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SHORT COMMUNICATION

Assessing the difference in learning gain between a mixed reality application and drawing screencasts in neuroanatomy

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Abstract

Augmented, mixed, and virtual reality applications and content have surged into the higher education arena, thereby allowing institutions to engage in research and development projects to better understand their efficacy within curricula. However, despite the increasing interest, there remains a lack of robust empirical evidence to justify the mainstream acceptance of this approach as an effective and efficient learning tool. In this study, the impact of a mixed reality application focused on long spinal cord sensory and motor pathways is explored in comparison to an existing resource already embedded within an active curriculum (e.g., anatomy drawing screencasts). To assess the changes in learner gain, a quasi-randomized control trial with a pre- and post-test methodology was used on a cohort of Year 2 medical students, with both the absolute and normalized gain calculated. Similar patterns of learner gain were observed between the two groups; only the multiple-choice questionnaires were shown to be answered significantly higher with the screencast group. This study adds important empirical data to the emerging field of immersive technologies and the specific impact on short-term knowledge gain for neuroanatomy teaching, specifically that of long sensory and motor pathways. Despite the limitations of the study, it provides important additional data to the field and intends to support colleagues across the education landscape in making evidence-informed decisions about the value of including such resources into their curricula.

KEYWORDS

anatomy teaching, computer-aided instruction, effectiveness of anatomy education, gross anatomy education, medical education, neuroanatomy education, neuroscience

INTRODUCTION

Anatomical education is at the forefront of utilizing novel technologies to enhance the learning experience of students enrolled in anatomy and other healthcare-related programs. This agile and responsive nature of anatomical education to the ever-changing technological landscape is longstanding (Trelease, 2016), with numerous programs around the globe continually finding new ways to integrate the latest innovative resources and create highly blended learning environments. For example, numerous programs have fully

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integrated online approaches as the primary method to deliver the required learning objectives, while other courses integrate individual digital learning tools as supplementary resources, such as eBooks (Stirling and Birt, 2014; Pickering, 2015), screencasting (Razik et al., 2011; Woodruff et al., 2014; Border, 2019), smartphone and tablet applications (Lewis et al., 2014; Sevda et al., 2016) social media (Hennessy et al., 2016; Pickering and Bickerdike, 2016), massive open online courses (MOOCs) (Reinders and de Jong, 2016; Swinnerton et al., 2017), 3D printed specimens (McMenamin et al., 2014; Lim et al., 2016), and most recently, augmented, mixed and virtual reality (VR) (Küçük et al., 2016; Moro et al., 2017).

Recently, this latter technology has surged into the higher education arena due to its increased availability and affordability, which has allowed institutions to engage in research and development projects to understand better its efficacy within curricula. However, despite this increasing interest and the substantial investment from leading technology-based commercial enterprises, such as Google, Samsung, Apple, and Microsoft (Goldstein Research, 2017), there currently remains a paucity of robust empirical evidence to justify the mainstream acceptance of this approach as an effective and efficient learning tool that can decisively support knowledge retention, problem-solving and transfer (Clunie et al., 2018). This balance between investment, innovation, and evaluation sits alongside the prediction that such technology will significantly change the way programs are delivered and students engage with their curriculum (Lee and Wong, 2008; Kuehn, 2018). A further complicating factor within educational settings is the range of "alternate reality" resources (i.e., augmented reality [AR], virtual reality [VR] and mixed reality [MR] applications—collectively termed X-reality [XR]; Paradiso and Landay, 2009) which are being developed and deployed.

Of the studies that have investigated the impact on learning outcomes with such learning resources, the results have proven to be variable. For example, Moro et al. (2017), found that assessment outcomes remained unchanged after the utilization of immersive AR and VR resources based on skull anatomy, alongside a more traditional tablet-based resource. The report also outlines a number of "student experience" findings, with subjects receiving the VR resource exhibiting negative health implications, such as headaches, dizziness, and blurred vision. In contrast, Küçük et al. (2016) developed and deployed an AR resource for neuroanatomy teaching and found students performed better in their assessment and also exhibited a reduction in cognitive load after using the resource. Furthermore, the impact of such tools across the science education literature on learning gain and engagement also remains mixed. Assessing the impact of a VR simulation-based resource that mimicked a biology laboratory setting, subjects learned less than an equivalent PC-based version, and also exhibited greater cognitive load determined through the use of electroencephalogram recordings (Makransky et al., 2017). A common area of development and understanding within this context is essential for many anatomical regions, but the focus on neuroanatomy is emerging due to the necessary conceptual understanding (Wiertelak and Ramirez, 2008; Watson, 2015). This discipline has routinely been the focus of attention for educators to develop supplementary and core teaching resources to support students (Carrick et al., 2017; Border, 2019).

