Getting Up Your Nose: A Virtual Reality Education Tool for Nasal Cavity Anatomy

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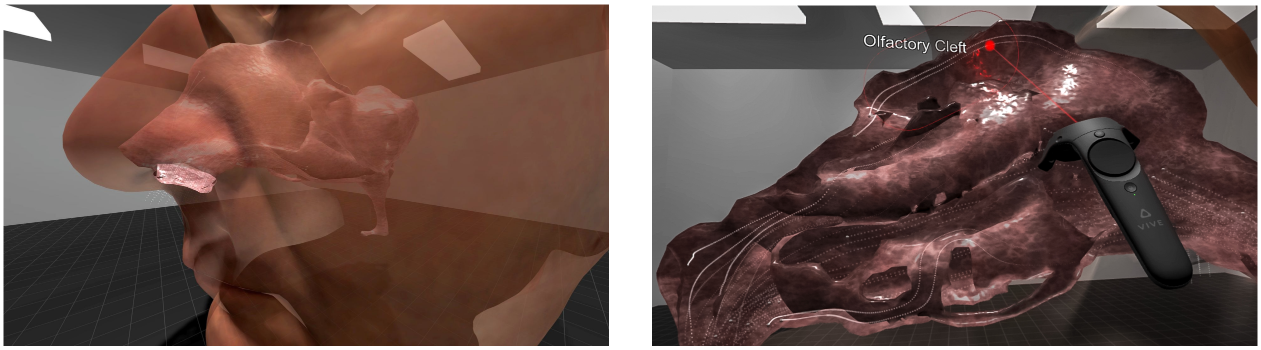

Figure 1: Example of a virtual reality render of the nasal cavity model (left) and an example of highlighting anatomical areas of interest using a hand controller (right).

ABSTRACT

This article explores the application of virtual reality (VR) to the area of anatomical education, specifically the shape of and the airflow through the human nasal cavity. We argue the benefits of VR technology in this specific domain, and describe the creation of the VR application which is intended to be used in future courses. Through two preliminary case studies, we describe our experiences, and discuss advantages and disadvantages of the use of VR in this area.

CCS CONCEPTS

•Human-centered computing → Virtual reality; Information visualization; •Computing methodologies → Virtual reality;

KEYWORDS

Virtual reality, visualization, anatomy, nasal cavity, education

ACM Reference format:
Stefan Marks, David White, and Manpreet Singh. 2017. Getting Up Your Nose: A Virtual Reality Education Tool for Nasal Cavity Anatomy. In *Proceedings of SA '17 Symposium on Education, Bangkok, Thailand, November 27-30, 2017,* 7 pages.
DOI: 10.1145/3134368.3139218

1 INTRODUCTION

The use of virtual reality (VR) in education is as old as the medium itself [Merchant et al. 2014; Winn 1993]. VR offers the opportunity to create virtual worlds with objects that are larger or smaller than in real life, to transcend the limitations of time and physics, to make the unseen visible, and to immerse the educator and students in those worlds to experience and interact with them [Fällman et al. 1999].

The concept of immersion is the strongest argument for the advocates of VR in education [Bailenson et al. 2008; Winn 1993]. Students are not merely bystanders who are presented with a steady stream of symbolic information. Instead, they are situated within the content and can interact with it more naturally than through mouse and keyboard alone [1]. This situated learning experience is argued to provide much more relevant and successful outcomes than other approaches that do not offer such a level of immersion. However, it is important to focus on the strengths of the medium, e.g., the direct interaction with objects through controllers or hand gestures, and to not merely replicate mouse and desktop metaphors in the virtual space [Hedberg and Alexander 1994].

Not every subject is suitable or sensible to be facilitated by VR tools. One has to consider which aspects of the learning experience are best facilitated by the specific properties of VR [Pantelidis 2010]. Two of those aspects which informed our decision to create a VR application for the anatomy of the human nasal cavity are among those listed in Fällman et al. [1999] and Dalgarno and Lee [2010]: variations in size and visualisation of the invisible. We enable

[1] In the context of this paper, we clearly distinguish between true 3D virtual reality that is presented through stereoscopic head mounted displays and controllers that are tracked in space. In contrast, content presented on a flat screen (Desktop VR), even if based on 3D models, does not fall under our definition in this case

our students to explore a structure that is normally only a few centimetres in size by enlarging it 15 times, and we use particles to visualize airstreams through the different regions of the cavity over time. These two aspects are the main advantages over the traditional materials that the students use to learn the structure and shape of the nasal cavity, such as books and plastic models that can be taken apart (see Figure 2).

