Advances in Experimental Medicine and Biology 1171

Paul M. Rea *Editor*

Biomedical Visualisation

Volume 4

Springer

Advances in Experimental Medicine and Biology

Volume 1171

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ISSN 0065-2598 ISSN 2214-8019 (electronic)
Advances in Experimental Medicine and Biology
ISBN 978-3-030-24280-0 ISBN 978-3-030-24281-7 (eBook)
https://doi.org/10.1007/978-3-030-24281-7

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Preface

The utilisation of technologies in the life sciences, medicine, dentistry, surgery and allied health professions has been utilised at an exponential rate over recent years. The way we view and examine data now is significantly different to what has been done perhaps 10 or 20 years ago.

With the growth, development and improvement of imaging and data visualisation techniques, the way we are able to interact with data is much more engaging than it has ever been.

These technologies have been used to enable improved visualisation in the biomedical fields but also how we engage our future generations of practitioners when they are students within our educational environment. Never before have we had such a wide range of tools and technologies available to engage our end-stage user. Therefore, it is a perfect time to bring this together to showcase and highlight the great investigative works that are going on globally.

This book will truly showcase the amazing work that our global colleagues are investigating, and researching, ultimately to improve student and patient education, understanding and engagement. By sharing best practice and innovation, we can truly aid our global development in understanding how best to use technology for the benefit of society as a whole.

Glasgow, UK   Paul M. Rea

Acknowledgements

I would like to truly thank every author who has contributed to the third edition of *Biomedical Visualisation*. By sharing our innovative approaches, we can truly benefit students, faculty, researchers, industry and beyond in our quest for the best uses of technologies and computers in the field of life sciences, medicine, allied health professions and beyond. In doing so, we can truly improve our global engagement and understanding about best practice in the use of these technologies for everyone. Thank you!

I would also like to extend out a personal note of thanks to the team at Springer Nature who have helped make this possible. The team I have been working with has been so incredibly kind and supportive, and without them, this would not have been possible. Thank you kindly!

About the Book

Following on from the success of the first three volumes, *Biomedical Visualisation*, Volume 4, will demonstrate the numerous options we have in using technology to enhance, support and challenge education. The chapters presented here highlight the wide use of tools, techniques and methodologies we have at our disposal in the digital age. These can be used to understand imaging of the human body and help educate patients, the public, faculty and students in the plethora of how to use cutting-edge technologies in visualising the human body and its processes, the creation and integration of platforms for teaching and education, and biological structures and pathological processes.

Chapters 1, 2, 3, 4, and 5 Education

The first five chapters examine a range of tools and technologies that can be used in anatomical, medical and bioscience education. These include screencasting and video for anatomical education; the role of xR visualisations, virtual patients, student-centred online e-resources and MOOCs; and what the current and future trends in this field are.

Chapters 6 and 7 Applications

The sixth and seventh chapters examine ways to utilise technologies in digital reconstruction, visualisation and anatomical examination to enhance the understanding of structures and their relations.

Chapter 8, 9, and 10 Interactive Technology

The final three chapters detail how to use technology in engaging patients and the wider public. The first of these chapters discusses a workflow methodology that can be used to create an interactive app for patient’s newly diagnosed with pancreatic cancer and demonstrates how this can be applied to different clinical scenarios. The penultimate chapter shows how an augmented reality tool can be used to educate children about skeletal anatomy and broken bones. The final chapter highlights how technology can be used to engage the public in bioscience education.

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About the Editor

Paul is a Professor of Digital and Anatomical Education at the University of Glasgow. He is qualified with a medical degree (MBChB), a MSc (by research) in craniofacial anatomy/surgery, a PhD in neuroscience, the Diploma in Forensic Medical Science (DipFMS), and an MEd with Merit (Learning and Teaching in Higher Education). He is an elected Fellow of the Royal Society for the encouragement of Arts, Manufactures and Commerce (FRSA), elected Fellow of the Royal Society of Biology (FRSB), Senior Fellow of the Higher Education Academy, professional member of the Institute of Medical Illustrators (MIMI) and a registered medical illustrator with the Academy for Healthcare Science.

Paul has published widely and presented at many national and international meetings, including invited talks. He sits on the Executive Editorial Committee for the Journal of Visual Communication in Medicine, is Associate Editor for the European Journal of Anatomy and reviews for 24 different journals/publishers.

He is the Public Engagement and Outreach lead for anatomy coordinating collaborative projects with the Glasgow Science Centre, NHS and Royal College of Physicians and Surgeons of Glasgow. Paul is also a STEM ambassador and has visited numerous schools to undertake outreach work.

His research involves a long-standing strategic partnership with the School of Simulation and Visualisation The Glasgow School of Art. This has led to multi-million pound investment in creating world leading 3D digital datasets to be used in undergraduate and postgraduate teaching to enhance learning and assessment. This successful collaboration resulted in the creation of the worlds first taught MSc Medical Visualisation and Human Anatomy combining anatomy and digital technologies. The Institute of Medical Illustrators also accredits it. This degree, now into its 8th year, has graduated almost 100 people, and created college-wide, industry, multi-institutional and NHS research linked projects for students. Paul is the Programme Director for this degree.

