Future of Neurology & Technology: Virtual and Augmented Reality in Neurology and Neuroscience Education: Applications and Curricular Strategies

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Abstract

Virtual reality and augmented reality have become increasingly prevalent in our lives. They are changing the way we see and interact with the world and have started percolating medical education. In this article, we reviewed key applications of virtual and augmented realities in neurology and neuroscience education, and discussed barriers and opportunities for implementation in the curriculum. Although long-term benefits of these approaches over more traditional learning methods and the optimal curricular
balance remain mostly unexplored, virtual and augmented reality can change how we teach neurology and neuroscience.

**Introduction**

Virtual reality (VR) and augmented reality (AR) are changing the way we see and interact with the world, and hold great potential for the future of education. Although often used interchangeably, these expressions refer to distinct approaches to enhance user experiences. VR simulates a real environment and permits the presentation and the control of stimuli within a multisensory, 3D dynamic environment while recording quantifiable responses\(^1\). Within an educational context, it provides an environment that is as similar as possible to a real-life scenario\(^2\). Instead, AR uses a view of the real world enhanced by overlaying and superimposing computer-generated information, including text, videos, or sounds, on the actual environment\(^2\). The development of mobile technologies have made AR possible via mobile devices\(^3\) and expanded the realm of potential applications to neurology education. In this manuscript, key applications of VR and AR in neurology and neuroscience education, including neuroanatomy and histology, as well as potential clinical applications, are reviewed. Opportunities and potential barriers to widespread implementation are discussed.

**The virtual classroom**

In this section, specific ways in which topics traditionally taught via didactics in the classroom can be transformed with VR/AR technology will be explored.
From cadaveric dissections to computers

During the last two decades, VR and AR tools have been used to teach basic and advanced neuroanatomy to enhance, or replace, traditional cadaveric dissection. A recent review of studies using different methods to teach neuroanatomy showed that nearly half of these already takes advantage of 3D teaching tools or AR. A cross-over design study was performed to assess the potential benefits of cadaveric versus 3D computer-based learning of neuroanatomy. 47 Undergraduate medical education students completed an anatomy knowledge and spatial ability test before being assigned to either a 3D neuroanatomy e-learning module or a gross anatomy laboratory featuring cadaveric dissection. Then, they completed a post-test and were crossed over to the other learning modality before taking a final post-test. Students assigned to the 3D neuroanatomy module performed better on the post-test (an absolute difference in mean scores of nearly 12%). Following cross-over, both groups performed similarly, but transitioning from the cadaveric anatomy module to the 3D learning module resulted in a significant increase in test scores.

Immersive VR neuroanatomy training

The impact of an immersive VR neuroanatomy training, as opposed to a neuroanatomy textbook, was assessed via a randomized controlled study featuring 64 first- and second-year medical students. Virtual material was created in Blender with T1-weighted anatomic magnetic resonance images and tract maps. Pre- and post-tests were designed with 13 questions assessing the material presented in the module and 9 questions on general neuroanatomic knowledge (not included in the modules), along with a 44-question test given one week after the sessions. A significantly higher number of students felt VR should be used in classrooms compared to the paper-based system (94% versus 33%) and felt less afraid of neuroanatomy following VR (81% versus 12%). The VR group did better than the paper-based group regarding the questions focused on the presented material. While this report suggests that...
integration of VR into training has the potential to increase study motivation and decrease neurophobia, as indicated by the results of the satisfaction survey, the follow-up period was brief and the number of questions to assess knowledge retention was probably too small.\(^5\)

Another study divided 84 students into three groups\(^6\). All groups attended a lecture, with one group having only traditional 2D images presented in a single view, the second group having access to VR 3D images shown in the lecture (with which they can interact), and the third group having the same interactive 3D images presented stereoscopically. The post-class assessments focused on naming the structures of the limbic system, followed by a practical examination requiring them to recognize the same structures on anatomic specimens\(^6\). No difference was observed between the stereoscopic versus traditional 3D VR groups, yet these two groups performed better on both the knowledge assessment and the practical anatomy assessment\(^6\). While these studies are limited to three institutions and had no assessments of long-term retention (e.g., one year or beyond), they demonstrate that VR-based learning of neuroanatomy is at least non-inferior, and potentially superior, to traditional learning methods of cadaveric anatomy and paper-based materials.