In this article, we will provide a list of comparable applications and examples in Section 2 and describe the implementation of the 3D nasal cavity model and the VR application in Section 3. Through two preliminary user studies with students elaborated in Sections 4.1 and 4.2, we evaluate the application, and discuss our findings in Sections 5 and 6.

2 RELATED WORK

While we found a large body of work related to virtual reality visualizations of upper body anatomy, e.g., by Tolsdorff et al. [2010], most of them are screen based surgery training tools and reduce the 3D reconstruction of the skull and nasal cavity geometry to a 2D image, therefore falling under the category "Desktop VR".

One step closer to true 3D immersion, Jang et al. [2017] employed a stereoscopic screen setup to visualise inner ear structures. The group found that students who directly manipulated the geometry via a joystick developed a better spatial understanding when compared to students who merely passively observed a rotating model.

The use of fully immersive and stereoscopic visualisation for nasal cavity and other upper body related anatomy is described in Chen et al. [2017], however the article does not go into detail about the use in classes and the authors' experiences.

In contrast, a very detailed evaluation of a VR application in class can be found in Seo et al. [2017], but the specific anatomical domain in this case is the canine skeletal system. Using a constructivist approach, the study compares the effective speed and students' experience when assembling bones using a physical "bone box" and a virtual anti-gravity room. While each student spent roughly the same time in each configuration, they reported more positively on using the VR application.

Figure 2: Traditional resources for learning the anatomy of the nasal cavity: Book [Proctor and Andersen 1982] (background) and plastic model (foreground).

It can be argued that the reasons for choosing the VR application over the physical tool are not as pronounced as in the case of a nasal cavity. Size of a skeletal system is not as much a factor as a nasal cavity. However, the authors list adding animations and muscle systems as their next steps, which would speak strongly in favour of the VR application again.

An example of an immersive VR system for the exploration of the human heart, but without the use of translational tracking is described by Ball and Johnsen [2016]. The application uses the GearVR [Samsung Electronics Co Ltd. 2016] hardware platform and a game controller for navigation and interaction.

3 IMPLEMENTATION

The implementation of our educational VR application was executed in three major steps. First, the 3D geometry of the nasal cavity needed to be constructed from MRI scans. Second, the geometry is used for the flow simulation. Third, we created the VR tool and incorporated the 3D model and the flow simulation data into it.

3.1 3D Nasal Cavity Model

After obtaining ethics approval, we used MRI scan data of one of the primary researchers to create the 3D geometric model of the in-vivo nasal cavity via image processing. Using the process of segmentation in the software ScanIP [Synopsys Inc. 2016], the functional areas of the human nose were created on MRI slices. The generation of the cavity volume involved creating masks, defining the boundaries of the functional areas and painting the areas based on the grey-scale values. Individual MRI slices in sagittal, coronal, and axial planes were used in the segmentation process to ensure the accuracy of the complex nasal geometry. The painting process created voxels on MRI slices which then formed the 3D geometry when stitched together. The final 3D geometric model of the nasal cavity after stitching the MRI slices is shown in Figure 3.

We then converted the nasal cavity volume into a surface model and exported it as an STL file to be used in the VR application (see Section 3.3) and for the following airflow simulation.

3.2 Airflow Simulation

For simulating the airflow in the human nose during human breathing, we performed Computational Fluid Dynamics (CFD) analysis [Mösges et al. 2010] (see Figure 4). The surface model acquired from image processing described in the section above was imported into SolidWorks [SolidWorks 2017]. Using the fluid simulation add-on, we set up the model by defining the computational domain and the boundary conditions, involving net mass flow of the air at the inlet (nares) and pressure at the outlet (pharynx).

The simulation was performed for the full breathing cycle with 2 s of inspiration and 4 s of expiration and resulted in 3D trajectory plots of air particles in the nasal cavity for both processes. We extracted the data from these plots in the form of position and velocity of each air particle in the 3D volume at a given time for the duration of the processes. Together with the 3D geometric model of the nasal cavity, this data was then integrated in the VR scene.