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Assessing the Role of Screencasting and Video Use in Anatomy Education

Scott Border

Abstract

The subject of anatomy, commonly taught with applied clinical focus on medical programmes, is frequently brought to life alongside art, imagery and visualization. Yet, despite being continually hailed as the cornerstone of medicine, the cyclic revalidation of its curricula has often found its educators in the unenviable position of maintaining knowledge standards in the face of reduced contact time. However, the gravity of such challenges has created an opportunity for creative and innovative solutions to these problems. The ease by which educational technology can now be used by non-experts is constantly increasing and the use of technology enhanced learning has now become universal within Higher Education. Many anatomical science educators have turned to building bespoke interactive and engaging online supplementary material which can be blended with face to face delivery as a way to circumvent the time pressure issues. Today's students appear to have a growing preference for visualising moving images and audio explanations as opposed to older traditional static resources, underpinned by vast pages of unattractive dense text and pictures. One such technique being used to provide flexible and student-centred learning is screencast videos. These digital recordings of screen captured drawings, with accompanying narration are overwhelmingly popular with students and on the ascendance. However, as new tools emerge, it becomes increasingly important to determine their impact on both the student experience and knowledge gain. It is also valuable for educators to share their classroom experiences or instructional techniques to optimise their use for learning. This chapter explores the rise of this application in anatomy education and discusses the evidence available investigating student engagement and learning outcomes in the context of well-established learning theories.

Keywords

Screencast · Screen capture · Anatomy education · Educational video · Theory of multimedia learning · Blended learning · Technology enhanced learning anatomy drawing · Whiteboard tutorials · Soton brain hub · Flipped classroom

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P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7_1

1.1 Introduction

The use of images in gross anatomy education have evolved significantly throughout its history. An issue with some of the earliest illustrations was the incorporation of erroneous detail that relates not to observation but to the prevailing medieval and mystical views of the time (Moxham and Plaisant 2014). So, despite being visually appealing, they were not suitable for education purposes. Since the Renaissance, De Vinci in particular, produced anatomical drawings of impressive accuracy. It has only fairly recently been revealed that De Vinci was in fact a talented anatomist in addition to his legendary status as an artist (Jose 2001). When viewing some of his most notable works, his passion for the subject is clearly evident through his intentions to record both the structure and function of human anatomy, with detailed drawing collections consisting of multiple angle views of the same structure along with extensive annotations to support them (Clayton 1993; Clayton et al. 2012).

The rise of Universities and the subsequent development of The Medical School witnessed a demand for the reproduction of texts, particularly because dissection was yet to become common place, or at least, it was largely an infrequent exercise in the majority of institutions during the time (Moxham and Plaisant 2014). Artists who were also responsible for some significant anatomical discoveries were later replaced by graphic illustrators as the pedagogy surrounding anatomy educational approaches intensified (Petherbridge et al. 1997). In the modern era, today's diagrams have been overly simplified and in the vast majority of cases are computer generated. As such, this has resulted in illustrations becoming less lifelike and realistic, in favour of layered schematic computer rendered representations that facilitate digestible learning and consolidation of knowledge (Tsafrir and Ohry 2001).

For many decades anatomical textbooks have been the most essential tool for supporting its education, but due to time constraints placed upon the majority of anatomy curricula (Drake et al. 2009), the teaching of anatomical sciences in the twenty-first Century has become a 'hot spot' for technology enhanced learning innovations (Trelease 2008; Sugand et al. 2010; Stewart and Choudhury 2015;). Moreover, there is currently a growing online community of anatomists who regularly engage with their students (and each other) via social media as a way to develop knowledge, answer questions, share resources and exchange views.

It was reported fairly recently in the literature by Jaffar (2012) that 98% of students use You Tube as an online information resource. A number of studies have since followed, scrutinising the use of other social media platforms in anatomy education (Jaffar 2014; Barry et al. 2015; Hennessy et al. 2016; Pickering 2017). The mounting literature on the use of videos in learning anatomy is both supportive and sceptical in equal measure (Saxena et al. 2008; Mahmud et al. 2011; Topping 2014). Advocates claim it enhances the student experience and used appropriately can become a useful addition to the anatomist's teaching toolkit. Sceptics however are concerned with the passive nature of excessive video use, which can potentially contribute to an artificial gain in subject confidence.

There is currently a paucity of evidence substantiating the use of many technological innovations in anatomy education (Clunie et al. 2018). However, the application of screencasts and video use fit well with the cognitive theory of multimedia learning and should be investigated thoroughly to see if they can become complementary to an effective and efficient means of instruction within the field of anatomical sciences (Pickering 2015).