**AR neuroanatomy with a smartphone**

AR neuroanatomy teaching was assessed with 70 students who participated in two lectures on basic, relevant concepts of the ascending and descending tracts of the medulla with 2D materials\(^7\). The control group studied on a book, whereas the experimental group used the same book as a MagicBook with tagged elements which, when viewed with a smartphone, permitted further interaction and visualization\(^7\). The group studying with AR materials performed better on the knowledge assessment, and students felt that utilizing the mobile AR application facilitated (79%), or partially facilitated (21%), their learning; three students out of four felt it helped decrease their cognitive load, and one out of four thought it partially decreased their cognitive load\(^7\).
VR wearables to manipulate neurons

An even more immersive experience was piloted using wearable VR technology and layered images allowing the virtual manipulation of a neuron. This was possible thanks to prototype favouring real-time interactions with high-resolution cellular modules. GLASS® technology wearables permitted a user-centric educational experience, which can be flexibly applied to histological and anatomical contexts, individually or in simultaneous, real-time group. This approach can be more useful with experienced learners, with certain visuospatial abilities and more complex anatomical aspects. A randomized trial of e-learning instructional design demonstrated that multiple views of a neuroanatomical element might impede learning, particularly for those with relatively low spatial ability; high degrees of control to the students can reduce the effectiveness of learning.

In conclusion, VR and AR allow learners to go beyond the limitations imposed by 2D, non-interactive images and create a training environment where visualization and manipulation are possible. However, future research will have to investigate personalized learning approaches capable of maximizing individual learning experience.

The virtual patient

VR/AR applications also encompass standardized simulations offering immersive experiences focused on decision making and clinical reasoning. The virtual patient is a computer program simulating real-life clinical scenarios. Students can conduct the patient’s anamnesis, physical exams, and define the diagnostic and the therapy, thus developing a series of cognitive clinical skills. A combined systematic review and meta-analysis in health professionals’ education showed that the use of virtual patients was associated with positive effects compared with no educational intervention. However, many studies were lacking key methodologic details, and less than half have been randomized. Hence a focus on rigorous study design methodology might allow better comparability among different works. It is difficult to ascertain whether the virtual
patients improved the learning process because of the more standardized experience offered or due to overall increased patient exposure. Therefore, future educational studies will have to clarify this aspect and create more varied clinical presentations.

**Simulating the patient experience**

Virtual technology permits experiencing symptoms and medical conditions, which can help medical providers understand specific pathologies. A VR device was developed to simulate Parkinson’s disease psychosis combining Oculus rift technology with the input of patients, caregivers, and healthcare providers\(^\text{11}\). More than 500 viewers experienced two hallucinatory scenarios during two international meetings. Motion sickness, which can be a negative consequence of this approach, was rarely reported. The VR scenarios were rated as ‘likely/very likely’ as effective teaching tools for HCP (87.5 %) and caregivers (90.8). One respondent out of two would even ‘likely/very likely’ change their medical practice\(^\text{11}\).

Building on previous work designed to provide a virtual simulation of hallucinations in the setting of schizophrenia, patient descriptions of auditory and visual hallucinations have been displayed in a virtual environment\(^\text{12}\). Using the virtual world system of Second Life (Linden Lab, San Francisco, CA), an inpatient psychiatric unit has been created to virtually experience hallucinations\(^\text{12}\). For 2 months, 579 users took the self-guided tour before completing a survey\(^\text{12}\). The experience improved the understanding of visual hallucinations (for 69% of users) of auditory hallucinations (for more than three people out of four)\(^\text{12}\). Disease simulation can be applied to other neurologic and psychiatry diseases: a VR simulation of a specific symptom can be paired with a video providing instruction to assess and treat the condition itself and coupled with a test.
The Virtual Operative Assistant

Simulation-based education (through VR and, to a lesser extent, AR) is another growing trend in neuroscience and neurology education. VR and AR can increase the efficiency of training and treatment delivery and improve patient outcomes by mitigating patient risk, decreasing the chances of error within a zero-risk training environment, and can be used to learn patient-specific anatomy. Over the last ten years, it has become increasingly prevalent in procedural fields, including neurosurgery. To name a few of them: skull base surgery, stereotactic and functional neurosurgery, vascular surgery, tumour resection, trauma, hydrocephalus and spinal neurosurgery. Promising data have also been obtained with VR simulators for neuroendovascular intervention and training of lumbar puncture.