Given the rapidly evolving educational landscape, it is important that further research and evaluation is conducted to ensure the deployment of such resources facilitate enjoyable, efficient and effective learning experiences. This is particularly important as discipline-specific pedagogical research has deep-rooted issues of generalizability that hinder the ability of curriculum designers and teachers to meaningfully transfer findings from one locale to another (Cleland, 2017). Such issues with pedagogical research are well known—as illustrated in the above examples—and are particularly acute within the emerging area of immersive teaching and learning due to the wide range of XR applications available and the degree to which the individual learner is *immersed*. Concomitant with these inherent limitations, there is the continuing need to match this expanding innovation with research and evaluation protocols to improve the statistical reliability and develop "useful knowledge" that can be used to support faculty members in deploying such resources (Trelease, 2016; Sandars et al., 2017).

Aims and research questions

This study aimed to explore the impact of an MR application in comparison to an existing resource already embedded within an active curriculum through an exploratory study perspective. The following research questions were developed: (1) Does a mixed-reality learning resource focused on long spinal cord sensory and motor pathways increase learning gain (e.g., knowledge retention and transfer)? and (2) Is there a difference between learning gain when compared to an anatomy drawing screencast that is focused on long spinal cord sensory and motor pathways?

MATERIALS AND METHODS

Participants and study design

The study was embedded within a specific clinical case tutorial session that forms part of the Year 2 Bachelor of Medicine and Surgery Program's Control and Movement module, University of Leeds, UK. This module focuses on the clinically relevant anatomy of the musculoskeletal system, head and neck region, and brain and spinal cord, in an integrated blended curriculum that utilizes active lectures (Pickering and Roberts, 2018), dissection- and prosection-based laboratory sessions, living anatomy, ultrasound, and radiology small group sessions and clinical case tutorials. A more detailed account of the curriculum is available in Pickering and Bickerdike (2016). Ethical approval for the study was granted from the Research Ethics Committee of the University of Leeds School of Medicine (protocol MREC 18-027). All Year 2 students were randomly divided into 12 groups of approximately 20 students and assigned to a small group tutorial room, with an anatomy teaching assistant available to facilitate the session. Each session lasted for 90 minutes with students expected to work in small groups (2–4) and complete three clinical cases that examined the motor (e.g., corticospinal) and sensory (e.g., spinothalamic, dorsal column, and trigeminothalamic pathways) pathways of the spinal cord and brain. A total of 200 students completed the pre- and post-tests. Prior to these small group sessions, students received active lectures on: (1) ascending sensory pathways and (2) descending motor pathways, in preparation for the class.

The learning objectives for the preceding lectures and clinical case tutorial class were as follows: (1) understand the somatosensory sub-modalities with ascending pathways; (2) detail the common characteristics of specific somatosensory pathways; (3) describe the somatosensory pathways carrying information from the limbs and trunk, including: spinothalamic pathway (location of components, function, and route), dorsal column pathway (location of components, function, and route), and trigeminothalamic pathway (location of components, function, and route); (4) describe the components, course, and functions of the corticospinal and corticobulbar pathways; (5) integrate a basic understanding of ascending and descending pathway via case histories of patients with motor and somatosensory deficits. The somatosensory system was chosen as the primary area of study due to its conceptual difficulty for student learning and the inherent difficulty of study this area of complex anatomy in other settings.

At the beginning of each session, students were required to complete a pre-test that contained ten multiple-choice questions (MCQs) that focused on the lower level of Bloom's taxonomy (e.g., remember, understand) and examined the basic anatomical principles of the pathways (10 marks). This was followed by a single short-answer question (SAQ) that focused on a clinical scenario and required students to propose the location for a specific lesion and the associated pathways that would be damaged for the given motor and sensory loss (7 marks). These assessments evaluated knowledge at higher levels of Bloom's taxonomy (e.g., analyze, evaluate). These questions were pulled from the existing question bank available for the session and had not been shared with the students previously (see Supporting Information). In four of these rooms, students were shown an anatomy drawing screencast that covered the learning objectives with narration from the author (J.D.P.) via the in-room computer and projector. Students in the two remaining rooms, which were the only ones that had been equipped with the two available MR setups, were exposed to the MR application via the room's projector that was physically tethered to a Lenovo ThinkPad X1 Carbon with the processor i7-8550U, memory 16 GB DDR3 and with solid-state drive 512 GB (Lenovo, Quarry Bay, Hong Kong). The laptop was remotely tethered to the Microsoft HoloLens 1 development edition (Windows 10 SDK build version 1809, codenamed "Redstone 5") head-set (Microsoft Corp., Redmond, WA) that had been installed with the relevant neuroanatomy MR application. Deployment of the resource was conducted using Microsoft's twin Hololens "Spectator View" setup. The disparity in group size was due to the availability of equipment and want to embed the evaluation within a timetable teaching session.