1.1.1 What Is the Difference Between a Screencast and an Educational Video?

A screencast is a video screen capture from your computer, tablet or smartphone which is narrated with audio, providing instruction for the learner (Ghilay and Ghilay 2015). Common examples include tutorials, slide sharing and video lessons (Carmichael and Pawlina 2000). However, what distinguishes a screencast from a video is that the lesson begins as a blank screen which builds in complexity alongside the audio explanations to provide a rich multimedia presentation (Pinder-Grover et al. 2011). By the time the lesson is complete the screen may appear complex and possibly disordered, but for those who have viewed it in its entirety, it will have most likely succeeded in delivering all of its learning objectives (Greene 2018). In the majority of cases screencasts are not intended to be high in production value, nor do they rely upon the artistic skill of its creator. They provide a versatile and flexible alternative to what many educators do live in the classroom using whiteboards (Pickering and Roberts 2018). In anatomy, it is an opportunity to transfer the popular drawing element of didactic lectures into a mobile format to promote flexible learning (Pickering 2017). In contrast, an instructional/educational video will usually be a polished short programme that may utilise pre-existing animations, images and/or transitions to provide a seamless narrative. A video is usually subject to hours of post-production editing and sequencing before it is ready to be viewed and may even involve narration by a non-subject specialist who is reading from a script. In a study at Southampton only 41.7% of students were aware of the differences between a screencast and educational video, despite greater than a third (37.5%) using YouTube videos as their 'first port of call' when learning something new in medicine or an allied healthcare subject (Scantling-Birch et al. 2018).

1.1.2 Using Screencasts and Video in Education

Screencasts and video have been utilised by educators in a variety of higher education disciplines and settings, including mathematics (Ellington and Hardin 2008), computing programming (Phillips and Billings 2007; Sugar et al. 2010), statistics (Lloyd and Robertson 2012), chemistry (Musallam 2010) and engineering (Green et al. 2012). According to the theory of multimedia learning it is the combination of auditory and visual information that enhances the learners experience over that of more traditional methods (Mayer 2002). The rationale for the use of multimedia teaching is that by presenting moving images with synchronised audio instruction minimizes the cognitive load burden (Pickering 2017). Learners are prompted by the narrator to the most relevant aspects of each visual, through a narrative driven process which subsequently reduces the extraneous load (De Koning et al. 2007).

The benefits can be broadly defined as increased flexibility for students and providing a viable option for increasing support, providing added value and enhancing the student experience (Oud 2009). The intention is not for these resources to replace face to face contact time; an issue which is timely, during an age where fee paying students are very conscious of the quality of staff engagement within their curriculum. There is however, a risk, that by offering up alternative methods of learning through approaches such as screencasting that this will have a negative impact on attendance (Mullamphy et al. 2010). Nevertheless, student's decision making on whether to attend lectures or not appears to be far more complex and is reported as not being dependent upon available technologies (Billings-Gagliardi and Mazor 2007). Conversely, if this approach is overused or used inappropriately it is possible that students may feel that their education has become 'distance learning' which will be seriously misaligned with their expectations of the course and cause dissatisfaction which may be reflected in module evaluations or even National Student Survey scores (Mullamphy et al. 2010).

1.1.3 How Effective Are They and Do Students Engage with Them?

The efficacy of screencast use is one of the central issues regarding its decision for implementation. Comparable studies from other disciplines should ideally mirror the cohort size and diversity of students as reflected by those studying clinical anatomy as part of a BMBS degree programme. In a large cohort study on engineering students by Pinder-Grover et al. (2011) it was reported that student's assessment performance significantly correlated with screencast use, and that it worked particularly well for students who may have been provided with less familiarity than other students on the programme. A follow up study was consistent with this report (Green et al. 2012). In relation to medicine, this may suggest screencasts could be deployed as part of widening access entry courses to medicine, or for postgraduate entry programmes that select from diverse backgrounds. In a further study, the authors provided reasons for why some students do not use screencasts. Those who reported not using them, chose to do so because they did not need additional assistance and already had a good grasp of the material (Pinder-Grover et al. 2011). One of the most difficult aspects of designing ethically valid methodologies within live curriculums is to simultaneously maintain an equitable learning experience for all students. Ideally, hypothesis driven research requires the testing of a null hypothesis, with a valid control group, which is often difficult to do in such a setting. However, this was achieved by Morris and Chikwa (2014) who were able to conclude a statistically significant positive 'screencast effect' with the experimental group outperforming the non-user control group academically. However, this still remains a single centre study and further work is essential to replicate this finding before it is possible to generalise. Although, more recently Greene (2018) has reported positive significant differences in course performance based on screencast use in anatomy education.

1.1.4 Impact of Screencasts Video on the Student Experience

Results from our own studies have revealed that 97% of students (n = 165) perceived the screencasts as being useful, while 75% of users felt that using them helped to achieve a higher examination grade (Pilborough et al. 2017). There is also some support of the view that their availability can alleviate stress and anxiety by allowing students to revisit material they had not fully understood from attending lectures (Winterbottom 2007; Morris and Chikwa 2014). The majority of satisfaction surveys conducted on screencast use are overwhelmingly favourable across a number of disciplines including anatomical sciences (Evans 2011; Mohorovičić 2012; Wakeman 2013; Pickering 2017). Despite these high satisfaction scores, the evidence from student feedback continually suggests that students do not want them to replace contact time with staff (McGarr 2009; Morris and Chikwa 2014). The study by Evans (2011) highlighted student's usage and reaction to their introduction on an embryology course. It was demonstrated that students did utilise them in a flexible way, accessing them both day and night, which is consistent with findings from Nieder and Nagy (2002). The students cited that they were useful for learning and were a very good supplementary resource to support lectures. Students used them most extensively for revision purposes – a finding also reported by our research at Southampton by Pilborough et al. (2017). Although, in our study, as much as 52% of subjects stated that they used them in advance of lectures too, for frontline learning.