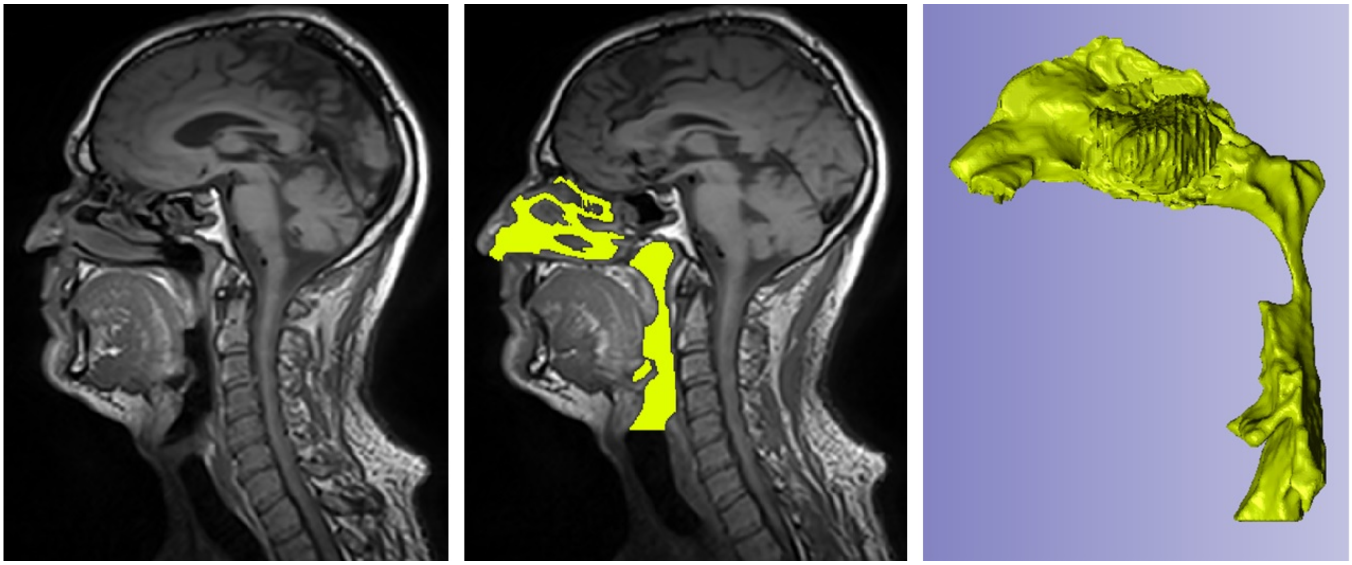

Figure 3: From left to right: MRI scan; Segmented nasal cavity; Extracted 3D model of the nasal cavity.

3.3 Virtual Reality Scene

We combined the 3D nasal cavity surface model and airflow modelling data into a 3D virtual reality scene using the Unity3D engine [Unity Technologies 2017] (see Figure 1). The engine was chosen for two main reasons:

(1) Our facility uses a development and teaching framework that has been developed mainly around this engine [Marks et al. 2014]. This framework allows us to run virtual reality scenarios not only with commercial off-the-shelf hardware such as the HTC Vive [HTC Corporation 2016] or the Oculus Rift [Oculus VR 2016], but also in Sentience Lab, our facility with a motion capture system and wireless head mounted displays (HMD). The framework detects automatically which hardware environment it is started in and adapts the scene accordingly, e.g., to a larger working volume or to different hardware controllers and interaction metaphors.
(2) The Unity3D engine allows for quick prototyping by providing a) import of custom 3D models and b) import of datasets through the in-built C# scripting system. We achieved a fast workflow by creating scripts that could read the file output of SolidWorks directly, allowing us to rapidly iterate several flow simulations and different forms of their visualisations.

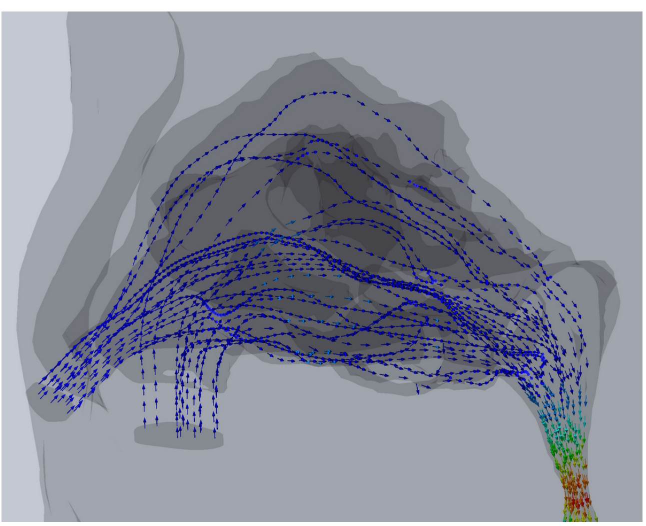

Figure 4: CFD modelling of inspiration airflow in the nasal cavity. Colours indicate the speed of the particles (blue: slow, red: fast).