Learning resource development

Anatomy drawing screencast

The instructional design principles for the anatomy drawing screencasts have been discussed elsewhere (see Pickering, 2016). Briefly, the screencast was designed in accordance with the Cognitive Theory of Multimedia Learning (CTML) that aims to limit extraneous information through a number of instructional design principles, including: spatial contiguity (i.e., position text adjacent to the corresponding image), temporal contiguity (i.e., position narration and animation at the same time), coherence (i.e., remove extraneous words, picture or sounds), signaling (i.e., only present essential information), and redundancy (i.e., do not use text with a narrated presentation) (Mayer and Moreno, 2003; Mayer, 2009). The drawing was created using illustration software (Illustrator, Adobe CS6, version 16.0.4, Adobe Systems Software Ireland Ltd., Dublin, Ireland), on a Wacom Cintiq 24HD (Wacom Technology Corp., Vancouver, WA) that was connected to an Apple MacBook Pro, 2.3 GHz Intel Core i7 (Apple Inc., Cupertino, CA). The audio–visual output was recorded via screen-capture software (Camtasia 2, version 2.6.0, Tech-Smith Corp., Okemos, MI). The narration audio was captured using a DC1 dynamic cardioid broadcast microphone (RoXdon, London, UK) via a Scarlett 2i2 recording interface preamp (Focusrite Audio Engineering Ltd., High Wycombe, Buckinghamshire, UK). The screencast was rendered to a video (.mp4) file.

Mixed reality application

Similar CTML principles were applied in the development of a holographic presentation of the ascending and descending pathways of the central nervous system. In order to align the resource with the spatial contiguity, temporal contiguity, coherence, and redundancy principles, the MR application was divided into five individual sequences (1, spinothalamic; 2, dorsal column; 3, trigeminothalamic; 4, corticospinal; 5, combined), with each sequence representing the specific neuronal pathways as they pass through the lower and upper spinal cord, the closed (caudal) and open (rostral) medulla, pons, midbrain, internal capsule and respective area of the cerebral cortex. The minimal text was added throughout the sequence being run, with each specific spinal cord and brainstem section being revealed upon activation by the facilitator, who narrated the passage in a manner similar to that presented on the anatomy drawing screencast. Upon the completion of each individual sequence, the combined sequence was initiated to show all four pathways within the hologram. Prototype pathway sequences were storyboarded and then converted to universal windows project (UWP) in the Unity3D platform, version 2017.3.1 (Unity Technologies, San Francisco, CA; Ntakakis et al., 2017). Once rendered, the MR application was uploaded to a HoloLens 1 development edition (Windows 10 SDK build version 1809 (Microsoft Corp., Redmond, WA) device.

Calculation of learning gain

A quasi-randomized control trial with a pre- and post-test methodology was used to assess learning gain, with the intervention being either the anatomy drawing screencast or neuroanatomy MR application. A detailed description of the procedure used to determine learning gain has been previously published (Pickering, 2016). Briefly, the absolute gain was calculated via Equation (1) to show the difference in learning gain between two-time points. However, as a strong negative correlation is observed between absolute learning gain (Equation 1) and pre-test scores, the normalized learning gain is calculated by dividing the absolute gain by the maximum possible gain (Equation 2) to reduce the influence of pre-test scores (Hake, 1998, 2002). The average of individual normalized learning gain (Equation 3) was then calculated with the associated standard deviations used to calculate the respective effect sizes. All pre- and post-tests were marked and second marked by the research team.

$$g = \text{post-test}\,(\%) - \text{pre-test}\,(\%) \tag{1}$$

$g = \text{learning gain (absolute)}$

$$g_i = \frac{[(\text{post-test}\,(\%)) - (\text{pre-test}\,(\%))]}{(100\% - \text{pre-test}\,(\%))} \tag{2}$$