1.1.5 Screencasting and the Cognitive Theory of Multimedia Learning (CTML)

As education looks towards technological advances to provide its innovative solutions, it becomes increasingly important to make sure those solutions are robustly grounded in pedagogy (Clunie et al. 2018). To convincingly advocate for instructional technologies to supplement our traditional resources, or even to be used as alternatives, we must understand how multimedia tools can enrich student learning.

Screencasting fits rather well with the guiding principles of this theory which essentially states that the learner has two distinctively separate systems which can be accessed during learning: a visual information processing system and a verbal information processing system. It is better to present explanations in words and images rather than just words, and in fact, both anatomy textbooks and videos do this rather well (Mayer 1989; Mayer and Gallini 1990). However, what screencasts can offer that textbooks can't is the contiguity factor – the idea that when the images and the words are presented together it is more effective for learning than if they have to be separated by paying attention to one and then the other in a sequence (Mousavi et al. 1995). Although this will work better if the relevant text is positioned near the picture in a textbook, it is still not as effective as when the most relative information to the image is heard at the time of viewing it – the more contiguity, the easier it is for working memory processing to assemble associations between them (Sweller and Chandler 1994; Mayer and Moreno 2003).

Furthermore, if the words are provided via narration it is more beneficial than on screen text. This is referred to by Meyer as the split attention principle – the concept that overloading the visual processing system is detrimental to learning, so the act of having the words spoken means that words are processed by the verbal information system and the animation in the visual system (Mayer 2002). It has been suggested that keeping screencasts and videos focussed on a single topic aligns very well with the coherence principle (Mayer and Moreno 2003; Pickering 2017).

Interestingly, within the theory of CTML there is evidence for a redundancy effect, whereby inserting additional details can distract from the main learning objectives. The theory is consistent with the idea that shorter more concise screencasts and videos and better outcomes for learning (Bobis et al. 1993). Such a theory resonates well with the average view time statistics from The University of Southampton's Soton Brain Hub channel (Lowry et al. 2016), where the average view length is 2.16 min with individual video length ranging from 1.31 min to 31.15 min across 105 videos. Results from our own studies indicate that video length is a major determining factor in the number of times a video will be viewed ($r = -0.43$, $P = 0.04$) as is the percentage of the video watched before the student exits the resource ($r = -0.78$, $P < 0.001$). This evidence enables us to tailor our future videos to better meet student needs and facilitate their learning. As a result of this we have since reduced the duration of all of our videos.

Essentially, both meaningful and deep learning can occur using either printed words or narration. The real advantage of using multimedia instruction over traditional text resources is that when designed appropriately they can serve to help reduce the risk of cognitive overload (Clark et al. 2011). Our brains have a limit to their speed and efficacy of cognition and unfortunately processing demands encountered during learning can often overload it. (Mayer and Moreno 2002). The challenge for those developing multimedia tools is to develop them so off load some of the cognitive burden placed on a single channel. One solution which screencasting can offer is to present words as narration – a process of reassigning cognitive responsibility from the visual channel to the verbal channel. This model of reducing cognitive load is well supported by the literature, suggesting that students performed better on objective learning outcomes measures when this was the case (Mayer and Moreno 1998; Moreno et al. 2004). This model fits well with the literature on effective methods for learning clinical anatomy, which is a subject rich in detail and requiring spatial ability (Smith et al. 2017).

Another overload scenario which screencasting can successfully neutralise is the segmentation effect. Cognitive load can be reduced by offering information in bite sized chunks (Mayer and Moreno 2003). Screencasts and videos offer very obvious and natural segmentation of information; their titles attempt to tackle one issue at a time and are arranged into discrete playlists. Although text books are organised in a logical chapter sequence, they are less well signposted and discernible to the learner. The tendency for them to have a focussed emphasis weeds out extraneous material. Since the words are being narrated attention to specific aspects of each videos can provide cues which also leads to better knowledge transfer (Moreno 2007).

In summary, there is sufficient empirical support for the role of the theory of CTML in effective in the ways in which students learn. We can additionally conclude that the use of screencasting and video tools can meet the challenge of reducing aspects of cognitive load. Therefore, it will be important for educators to develop these applications with cognitive load sensitivity in mind for them to be optimised for student learning.

1.1.6 Using Screencasts and Video to Learn Clinically Orientated Anatomy

The use of screen casting and video in anatomy education is appealing because it is a very visual subject. The curriculum is dense and compact so supplementary resources to use outside of the dissecting room are welcomed by students, so they can utilise them at their own pace. A study by Evans (2011) showed that their use was well received when used as a miniseries to teaching embryology. The students recognised the resources as both useful for learning and good support for lectures. Interesting the most popular time for downloading the screencasts were between 8 and 9 pm and were most frequently downloaded in the fourth quartile which was the closest to the assessment. Most importantly, there was a significant improvement in assessment scores from the student cohort who had access to the screencasts compared to those who didn't.

