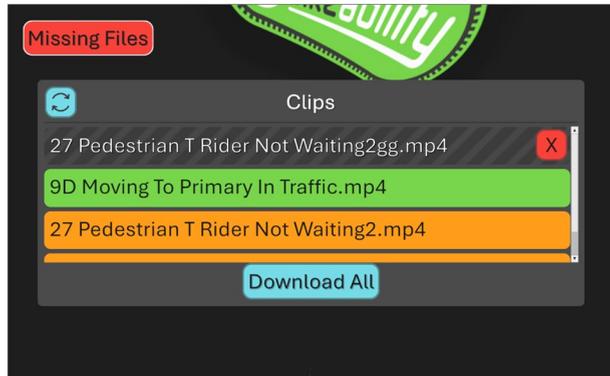


bar that corresponds to the time in the footage, and a play/pause button which allows users to toggle between playing and pausing footage. At the top of the screen is a drop down selector which lists all video clips available on the device. Selecting from this list causes the clip to be loaded immediately. In the top right corner is an element which represents the synchronisation status of all connected *Student* apps in aggregate, where the circle is green if all devices are synced, and amber otherwise. On selection, this element expands into a list of connected devices and their individual synchronisation status, as shown in Fig. 5. From this expanded view, the user can set the alias of individual *Student* instances.

The *Student* app provides a minimal interface that only fades in when the user taps the screen, and fades out after 3 seconds. Identification is provided at the top of the screen in the form of the UID and current alias according to the connected *Instructor* app. A button in the top right of the UI opens a panel from which the download of unsynced clips can be initiated. This file synchronisation panel, shown in Fig. 7 provides a colour coded list of clips based on the result of Algorithm 3.1. The download of all unsynced clips is initiated by pressing a single "Download All" button.

Both interfaces feature a button for recentring the 360° camera. This is found in the bottom-centre of the *Student* app and above the time bar on the *Instructor* app.

**Fig. 7** *Student* app file synchronisation UI



## 4 System Metrics

To assess the performance of the two apps, the network latency and speed of operations were asynchronously recorded into a log file on each device. We collected these logs on both *Instructor* and *Student* apps, installed on Lenovo K11 tablets and a selection of other available Android devices.

Our test setup consisted of 5 *Student* apps connected to a single *Instructor* app via a TP-Link Archer BE3600 Wi-Fi router which was not internet connected. All devices were situated within the same room with no obstructions between them. The device running the *Instructor* app was changed between each test, for a total of 6 tests to account for variability in individual devices. We repeated this set of 6 tests with three different video clips that were later used in the pilot tests. These videos each had a play-length of 2 minutes and 30 seconds, which is the intended length of Bikeability training videos, and were played twice in each test, resulting in 5 minutes of playback, followed by 10 seek operations. These seek operations were randomly chosen based on a uniform distribution.

As expected, during the idle state of the app, the network router ping RTT is approximately 100ms. Once there is actual activity in the apps and hence real network traffic, the router also becomes active. Thus, we report the RTT values during active states.

We found no significant difference in results between the devices and the three videos. Table 3 presents results from all tests in aggregate, including the network round-trip time (RTT), as well as the clip load time and clip seek time for both *Instructor* and *Student* devices measured in milliseconds (ms). The RTT with this setup is shown to be consistent with few spikes, as shown by a 95th percentile of 10ms and a maximum value of 259ms.

**Table 3** The mean, standard deviation (SD), minimum, maximum, median and 95th percentile for network round-trip time (RTT), clip load time and clip seek time in milliseconds

Operation	Mean	SD	Min	Max	Median	95%
RTT	8.96	17.91	4.01	259.25	6.14	10.03
Clip load time ( <i>Instructor</i> )	757.15	217.15	589.33	1123.26	591.54	1076.98
Clip load time ( <i>Student</i> )	493.87	42.23	453.64	586.25	475.98	565.32
Clip seek time ( <i>Instructor</i> )	275.04	74.95	132.61	433.23	282.38	399.23
Clip seek time ( <i>Student</i> )	248.08	164.71	23.87	498.81	297.30	480.32

While clip loading times are slightly higher in the *Instructor* app, likely due to the additional processing required for synchronisation, this does not negatively impact the experience as the *Student* apps can load before the *Instructor* app can perform further operations.

## 5 Pilot study

To validate our two mobile apps we conducted a pilot study in which the semi-immersive training was delivered to four groups of children aged 9-11 years in their classrooms, as illustrated in Fig. 8.