$g_i = \text{normalized learning gain (absolute)}$

$$g_{ave} = \frac{\sum_{\text{from 1 to } n(g_i)}}{n} \tag{3}$$

$g_{ave} = \text{average of normalized learning gain}$

Statistical analysis

Pre- and post-tests were scored out of 17 and converted to a percentage, with descriptive statistics including the mean and ±standard deviation (±SD) calculated for each intervention. The pre- and post-tests assessments were the same. A dependent *t*-test was deployed to determine statistical significance within groups. Absolute learning gain (Equation 1) and the average normalized learning gain (Equation 3) were calculated and an independent *t*-test deployed to determine statistical significance between groups. A Cronbach's alpha of 0.67 and 0.73 was calculated from the pre-test and post-test, respectively. The effect size for pairwise comparisons throughout was calculated using Cohen's *d* (Becker, 2000), with an alpha of <0.05 used for all statistical tests. Data sorting was conducted using Microsoft Excel 2015, version 15.14 (Microsoft Corp., Redmond, WA) and statistical analysis performed in Statistical Package for Social Sciences, version 22 (IBM Corp., Armonk, NY).

RESULTS

Learning gain determination using overall percentage scores

The overall percentage scores calculated after the pre- and post-tests for both within- and between groups are detailed in Figure 1 and Table 1. For both the MR application and screencast groups, the percentage scores significantly increased for the MCQ (screencast: $t\ (126) = 15.731$, $P < 0.001$, $d = 1.26$; MR application, $t\ (74) = 11.365$, $P < 0.001$, $d = 0.790$), SAQ (screencast: $t\ (83) = 13.600$, $P < 0.001$, $d = 1.675$; MR application, $t\ (61) = 13.213$, $P < 0.001$, $d = 1.860$), and

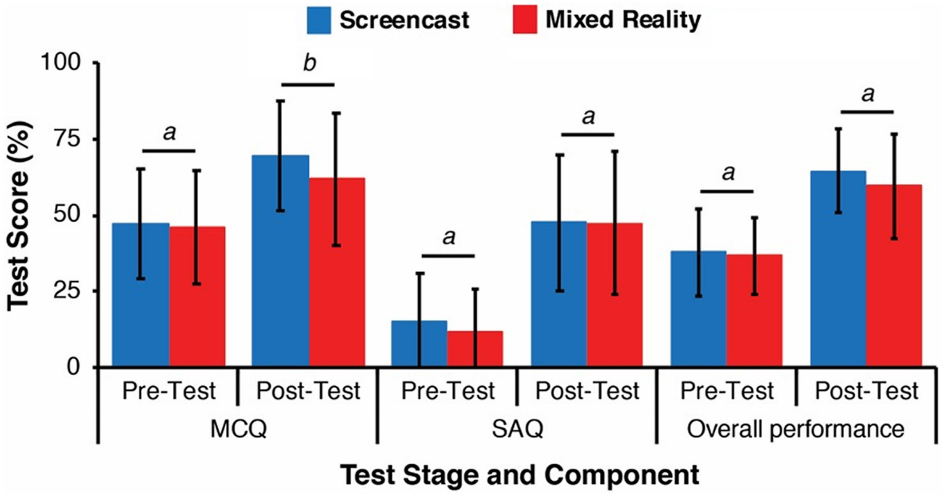

FIGURE 1 Bar chart displays the percentage of correct answers for the multiple-choice, short-answer questions, and overall performance in the pre- and post-test for the screencast and mixed reality application groups. Error bars indicate standard deviation. Horizontal bars indicate between group significance and effect size; $^{a}P > 0.05$; $^{b}P < 0.05$; Cohen's effect size was calculated as 0.388 for screencast versus mixed reality, MCQ post-test; MCQ, multiple-choice question; SAQ, short-answer question

TABLE 1 Pre-test and post-test results for the screencast and mixed reality application groups

Test component	Resource (number of participants)	Pre-test	Post-test	Within-groups significance (paired t-test P-value)	Cohen's d
		Score mean % (±SD)	Score mean % (±SD)		
MCQ	Screencast (n = 127)	47.1 (±17.9)	69.6 (±17.9)	<0.001	1.260
	Mixed reality (n = 75)	45.9 (±18.4)	61.9 (±21.9)	<0.001	0.790
SAQ	Screencast (n = 84)	15.3 (±15.7)	47.6 (±22.4)	<0.001	1.675
	Mixed reality (n = 62)	11.8 (±14.2)	47.4 (±23.6)	<0.001	1.860
Overall	Screencast (n = 84)	37.9 (±14.2)	64.4 (±13.7)	<0.001	1.898
	Mixed reality (n = 62)	36.7 (±12.6)	59.5 (±16.9)	<0.001	0.552

Note: Within-group significance and effect size is calculated using mean percentage data.