The sustained application of screencasting technologies has been led by Dr. James Pickering, an associate Professor in anatomy and National Teaching Fellow at Leeds University. His work (Pickering 2015, 2017) has channelled the rationale for screencasting based upon the constraints of teaching anatomy within modern medical curricula. The time dedicated to anatomy education has receded and intuitions are required to maintain the quality of their teaching standards with less time in the curriculum to deliver it (Turney 2007). This issue has been a well-known, prolonged and persistent concern of anatomists in the United Kingdom for many years. Having scrutinised usage data of his own screencasts produced on the topics of the vascular supply to the pelvis, autonomic & somatic nerves of the pelvis, muscles of the pelvis the perineal pouches. It was concluded that 93% of students accessed these anatomy screencasts. Comments from students and usage analytics compare well with the study by Evans but in contrast, no notable increase in assessment scores was reported. However, greater insight into the student experience was achieved, with students stating a preference for these over traditional resources such as textbooks and searching the internet.

In Pickering's follow up study the focus shifted to measuring learning gain in a study comparing screencasts with traditional textbook resources. The paper concluded that this format of multimedia learning which are based on the principles of the CTML provide greater knowledge retention compared to studying the still images and associated text in a textbook. Such a finding came at a critical time for the field since the growth of technology enhanced learning resources has been rapid in the disciplines of anatomical and medical education. One particular strength of this study was the thoroughness of its statistical analysis, accounting for both normalised learner gain and effect size.

Our current investigations in the field of clinical neuroanatomy education support the view that screencast use is hugely popular. When incorporated into an undergraduate medical curriculum, students found supplementation of existing teaching with Soton Brain Hub resources more popular than anatomy practical sessions alone ($P < 0.001$) (Lowry et al. 2016), but we have been unable to reproduce a positive screencast effect when comparing them with matched interactive video and traditional text book resources (Scantling-Birch et al. 2018). Our findings suggest that interactive videos do not offer an advantage for learning gain as some educators have predicted. Nevertheless, they did offer a non-significant improvement in retention suggesting the possibility of deeper learning processes at the time of study (Smith et al. 2017).

1.1.7 The Innovative Applications of Screencast/Videos in Anatomy Education

There is a desire for flexible learning opportunities by the majority of students in higher education. They enjoy the ability to access materials from outside the University at unusual times of the day and night (Evans 2011). The benefits of this strategy is that students can now easily view material which is instantly configured and compatible with computers, tablets and smartphones. With the increasingly reliability of 3G and 4G mobile connections and wireless connections, these resources are readily accessible. Another advantage, is that videos can be paused, rewound and replayed. This can be a good strategy for courses such as medicine which are fast paced, rich in detailed information and demanding in longitudinal knowledge retention. Students have often reported that in head and neck and clinical neuroanatomy education the videos reduce apprehension, stress and anxiety due to minimising the risk of missing important content, due to well-known difficulty of the topic (Kramer and Soley 2002; Hall et al. 2018a, b).

Teaching staff are able to track and follow which resources are most popular which enables them to inform their own teaching practices and use screencasts to integrate with face to face teaching. One popular innovative application is through the flipped classroom approach where students gain exposure to some of the material before the lesson (often a principle or concept) Missildine et al. 2013. The face to face session is then used for synthesising, analysing or problem solving using knowledge gained from the pre-learning material. This allows for the contact time to be less didactic and more engaging (Chen et al. 2017). Although this technique is not specific to the use of screencasts or video per se, these resources do provide more of an incentive than reading text as a way of preparing for the session beforehand and increase the probability that it will be successful. There has been an increase in the number of reports of flipped classroom use in medical education, many of which involve screencast/video use (Lin and Hwang 2018). It is considered effective, not least of all because the current evidence suggests that pre-learning exercises are successful in reducing intrinsic load (Musallam 2010). The flipped classroom approach might be considered part of a wider definition applied to the incorporation of teaching approaches within the content of a single course or module called blended learning (Osguthorpe and Graham 2003; Graham 2006). The important aspect of this approach is that the online material is tailored and signposted by the educator and integrated into their learning, rather than just being a repository or collection of resources online for students to self-select. There is a distinct difference between adopting this approach and simply embedding videos as part of your lecture slides to illustrate an example of something (Valiathan 2002). When used appropriately it can yield a learning advantage over traditional delivery in anatomy education (Pereira et al. 2007). At the University Southampton this approach has been used to transform the student experience in teaching histology and has had a positive impact on assessment performance (Paterson et al. 2015; Morton et al. 2016).

An example of one innovative approach was to create Quick Response Codes (QR codes) for videos and place them on lecture handouts and/or in practical workbooks. This method of signposting prompts the student to access the screencast/video at the most appropriate time as guided and advised by their academics. They have been used both successfully in a dissection room setting (Traser et al. 2015) and with associated lectures and laboratory workbooks at Southampton (Elmansouri et al. 2018). In particular, our study demonstrated that QR codes are used by students most when blended with traditional delivery of information rather than in isolation. However, many students still prefer to search for videos themselves using desktop computers rather than mobile phones.

On occasion it might be appropriate for entire components of a module to be taught through e-learning packages that include video episodes to be watched in sequence. This has been the case at Southampton where aspects of medical embryology and taught via a mini series of screencasts which is presented as a playlist in YouTube. To promote inclusivity the still images were also presented alongside a transcript of the audio and presented as an interactive e-booklet using Microsoft Sway™ (Sidebottom et al. 2016). This is a smaller scale approach of a method used extensively in the field of Massive Open Online Courses (MOOCs) (Swinnerton et al. 2017).