The 3D model of the nasal cavity was enlarged roughly 15 times so that the nasal cavity could be explored by walking around it in a 4 m × 4 m space, the maximum area possible with the current state of commercial VR systems such as the HTC Vive. In the 3D editing tool Blender [Blender Foundation 2017], we added UV mapping so that we could render the nasal cavity model in Unity with a flesh-like texture, including glossiness and detail that would assist with spatial perception and therefore assist in orientation. By rendering the inside surface solid, and the outside surface darker and transparent (see Figure 5), we attempted to make it easier to distinguish between the actual cavity and the volume that would naturally be occupied by muscle, bone, or tissue. The success of this decision is discussed in the first preliminary study (see Section4.1).

We also added a frontal half-transparent photogrammetry scan of the face of the person whose nasal cavity was scanned to provide an idea of size proportions and the position of the cavity in the human head. Hand controllers were integrated into the 3D scene for interaction. By pressing a button on the controller, a laser pointer is activated that enables the user to point at specific areas of the 3D model which are then highlighted and labelled. For the prototype,

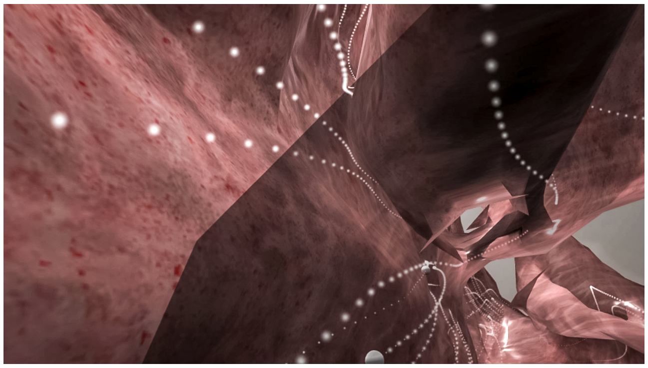

Figure 5: Example of the difference in rendering interior (left) and exterior (right) sections of the nasal cavity.

we highlighted 3 regions: the olfactory bulb (see Figure 1), the sinusoidal cavity, and the nasopharynx.

Since a HMD isolates the user from the audience, the controllers acts as a communication device in that in addition to talking, the user can point out areas of interest with the laser pointer, or follow trajectories with the controller to emphasize specific streamlines. The opposite way of communication is also possible for the audience by taking a controller and indicating objects to the user under the HMD. This requires clear view of the screen, e.g., by using a projector.

We also added sound to the visualisation to distinguish the inspiration and expiration cycles. This was achieved by recording breathing sounds, separating them into the two phases, and playing them back slowed down to 25 % of the original speed to match the duration of the particle simulation.

4 EVALUATION

Due to the advanced stage of the semester at the completion of the VR model, we were only able to evaluate the suitability of the nasal cavity model through two preliminary studies:

(1) A group of year 4 students of Mechanical Engineering who were exposed to the VR application in addition to the standard lecture material.
(2) Two Bachelor of Engineering Technology students in their final year project tasked to design a nasal stent that can be 3D printed.

A more detailed study that involves a comparison of using the VR application against a control group is planned as the next iteration of this project (see Section 5).

4.1 Classroom

The first preliminary evaluation involved a group of year 4 students of Mechanical Engineering in an elective Biomedical Thermofluids Modelling class. Prior to the introduction to the VR application, the students had used 2D drawings from textbooks to gain understanding. To provide sufficient space required for exploring the VR application, we chose a dedicated performance space in the institution, a 10 m × 15 m empty room with facilities for projection and sound. An independent observer took notes during class so that the primary researchers could fully concentrate on the students and the content (see Figure 6).

We started with an open and transparent introduction of the students to the project and the technology, and gave a health and safety briefing around the possible risks of using VR equipment, such as disorientation and simulator sickness [Kolasinski 1995]. The students appeared engaged due to the unusual nature of the class, the new location, and the equipment.

The lecturer then summarised the content of the last lecture, provided a transition to the anatomy of the nasal cavity, and explained the origin of the 3D model and flow simulation the students were about to see. He then equipped the HMD and started a guided tour through the model, beginning at the outside, in front of the face, and "working" his way into the complex structures of the cavity.