Abbreviations: MCQ, multiple-choice question; SAQ, short-answer question.

the tests overall (screencast: t (83) = 19.821, $P < 0.001$, d = 1.898; MR application, t (61) = 16.938, $P < 0.001$, d = 0.552). The effect size was greater for the neuroanatomy screencast for the MCQs within the pre- and post-test and overall. Between groups (pairwise comparisons), a significant difference on overall percentage scores was observed for the MCQs in the post-test, t (200) = 2.733, P = 0.007, d = 0.388. The between group scores for the MCQs in the pre-test and all other tests were not significantly different (MCQ pre-test: t (200) = 0.462, P = 0.644; SAQ pre-test: t (144) = 1.371, P = 0.173 and post-test, t (144) = 0.520, P = 0.958; overall pre-test, t (144) = 0.515, P = 0.607 and post-test, t (144) = 1.962, P = 0.052). Summarizing, while both the MR application and screencast groups presented significantly improved knowledge retention, the screencast groups demonstrated a greater effect in knowledge retention than the MR application.

Learning gain determination using absolute and normalized gain

To increase the validity of the results, both the absolute and normalized gain were calculated and are provided in Table 2. In alignment with the findings presented above, a similar pattern was observed between the two groups, with only the MCQs providing a significant increase in learning gain for the screencast group: absolute gain, t (200) = 3.025, P = 0.003, d = 0.456, and normalized gain, t (200) = 2.557, P = 0.01, d = 0.378. All other between group comparisons for the SAQs and overall performance in the tests was not significantly different (SAQ: absolute gain, t (144) = 0.903, P = 0.368; normalized gain, t (144) = 0.576, P = 0.565; overall performance: absolute gain, t (144) = 1.960, P = 0.052; normalized gain, t (144) = 1.619, P = 0.108). Normalizing gains demonstrate, like above, that the screencast groups present a demonstrably significant effect against no such effect in normalized gains from the MR group.

DISCUSSION

The use of innovative technologically based learning resources has been a longstanding goal for anatomy educators, with the use of XR applications, the latest tool currently entering this arena. Against this backdrop, this study has attempted to provide some additional empirical evidence into the rapidly changing and diverse landscape, revealing that the inclusion of such technology can be integrated with success in the classroom. The novel MR app used in this study has been demonstrated to support learning in the classroom setting when comparing pre- and post-test results, although it should be noted that this was at a marginally lower level than those of the control group which used the screencast learning approach.

Although this result appears to undermine the efficacy of MR resources in anatomy education since a much simpler technologically application (the screencast) yields enhanced learning

TABLE 2 Between group absolute and average normalized learning gain results for the screencast and mixed reality application groups

Test component	Resource (number of participants)	Absolute gain mean % (±SD)	Between groups significance (unpaired t-test P-value)	Cohen's d	Normalized gain mean (±SD)	Between groups significance (unpaired t-test P-value)	Cohen's d
MCQ	Screencast (n = 127)	22.5 (±16.1)	0.003	0.456	0.43 (±0.30)	0.01	0.378
	Mixed reality (n = 75)	16.0 (±12.2)			0.33 (±0.26)		
SAQ	Screencast (n = 84)	32.4 (±21.8)	0.368	–	0.38 (±0.24)	0.565	–
	Mixed reality (n = 62)	35.6 (±21.2)			0.41 (±0.25)		
Overall	Screencast (n = 84)	26.5 (±12.3)	0.052	–	0.43 (±0.18)	0.108	–
	Mixed reality (n = 62)	22.7 (±10.6)			0.38 (±0.20)		

Abbreviations: MCQ, multiple-choice question; SAQ, short-answer question.