Another innovative approach to developing and using screencasts is through Peer Assisted Learning. The benefits of face to face peer instruction are well established in anatomical sciences (Evans and Cuffe 2009; Tayler et al. 2015; Stephens et al. 2016; Harrison et al. 2017; Border et al. 2017) but this application can be extended to include online peer delivery and there is no reason to believe that the benefits of this intervention cannot be transferred to online teaching. Students have a level of natural cognitive and social congruence with the learners and will explain things using alternative terminology which may be helpful with more difficult subject matter (Lockspeiser et al. 2008; Hall et al. 2014; Hall et al. 2018a, b). Furthermore, students enjoy the creative nature of making screencasts and are familiar with application based editing software for film and audio. For the student creators, the perception is that it reinforces and strengthens their knowledge in the same way that traditional peer teaching would do (Pilborough et al. 2017). However, the benefit is that their resource can continue to be used once they have moved on and graduated, so it negates the sustainability issue of planning and delivering such programmes year on year.

1.1.8 Instructional Strategies for Screencast Creation

Having provided some evidence for the effectiveness of screencasting in higher education, and more specifically within the field of anatomical sciences education it would be sensible to provide some important considerations for those educators wishing to pursue this avenue of this technology in their own teaching.

There are many common structural elements to screencast construction which will influence the effectiveness of its use, and ultimately the success of the resource. Success can be measured in a number of ways, either academically via empirical studies such as the aforementioned research on learning improvements, or through evaluating the student experience. The majority of online platforms provide basic analytical features that count video views, count subscribers to your feed/channel, permit comments and also tally likes and dislikes. This basic information can inform future practice of screencast creation.

For the most part, virtual learning environments are not equipped to support the upload of multiple video files as resources and are inherently designed only to use linked to resources. Therefore, the best options for uploading is via publicly accessible applications such as You Tube. Although, this does still offer the option to be used privately and to share content with selected groups. What follows are guidelines for the production value of your resource and for approaches towards the taught element.

The common elements that make up a screencast are the intro sequence, the main instructional visual portion (which is the body of the screencast), the narration (audio portion synchronised to what is happening on screen) and the end screen (Mullamphy et al. 2010). The intro and outro sequence, also known as ‘bumpers’ provide an important statement of identity (Sugar et al. 2010). The style of screen movement is also key – some screencasts have a dynamic style which allows the video frame to focus in on areas of interest and, for the time being, eliminate irrelevant on-screen material. The majority however are static, with a single frame that simply builds content in a logical and sequential order (Brown et al. 2009; Sugar et al. 2010).

Findings from our own investigations suggest that the highest priority production variable is audio. Therefore, acquiring a good quality dynamic of condenser microphone is strongly advised for anyone wishing to create their own videos Furthermore, the narration must be high quality to satisfy student expectations. Our own students consistently report that they much prefer bespoke resources made by their own institution, even if there are more professionally produced alternatives available elsewhere; students constantly strive for continuity and alignment with their own curriculum (Geoghegan et al. 2018).

It is important to establish a brand for the educational product. Standardised logos, colours, formatting and sequencing all help in establishing a recognisable profile and serve to establish a favourable reputation. In a recent survey evaluating use of the Soton Brain Hub Chanel it was found that 70% of the medical student cohort (n = 253) rated the channel as excellent (5/5) suggesting a strong endorsement for quality and accuracy. Students commented of the consistency of design and style of the screencasts, which had an influence on their impression of the resource. Providing new content on a regular basis will also encourage more subscribers to the channel (Lowry et al. 2017). If developers are in a position to tell their users the frequency of uploads it will increase the probability of attracting a loyal following. These factors, commonly referred to as broadcast variables are as important as the content if you wish to build a national and international impact with your screencast resources.

When reviewing instructional techniques there are a number of approaches, but keeping in mind how these can remain consistent with the theory of CTML is a worthy deliberation. In some cases, it might be necessary to adjust the speed of the on-screen drawing time to reduce redundancy and the overall length of the video. It has been reported that students find it difficult to concentrate on videos that exceed 10 min in length (Morris and Chikwa 2014), something which is consistent with our own findings (Lowry et al. 2016). Narration can be recorded at the adjusted speed and can be fully scripted or semi scripted. The latter allows for a slightly more informal conversational style, but with the increased risk of compromising the contiguity and redundancy principles. In summary, screencasts should be short, accessible, preferably downloadable and compatible with both IOS and Android software. (Morris and Chikwa 2014).

1.1.9 The Benefits of Working in Partnership with Students to Create Screencasts

Although in the majority of cases educators may wish to develop screencast resources with their academic colleagues or independently, there are some major advantages to partnering with students on these projects (Pilborough et al. 2017). Firstly, millennials have experience of creating and manipulating video for recreational purposes, so the designing and creating element of screencast development comes as a fairly intuitive skill which could be said to be a ubiquitous characteristic of this particular generation. Secondly, they [the students] have more available time to create them, which if timed correctly may even complement an area of their own personal interest, or deepen knowledge in a topic that is required in an aspect of the formal curriculum. This is very much consistent with the benefits achieved from traditional near peer teaching programmes. (Hall et al. 2018a, b).