App installation files (APKs) and the required devices were supplied to a Bikeability training provider in Bournemouth, UK. Applications were installed on the same hardware as the system metrics; 34 Lenovo K11 tablets, which were connected to a TP-Link Archer BE3600 Wi-Fi router that was not internet-connected.

### 5.1 Feedback analysis

Two instructors (Instructors 1 & 2) delivered the sessions, and a third instructor (Instructor 3) recorded the sessions and posed questions to their colleagues and the children. Instructors 1 and 2 agreed, that the newly developed app improved the experience, both for themselves and the children: *"And I think they got a lot more out of it with this new setup than previously. It was probably better doing it this way than the previous way. But I think it was a noticeable difference with the Year 5s [9-10-year-olds]. Definitely so."*

However, there were technical challenges – notably, the additional demands the new app placed on battery resources, which potentially became more of an issue in the fourth and final session: *"I don't think the equipment's quite set up to last so many sessions. Or to charge up that many tablets in such a short amount of time."*



**Fig. 8** Students learning in a classroom setting using the apps during pilot study

The training was well received by the children, captured in the summary of one student: *"when you can't actually do Bikeability physically... it would be a good experience because it would probably make people want to learn how to ride a bike... it is quite nice so you can learn how to do it but without having a stress..."*

Instructor 3 asked the children for some feedback on elements of the protocol they would improve. The elements students identified were mostly related to interactivity of the protocol, rather than the functions of the app.

The feedback from both *Instructor* and *Student* groups were analysed further using a high-level thematic analysis inspired approach to identify the main themes in the feedback. This allowed for a number of insights to emerge from the raw data which cover both the advantages and limitations of the current implementation of the architecture. These are presented in Table 4.

Feedback from both instructors and students indicate that the apps provide an improvement in experience over the use of non-specialised apps. Instructors find that the centralisation of control speeds up delivery of training and reduces the need to intervene and "fix" the devices. Furthermore, the reduced control on the *Student* devices resulted in a more

**Table 4** Feedback summary and insights from feedback of *Instructors* and *Students*

	Theme	Count	Quote
Advantages	Improvement to learning	6	<i>"it is quite nice so you can learn how to do it but without having a stress... you can feel more confident because you know how it will feel" [8/9 students felt more confident]</i>
	Greater access to learning	3	<i>"Absolutely brilliant. Especially for those that don't have the opportunity of doing Bikeability for whatever reason..."</i>
	Improvement to user experience	5	<i>"So, it was easier to set up at the beginning... it was faster. And then... the first two sessions were really, really smooth..."</i>
	Increased control for <i>Instructors</i>	2	<i>"It was great having the control from the children... less things for them to touch. So less fixing for us to do."</i>
	Increased focus for <i>Students</i>	2	<i>"They weren't fiddling as much with them or anything"</i>
Limitations	Battery life	5	<i>"I said at the beginning of the day, 'are we going to have the battery for this [4 back-to-back 1-hour sessions]?', and I didn't realise it was going to run out quite so quickly"</i>
	Limited interactivity for <i>Students</i>	3	<i>"...you should be able to control it and maybe like be able to pick which different directions you could go"</i>

consistent and focused experience for the students. Instructors and students both mention that this approach to training is more accessible for students that have less opportunities to cycle on-road, whether this is due to parent concerns or student confidence.

Students identify that they would be more engaged if they had more agency and access to interactive or immersive functionality, such as steering, peddling and decision making. On a technical level, battery life is a concern for longer sessions, particularly that of the *Instructor* device. This can be mitigated with further improvements to the network architecture in order to reduce the processing load on *Instructor* devices. For example, making device discovery *Student* device-driven, so that the *Instructor* device does not need to continuously broadcast. Further optimisations could also include batching OSC messages and reducing the polling frequency during playback. Moreover, extra *Instructor* and *Student* devices can be held in reserve to swap with low battery devices when needed, while additional battery packs may also be utilised. Alternatively, this issue may be addressed by launching the *Instructor* controls on a more powerful device, such as a laptop.

## 5.2 Survey feedback

To expand on the interview findings, we collected additional quantitative data from students via a short survey.

Survey feedback was obtained from 67 children aged 9-11 years in three classes (*A*, *B* and *C*), in two UK primary schools. After completing a semi-immersive cycle training (sICT) session with Bikeability instructors, using the tablets, pupils were asked to rate the interestingness of the sICT, the immersiveness of the sICT, and the ease with which they could use the tablets - all on 11-point scales ranging from 0 (zero; "Not at all...") to 10 ("Extremely..."). They could also provide written comments and suggestions for improvements.