outcomes, the methodological context of the study should make apparent that the more interesting aspect of the results is the actual impact of the MR resource. As was described in the materials and methods section, the MR resources were deployed with limitations to maintain full compatibility with the existing pedagogy, and only the teaching assistants utilizing the resource through the Microsoft HoloLens in MR. Thus, the impact that this resource had was due to the immersive nature of the 3D exploratory narrative as delivered through a 2D screen and without its sense of presence and immediacy. However, in that context, this study demonstrated the potential that this educational modality has when the teaching paradigm shifts. VR has proven efficacy regarding engagement in several disciplines, such as physics, chemistry or astronomy (Klopfer and Squire, 2008; Dede, 2009; Chiu et al., 2015). The sense of presence and immediacy that is conveyed by the user when they experience the phenomena or structures described has been discussed elsewhere (Shelton and Hedley, 2003; Olympiou and Zacharia, 2011); this study is one of the first that explores learning efficacy, because it demonstrates clearly that MR has an educational impact by significantly improving knowledge retention and not just engagement and interest in the subject matter, as is the case with the bulk of the literature, especially regarding anatomy. This initial finding within the specific context described here should be viewed alongside other work in this field that has drawn links with VR and physical models in regard to stereopsis (Wainman et al., 2019).

MR and other similar immersive educational resources are becoming established within the anatomy and medical disciplines with numerous studies presenting their findings on numerous aspects of the educational journey. However, while these are mostly small-scale studies and limited to certain disciplines, the full model for their comprehensive integration into formal curricula is underdeveloped. This point is compounded by Zhu et al. (2014), which revealed that although a large volume of individual studies has been reported since 2012, after rigorous filtering and analysis it was evident that these studies were mostly lacking in a pedagogical underpinning and that more work was needed to fully appreciate the pedagogical basis for their inclusion. This view is in line with a more recently published systematic review that revealed the majority of anatomy education studies that have evaluated technology-based learning resources are not robustly scrutinized for their efficacy in knowledge acquisition, but primarily focused on behavioral and emotional engagement (Clunie et al., 2018). Moreover, a more recent review by Barsom et al. (2016) described an evolving, technologically volatile environment that supports blended learning to increase engagement with the content; however, it also outlined a weakness of the literature in being able to verify that immersive MR resources can facilitate the authentic transfer of medical knowledge in comparison to the verified methods of contemporary medical education.

In light of the mixed results within the literature, the variability in XR applications deployed across disciplines, locale and curriculum-specific differences prevalent across the sector, and the maturity of the technology under investigation, this study has attempted to add some additional empirical data to the growing evidence base. It is important, therefore, to consider the findings of this study within the specific context in which they were delivered and make judgments on its transferable utility with these factors in mind. Given the above caveats, this study has highlighted how the incorporation of an MR learning resource into a formal curriculum through the deliberate limitation of its capabilities (i.e., by utilizing it as a visual aid with limited interactivity through overhead projection to the learning audience, rather than a fully immersive environment). In this limiting context, the principle results demonstrate that MR immersive technology facilitates knowledge transfer across multiple domains of Bloom's taxonomy and that this resource broadly matches that of an existing learning resource already actively employed throughout the curriculum.

Limitations and future work

While the most significant methodological limitation of this study is the small number of students per group of teaching, the main, more fundamental, limitation is that of the generalizability of the findings due to the nuance of educational delivery across continents, curricula, student groups, and other sector-specific demands. As with many educational interventions, the impact of the learning resource is mediated by a number of factors that are not always obvious, and even those that are, are not always controllable. Therefore, the purpose of this study has been to add empirical data to the emerging evidence base and to support colleagues in having an insight into the impact of such an intervention within the specific context as described. As with any intervention, several factors will need to be taken into consideration when deciding whether to deploy a similar resource, such as student, faculty, institutional, and sector-specific aspects that will need to be given due consideration. This is not to discount the findings presented in the study but to couch them in the appropriate context. Future work will seek to continue the validation of the resource and start to compare the visualization of the holographic image in 2D and immersive 3D environments in regards to short-term learner gain, with additional work also exploring the knowledge transfer differences between groups of students with varying technology acceptance and perceptions levels, alongside elements of content co-creation (Antoniou and Bamidis, 2018).

CONCLUSIONS

The overall results of this study form part of an initial and required, validating stage for deploying MR and other immersive resources within the neuroanatomy area. This understanding is essential in transferring innovative approaches from the realm of novelty and proof of application to the realm of curriculum integration and acceptance. The findings from the study indicate that such MR resources can be incorporated, with equal validity in learning outcomes when compared to other existing 2D learning resources, when deployed within formal curricula and supports the larger scale exploration of their impact both in established and novel curricular paradigms. Further research with more complex and interactive user cases will provide the necessary refinements to the methodology to ensure that MR resources find their place in formal medical curricula not as novelties but as standard medical education enablers.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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