At Southampton the collaborative approach to producing screencasts was extremely well received, with 92% of users in favour of medical students being partners in the project (Pilborough et al. 2017). In addition, the case for student partnership has been made by The Higher Education Academy and has been implied as good practice (Healey 2017), but its adoption does involve a shift in working culture which has the potential to conflict with hierarchical structures within Higher Education institutions (Border 2017). Apart from establishing trust, the most important role of the faculty within the partnership becomes one of quality assurance and adherence to academic integrity policies (Seaby et al. 2015). Evidence accessed from the Soton Brain Hub channel suggests that screencasts created by students are frequently more popular than those created by staff (Pilborough et al. 2015). In a transcript from an unpublished focus group dataset, participants in our study frequently stated that the student's style of narration is often more friendly, supportive and carries a sense of warmth compared to that of formal faculty delivered explanations (Patel et al. 2017; McElligott et al.

2016). Further scrutiny, (mostly of the comments section of each video) reveals that viewers emphasise praise for helpful ways to remember information, or signposting of the core facts for the assessments. Students clearly welcome this aspect of support for learning a new subject in its early stages (Smith and Border 2019). This would very much suggest that near peer teachers can act as useful and dependable role models in an online capacity as well as face to face.

1.2 Conclusions

It is very clear that the adoption of screencast technology, blended with face to face contact, can make a very positive impression on students studying in the field of anatomical sciences. More important than the consistently overwhelming positive evaluations reported from their use, is the encouraging results from those studies assessing the impact on learning using objective outcome measures. Despite some promising findings in learning gain, more substantial evidence is required, preferably conducted through appropriately powered, robust multi centred studies. Whilst the majority of available evidence supports the use of screencasts it is important not to overlook the potential problems. Less face to face contact time may affect the staff/student relationship or rapport. Their introduction may also contribute to the belief that this will lead to a decline in attendance, although at the present time this hypothesis has not been substantiated. Both of these points could be interpreted as contributing factors towards the perception that lectures and the lecturer will become obsolete in time with the evolution of learning technologies.

The recommendations from this review suggest that adopting tailored screencast use with an associated educational strategy involving the solid integration of these resources within the curriculum is most ideal. Although it is possible for screencasts to be stored and accessed via an online repository for independent study requirements, the author strongly encourages the innovative application of these resources through techniques such as ‘flipping the classroom’, social media integration and adopting tools such as QR codes, which serve to signpost them at the most appropriate time for the students learning. All of these techniques aim to introduce screencast technology without negating the role of the educator – in fact quite the opposite, the educator’s role becomes pivotal to its success. To enable the sustainable creation of screencast resources and to increase the vertical integration of anatomy education through medical programmes, senior medical students can form partnerships with faculty members to achieve some of the mutual benefits similar to those witnessed by hands on peer assisted learning. It should be acknowledged that adopting this policy comes with a certain degree of risk and may require a subversive approach! However, if academics are willing to foster the trust and shared ownership of these digital resources, there is the potential for the creation of rich and engaging learning resources which are cognitively and socially congruent with their audience. It is clear that the way in which images (static/interactive/mobile) are used in the education of anatomical sciences is constantly expanding. As applications continue to offer more sophisticated and professional looking results, using simple and intuitive interfaces, educators will have some powerful tools at their disposal to offer a variety of innovative approaches to advance anatomy education.

References

Barry D, Tierney P, O’Keeffe G (2015) Anatomy education for the YouTube generation. FASEB J 29(1_supplement):LB13

Billings-Gagliardi S, Mazor KM (2007) Student decisions about lecture attendance: do electronic course materials matter? Acad Med 82(10):S73–S76

Bobis J, Sweller J, Cooper J (1993) Cognitive load effects in a primary-school geometry task. Learn Instr 3:1–21

Border S (2017) Working with students as partners in anatomy education. Anat Sci Educ 10(6):613–614

Border S, Parton W, Myers M, Elmansouri A, Harrison C, Stephens J, Seaby E, Hall S (2017) Ten considerations for implementing effective and sustainable near-peer teaching in clinical anatomy education. MedEdPublish 6. https://doi.org/10.15694/mep.2017.000082

Brown A, Luterbach K, Sugar W (2009, March) The current state of screencast technology and what is known about its instructional effectiveness. In: Society for information technology & teacher education international conference. Association for the Advancement of Computing in Education (AACE), Amsterdam, pp 1748–1753

Carmichael SW, Pawlina W (2000) Animated PowerPoint as a tool to teach anatomy. Anat Rec Off Publ Am Assoc Anat 261(2):83–88

Chen F, Lui AM, Martinelli SM (2017) A systematic review of the effectiveness of flipped classrooms in medical education. Med Educ 51(6):585–597

Clark RC, Nguyen F, Sweller J (2011) Efficiency in learning: evidence-based guidelines to manage cognitive load. John Wiley & Sons, Hoboken

Clayton M (1993) Leonardo Da Vinci: the anatomy of man. Plast Reconstr Surg 92(5):973