Overall, the feedback was generally positive with considerably high ratings for ease of use, as shown in Table 5. We assessed the normality of our samples by conducting Kolmogorov-Smirnov (KS) tests and inspecting Q-Q plots, from which all samples indicated approximate normality. A one-sample T-test was conducted for each question in the full dataset, to determine deviation from a neutral score of 5. Results show that the means of all three questions were significantly above 5 ( $p < .05$ ), indicating greater than neutral responses. We conducted a one-way analysis of variance (ANOVA) for each question between the three groups, from which we only find a significant difference in tablet ease of use ( $p < .05$ ). In this case, a post-hoc Tukey test confirms that class *C* had much higher ratings for ease of use than the other two classes. We also identify that, although not a statistically significant difference, lower scores for interestingness and immersiveness were given by class *A*, as shown in Table 6.

**Table 5** Overall mean, median, standard deviation (SD), one sample T-test  $p$  value and ANOVA  $p$  value of results for the three survey questions (N=67) with an 11-point scale ranging from 0 ("Not at all...") to 10 ("Extremely...")

Question	Mean	Median	SD	$p$ (T-test)	$p$ (ANOVA)
How interesting was the cycle training?	5.97	6	2.83	<.01	.15
How immersive was the cycle training?	6.19	6	2.86	<.01	.06
How easy was it to use the tablet?	7.93	9	2.31	<.01	<.01

**Table 6** Mean, median and standard deviation (SD) results for the three survey questions, by class

Class	N	Question	Mean	Median	SD
Class A	26	How interesting was the cycle training?	5.12	5	3.11
		How immersive was the cycle training?	5.08	5	3.05
		How easy was it to use the tablet?	7.92	9	2.49
Class B	28	How interesting was the cycle training?	6.32	7	2.47
		How immersive was the cycle training?	7.25	8	2.44
		How easy was it to use the tablet?	7.39	7	1.81
Class C	13	How interesting was the cycle training?	7.30	8	2.09
		How immersive was the cycle training?	6.54	7	2.07
		How easy was it to use the tablet?	9.69	10	0.48

Our findings are comparable with similar research examining immersive HMD cycling [40], in which various levels of apparatus were tested ranging from HMD with no controls, to steering and pedalling on a moving bicycle (*tandem*). Here, the *bikeless* and *tandem* tests obtained median scores of 5 and 5.5 (on a 7-point likert scale) respectively for "general presence", as well as 2.1 and 2.3 respectively for "experienced realism". Realism ratings were also collected on a 5-point likert scale, with *bikeless* (no controls) obtaining a median score of 2 and *tandem* (no controls) obtaining a median score of 3. This would suggest that, with regard to immersion, our approach is at least close to control-less HMD based approaches.

In the written comments there were frequent mentions of both the lack of sound (in 20 comments) and blur at the bottom of the footage (in 17 comments). These comments somewhat align with the *only moderately positive* survey scores for immersion and interest. It is understandable that a lack of sound in the experience affects the immersion of students, however the inclusion of sound would also detract from the ability of instructors to give clear verbal guidance. Naturally, this is a challenge for all immersive training that requires real-time verbal instruction. The blur, on the other hand, was added in order to avoid distracting users with a view of the recording apparatus. This, however, is not relevant with regard to the training approach itself.

We also note the difficulty that some training providers have experienced regarding troubleshooting poor connection between *Instructor* and *Student* apps, largely due to Wi-Fi interference and devices switching to different internet connected routers. This is particularly a challenge for less tech savvy users.

## 6 Concluding discussions

In this paper, we highlight the potential of hand-held smart devices for providing scalable semi-immersive experiences, as a cost effective, low complexity approach to supervised classroom training. The insights gained from the pilot study highlight greater access to learning and increased engagement and focus. They also demonstrate improved user experience.

## 6.1 Costs and logistics

While VR technology such as HMDs continue to improve and become more accessible, they are still not nearly as ubiquitous as smart phones and tablets. A single Meta Quest 3 HMD (QHMD) is priced at £469.99, while a Lenovo K11 is priced at £190.28, therefore approximately five K11s can be purchased for the price of two QHMDs. Furthermore, each QHMD's smallest dimension is 98mm, while each k11's smallest dimension is 7mm. The form factor of the latter makes it far easier to flat pack and therefore transport in larger numbers. Table 7 presents an estimated cost, weight and dimension of devices to transfer for a training session with 30 users.