VR has also been coupled with artificial intelligence (AI) to develop the ‘Virtual Operative Assistant’. This automated educational feedback platform was piloted in 50 among neurosurgeons, fellows, residents, and students, divided into skilled and novice groups to use the VR simulator to perform a subpial brain tumour resection task. The Virtual Operative Assistant correctly classified skilled and novice participants using four metrics with 92% accuracy. Overall, it showed the feasibility of a new educational paradigm based on objective feedback based on proficiency benchmarks, expertise classification and instructor input.

Future developments and curricular strategies

The aim of reaching a fully immersive, dynamic multisensory fusion of virtual and real information, which can provide a useful platform for real-time navigation for educational and training purposes, remains elusive. As demonstrated from the examples discussed above, using VR/AR technologies can bring advantages, also in terms of increased confidence levels and procedural competency, while offering a safe
training environment. There are barriers to overcome, but the steps here described can mitigate them and facilitate the implementation of VR/AR (Figure 1).

The first step is an accurate cost-benefit analysis for development and usability of these devices. Costs can vary dramatically based on the technology used. These figures are rarely mentioned in peer-reviewed publications, and very few reports have evaluated the feasibility of implementing VR/AR elements within the curriculum\textsuperscript{13}. The lack of a robust financial model or, at least, of a framework, increases the difficulty of evaluating feasibility and sustainability of technological devices across educational settings, particularly the under-resourced ones. On the one side, VR/AR technologies might provide access to educational opportunities that otherwise might not be available to specific groups of learners, hence addressing gaps in medical education. On the other side, while collaborations with industry or start-ups (and renting, instead of buying, equipment) might mitigate the cost\textsuperscript{13}, money for device maintenance or software updates, i.e., to increase real-life aspects further and improve the immersivity and interactivity, must be budgeted, and represents another barrier.

An additional challenge is linked to identifying contents to be used with VR or AR and proper curricular space. Not all educational opportunities might be equally suited for VR/AR, and foundational aspects, more than the advanced ones, had a more widespread adoption so far. To ensure that the identified VR/AR solution factually addresses the needed gaps in the curriculum, it is necessary to re-evaluate and re-align the learning objectives within the context of the VR/AR training module. Besides the timing of the curricular adoption, the modality of the implementation (i.e., as a standalone module vs integration into a multimodal educational unit\textsuperscript{2}) must be pondered.

Beyond financial resources, VR and AR typically require an investment in human resources and expertise. Cognitive biases, such as the reluctance of some educators to change the educational status quo, can slow the adoption rate of such technologies. Increasing awareness of the potential benefits of VR/AR can help in this case. Moreover, a lack of local expertise can be compensated by national and international
collaborations: sharing resources can fast forward new tools to be used across medical education. Educationally, national and international collaborative efforts might lead to a better standardization of experimental methods and outcomes assessment. This, in turn, will potentially provide the playing field for educational alignment and the creation of new educational benchmarks, in collaboration with societies and relevant stakeholders.

While computer-based training enhanced the educational landscape, new technological devices have raised novel ethical and legal questions. AI’s intrinsic limitations, transparency over data collection methods, and data ownership need to be carefully considered. With VR, besides personal data about location, search queries, and verbal communications, non-verbal behaviour such as eye movements, facial expressions, posture are collected: 20 minutes of VR simulation leads to 2 million unique recordings of body language. While these datasets may provide significant scholarly opportunities, they open up considerable privacy concerns for participants. When implementing VR/AR tools for teaching or educational research purposes, considerations of data storage and data protection should be in order.

Conclusions

VR and AR applications have already altered the educational landscape and constitute promising approaches in medical education. These tools have made their way into neuroscience and neurological education, in particular neuroanatomy. Simulations of patient experiences in disease states and surgical simulators have become available, although potential barriers, including cost and the necessary expertise to use these tools, persist. As VR and AR become more prevalent, medical educators need to identify ways to adapt curricula to incorporate these teaching tools. Looking forward, collaboration across multiple centers to assess their long-term value remains a crucial opportunity for educational research into VR/AR.
**Figure 1:** Ten steps towards curricular implementation of virtual and augmented reality in neurology education.

1. Cost benefit analysis
2. Identifying content ideally suited to AR/VR teaching
3. Time and resources to develop new AR and VR devices
4. Redefinition of learning outcomes and identification of curricular space
5. Ethical and legal issues
6. Favoring multicenter and multiprogram collaborations
7. Establishing national and international benchmarks
8. Educational research with rigorous methodologic standards
9. Integrating neuroscience research into education
10. Updating software and devices to increase real-life aspects

**Appendix 1. Authors**

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References


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