Due to the video projection of the point of view of the HMD and the audio, the students effectively experienced an interactive video of the anatomy of the nasal cavity, including the lecturer's explanations, and the opportunity to ask questions and to guide the viewpoint for further discussions. However, because the HMD blocks any direct eye contact with the students, this method requires a certain amount of classroom discipline and trust on the lecturer's side.

After the initial explanation, students were invited to experience the VR application by themselves. Initially, this was met with hesitance, most likely due to the fear of embarrassing oneself in front of the class by wearing a HMD and moving so as to look at something that is only indirectly apparent on the screen to the other students in class. However, after the first volunteer started exploring the nasal cavity, the full strength of the VR application became evident as now the lecturer could interact not only with the class but also incorporate the exploring student's comments and guide his or her attention and explorations. Most students were even more engaged through this mode of delivery, although we also observed a certain amount of distraction caused by amusement in observing their classmate moving around in the seemingly empty physical space.

The students who engaged with the VR version of the nasal cavity commented positively on the realistic and near tangible nature of the 3D model through the use of the controller. Several comments addressed the aspect of increased understanding of the shapes of the nasal cavity compared to 2D drawings or videos. Especially proportions of volumes of space became much more apparent to them.

Initially, most students demonstrated slow and sparse movements within the VR world, but over time most of them gained confidence and moved around more. We observed a larger hesitance in students for whom this was their first experience, specifically when having to move "through" seemingly solid surfaces, but overall, the navigation within the VR space and the use of the controller appeared intuitive and did not require much explanation.

Unknown to the researchers, the VR computer had become unstable due to an automatic recent graphics card driver update, which resulted in crashes of the VR application after about 2 minutes into the experience. Disruptive as this problem was, it highlighted two aspects. First, the audible disappointment of the students at each crash confirmed their high engagement. Second, it was of advantage to have one of the researchers available to reboot the

Figure 6: Photo of the classroom study. A student is navigating the 3D model while the lecturer guides him and points out to the class what they are seeing. An independent observer (left) is taking notes.

system while the other was able to "hold the class" and continue the topic and the train of thought.

A feedback round at the end of the class brought some additional aspects to light for improving the VR application. Since the viewpoint of the projected video for the class was driven directly by the head movement of the exploring person, it was jerky and rapid, making it difficult for the students to watch and to follow. In a few cases, the students even had to look away to avoid nausea. A solution to explore in future evaluations is the addition of a secondary camera view that is driven by smoothed and filtered HMD movement, possibly even avoiding rolling around the camera's Z axis.

A second problem that was mentioned by more than one student was the difficulty to discern between the interior and exterior of the nasal cavity (see Figure 5). We will have to explore additional options of rendering those two features to make orientation and navigation easier. One solution suggested by the students is to render the tissue and bone volumes solid, but that would obstruct the view of everything else and possibly lead to disorientation in those volumes. Possible alternative solutions, e.g., tinting or additional geometry for bone and muscle volumes needs to preserve the possibility to look at the entirety of the structure of the nasal cavity from the "outside".

A week after the exposure of the class to the VR application, the lecturer was able to get additional feedback from the class. He reported a fascination with the topic itself that he had not seen in the occurrences of the classes before. The students' enthusiasm was unlocked, discussions around the topic flowed more freely, and the students demonstrated a deeper understanding of the material through their questions and answers, e.g., around the flow of air in the olfactory cleft, and forming of vortices in the nasopharynx during expiration.

4.2 Project Work

A second opportunity to get preliminary feedback for the VR application were two Bachelor of Engineering Technology students in their final year project tasked to design a nasal stent that can be 3D printed. Prior to experiencing the VR application, they had gathered information about the nasal cavity structure from books and 2D videos of endoscopic procedures.

Before their first experience with the application, they were also briefed on the health and safety risks of VR. They then commenced to explore the nasal cavity structure for their research. Their first comments revolved around the unexpected complexity of the shapes that were not apparent through their previous learning materials. To that point, the students were not aware of how the shape of the nostril transitioned from round and open at the nares to narrow and curvy structures in the turbinal.