## 6.2 Effective learning

Our findings indicate that our approach allows groups of students to learn simultaneously in an effective manner, with *Students* stating that they feel more "confident" [8/9 in the interview group], and *Instructors* suggesting that *Students* "got more out of it", with a "noticeable difference". Furthermore, the accessibility of this learning method is noted, with *Students* and *Instructors* both suggesting that it allows students to learn without "stress" and when they don't have the "opportunity" to do on-road cycle training. These findings indicate the effectiveness of the learning experience against current approaches as well as existing immersive/semi-immersive approaches which achieve similar learning but lack the logistical mobility, availability, reach, scalability and cost-effectiveness of our approach.

## 6.3 Usability and practicality

Our approach achieves at-scale learning (30+ students), that is easy to transport and setup thanks to its compactness. While HMD usage can be practical for individual users, especially as the demand grows for VR entertainment and the technology becomes more widespread. For users to experience control, additional hardware such as handlebar and pedal simulacra are needed [35, 40]. There is a clear appetite for this form of training, with *Students* suggesting that "you should be able to control it and... pick which different directions you could go", however, such approaches may be less practical for group learning.

Furthermore, the ubiquitousness of the hardware makes our approach easier to setup and problem solve due to *Instructor* and *Student* familiarity with the technology. Our quantitative results show that *Students* found the tablets easy to use, and *Instructors* noted that the lack of *Student* controls improved *Student* focus and reduced "fiddling". A vast improvement over the previous hand-held approach [37].

**Table 7** Cost, and logistics parameters, i.e. dimension and weight, for HMD vs tablet setups.

Unit	cost (pu)	Space (pu)	Weight (pu)	cost ( $\times 30$ )	Space ( $\times 30$ )	Weight ( $\times 30$ )
Meta Quest 3	£469.99	HMD + 2 Controllers $\sim 3,611\text{cm}^3$	HMD + 2 Controllers 641gr	£14,000	$\sim 100,000\text{cm}^3$	19,230gr
Lenovo K11	£190.28	$\sim 303.5\text{cm}^3$	465gr	£ 5,700	$\sim 10,000\text{cm}^3$	13,950gr

## 6.4 Limitations and future work

While there are clear technical challenges, such as battery life and Wi-Fi connectivity, we argue that these are easier for non-specialist users to deal with than issues that can occur with HMD based approaches [41], where the technology is much less ubiquitous. Moreover, while HMD approaches are more costly, bulky and challenging to set up, all of which are factors that work against at-scale group learning, they do provide a more immersive individual experience. The immersion and learning effectiveness of our approach could be improved by introducing interactivity through means of the same sensors used in 360° playback, though further work would need to determine how this can be applied in alignment with the goals of instructors. We improve upon the non-synchronised approach [37] in which students are trusted to individually play, pause and seek through the footage. Centralisation of control has reduced the time wasted in manual synchronisation and reduced distractions in the form of superfluous controls. On the other hand, there are additional technical challenges, such as increased battery drain and Wi-Fi inconsistency, though these issues can be mitigated.

Our system has been deployed as mobile applications for tablets. Yet, our proposed architecture is not limited to these types of devices. The *Student* app could be deployed for desktop VR or stand-alone VR such as Meta Quest HMDs. The *Instructor* app can be deployed as a web app, or desktop program, which would considerably reduce concerns of battery life. Moreover, this opens the door to a variety of potentially beneficial device configurations and further highlights the scalability and ubiquitousness of the architecture. As this sICT method is rolled out nationwide to Bikeability training providers, larger studies will be possible, with larger sample sizes and control groups.

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**Data Availability** Parts of the data, beyond what is in the paper, is confidential. Anonymised, non-confidential data can be made available upon reasonable request.

## Declarations

**Conflict of interest/Competing interests** Not applicable

**Ethics approval and consent to participate** Pilot data collection was approved by the College of Health, Medicine, and Life Sciences Research Ethics Committee (ref. 48350-MHR-Jun/2024-51590-3) at Brunel University of London. All participants gave their verbal consent to take part and were made aware of their right to withdraw from the study to no personal disadvantage, at any point.

**Consent for publication** All relevant permissions for video and audio recording, plus use of photographic material and quotes used in this article were obtained.

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