Discussions among the students around these shapes using the VR application as a communication tool. The person in VR used the hand controller to point out pathways and objects on the screen, while the student outside used the second controller and the screen used to communicate his ideas "back into VR". The students were quickly able to develop ideas around 3-dimensional shapes of the stent to be designed using the VR application. We discussed a methodology for rapid prototyping designs of the stent by simply bringing them into the 3D domain and trying to fit them using the hand controller. The ability of the Unity3D engine to quickly import new 3D files and to also swap geometry on the fly would support this methodology. The simulation of soft tissue deformation by the stent would not be natively supported by the application, but this feature could either be extended in a separate research project or the switch to such simulation tools could be a second stage after the initial shape exploration using the VR application. This could potentially reduce the number of computationally expensive simulation iterations.

5 DISCUSSION

The qualitative feedback from the preliminary studies indicates that the educational VR application for nasal cavity anatomy is useful and has advantages for the students in terms of engagement and understanding and retention. We will explore this hypothesis further in the next stage of this project where we will quantitatively and qualitatively compare the different forms of content and delivery.

Because the 3D nasal cavity model was created from MRI scans of one of the lecturers of the students, we further hypothesize that the model carried a specific relevance for the student. It is not merely a 3D model created by an unknown 3D modeller. It is part of a person they know, and it has been processed by a postgraduate student in their area of study. Factors such as these are important for increasing relevance of content and motivation of students [Knowles et al. 2005, p.149].

In addition, this form of content creation serves a dual purpose in that it provides postgraduate students with the relevant and challenging task to acquire and post-process 3D models that can then be used in undergraduate or even postgraduate teaching. We found that by connecting undergraduate and postgraduate students through projects and exchange of experience, students develop a higher motivation and is it also more likely for undergraduates to continue into postgraduate studies.

The project was interdisciplinary by nature in that it involved engineering, biology, and computer science. While this posed some challenges for staff and students in communication and the understanding of each others' topic areas, it was also a powerful learning experience for all and a showcase for interdisciplinary work between different schools of our institute which is increasingly encouraged. FOr the next stages of this project, and possible spin-offs, we will include other disciplines such as digital design and communications, increasing not only the quality and usability of the product, but also creating more opportunities for project-based learning in other disciplines.

The problems with the stability of the hardware highlighted the negative sides of introducing more technology into the classroom. Any tool used in education needs to be stable. At the least, the lecturer needs to have backup plans. The stakes are even higher if those tools are vital for any form of assessment. Any application needs to be easy and intuitive to use so that the attention of the lecturer is not diverted from holding the class or the attention of the student is not diverted from the actual content.

With respect to stability and cost, a book, a plastic model, or a YouTube video have clear advantages. The investment into VR technology only makes sense when it is used not only for a one-off project, but is consistently integrated into courses of one or even more disciplines. One option, which is implemented in our institution, is to provide a dedicated facility that houses this technology and can be used by several schools as a resource.

As an alternative, VR content can be deployed on lower cost devices such as the students' mobile phones through frameworks such as Google Cardboard [Google Inc. 2017a]. Google Expeditions [Google Inc. 2016] is an example where students use smartphones with cardboard viewers, and the teacher controls the content that they are viewing. Through a controller application, the teacher can decide on the progress through the 3D content, and has feedback as to what the students are actively looking at. However, at least at the moment, this technology has two major drawbacks: For one, due to the lower hardware capabilities of smartphones, the quality of the content cannot be as detailed as when using dedicated VR computers. Second, the user is currently only free to look around in a scene in all directions, but cannot actively move around by using body movement. This will change with the advent of inside-out tracking technologies such as in the Microsoft HoloLens [Microsoft 2017], Occipital's Structure Sensor [Occipital Inc. 2017], or Google Tango [Google Inc. 2017b], and increasingly powerful rendering hardware in mobile devices. Regardless, the concept of some form of central control application and monitoring of student behaviour in the VR space is useful and another option to be integrated into a future version of our application.

6 CONCLUSION AND FUTURE WORK

We have presented an educational VR application for the exploration of the nasal cavity structure and anatomy, including the process of the shape acquisition, the design of the application, and two preliminary evaluations involving students. The feedback was very positive and encouraged us to pursue this project to create an improved version that has more features and anatomical landmarks, clearer distinction between inside and outside areas, smooth camera movement, etc. We will improvethe application accordingly and use it to follow up our preliminary studies with a full user study including ethics for comparing the conventional use of course material (videos, written) with use of the 3D application.

7 ACKNOWLEDGEMENTS

For obtaining and processing the MRI scans, we applied for and were granted ethics approval under the number AUTEC 10/121.

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Received June 2017; accepted August 2017