Clayton M, Philo R, Palace B (2012) Leonardo da Vinci: anatomist. Royal Collection Publications, London

Clunie L, Morris NP, Joynes VC, Pickering JD (2018) How comprehensive are research studies investigating the efficacy of technology-enhanced learning resources in anatomy education? A systematic review. Anat Sci Educ 11(3):303–319

De Koning BB, Tabbers HK, Rikers RM, Paas F (2007) Attention cueing as a means to enhance learning from an animation. Appl Cogn Psychol: Official J Soc Appl Res Mem Cognit 21(6):731–746

Drake RL, McBride JM, Lachman N, Pawlina W (2009) Medical education in the anatomical sciences: the winds of change continue to blow. Anat Sci Educ 2(6):253–259

Elmansouri A, Myers M, Parton W, Harrison CH, Hall S, Stephens J, Merzougui W, Border S (2018) Using quick response codes to combine online digital media with traditional anatomy teaching methods. Solving clinical problems with anatomical solutions. J Anat 232:1038–1064. https://doi.org/10.1111/joa.12806

Ellington AJ, Hardin JR (2008) The use of video tutorials in a mathematical modeling course. Math Comput Educ 42(2):109

Evans DJ (2011) Using embryology screencasts: a useful addition to the student learning experience? Anat Sci Educ 4(2):57–63

Evans DJ, Cuffe T (2009) Near-peer teaching in anatomy: an approach for deeper learning. Anat Sci Educ 2(5):227–233

Geoghegan K, Payne DR, Myers MA, Hall S, Elmansouri A, Parton WJ, Harrison CH, Stephens J, Parker R, Rae S, Merzougui W (2018) The National Undergraduate Neuroanatomy Competition: lessons learned from partnering with students to innovate undergraduate neuroanatomy education. Neuroscientist. https://doi.org/10.1177/1073858418788000

Ghilay Y, Ghilay R (2015) Computer courses in higher-education: improving learning by screencast technology. J Educ Technol 11(4):15–26

Graham CR (2006) Blended learning systems. The handbook of blended learning. Pfeiffer Publishing, San Francisco, pp 3–21

Green KR, Pinder-grover T, Millunchick JM (2012) Impact of screencast technology: connecting the perception of usefulness and the reality of performance. J Eng Educ 101(4):717–737

Greene SJ (2018) The use and effectiveness of interactive progressive drawing in anatomy education. Anat Sci Educ 11:445–460

Hall S, Stephens J, Andrade T, Davids J, Powell M, Border S (2014) Perceptions of junior doctors and undergraduate medical students as anatomy teachers: investigating distance along the near-peer teaching spectrum. Anat Sci Educ 7(3):242–247

Hall S, Harrison CH, Stephens J, Andrade MG, Seaby EG, Parton W, McElligott S, Myers MA, Elmansouri A, Ahn M, Parrott R, Smith CF, Border S (2018a) The benefits of being a near-peer teacher. Clin Teach. https://doi.org/10.1111/tct.12784

Hall S, Stephens J, Parton W et al (2018b) Identifying medical student perceptions on the difficulty of learning different topics of the undergraduate anatomy curriculum. Med Sci Educ 28:469. https://doi.org/10.1007/s40670-018-0572-z

Harrison CH, Elmansouri A, Parton W, Myers MA, Hall S, Stephens JR, Seaby EG, Border S (2017) The efficacy of frontline near-peer teaching in a modern medical curriculum. Anat Sci Educ 12(3):236–244

Healey M (2017) Students as partners and change agents in learning and teaching in higher education

Hennessy CM, Kirkpatrick E, Smith CF, Border S (2016) Social media and anatomy education: using Twitter to enhance the student learning experience in anatomy. Anat Sci Educ 9(6):505–515

Jaffar AA (2012) YouTube: an emerging tool in anatomy education. Anat Sci Educ 5(3):158–164

Jaffar AA (2014) Exploring the use of a Facebook page in anatomy education. Anat Sci Educ 7(3):199–208

Jose AM (2001) Anatomy and Leonardo da Vinci. Yale J Biol Med 74(3):185

Kramer B, Soley JT (2002) Medical student perception of problem topics in anatomy. East Afr Med J 79(8):408–414

Lin HC, Hwang GJ (2018) Research trends of flipped classroom studies for medical courses: a review of journal publications from 2008 to 2017 based on the technology-enhanced learning model. Interact Learn Environ 50:1–17

Lloyd SA, Robertson CL (2012) Screencast tutorials enhance student learning of statistics. Teach Psychol 39(1):67–71

Lockspeiser TM, O'Sullivan P, Teherani A, Muller J (2008) Understanding the experience of being taught by peers: the value of social and cognitive congruence. Adv Health Sci Educ 13(3):361–372

Lowry A, Seaby E, Stephens J, Hall S, Border S (2017) Soton brain hub: the development of an online neuroscience course. Back to the future. Establishing a para-curriculum in anatomy. J Anat 230:165–195. https://doi.org/10.1111/joa.12488

Lowry A, Seaby E, Hall S, McElligott S, Sidebottom D, Pilborough E, Ahn M, Stephens J, Parton W, Border S

(2016) Soton brain hub: the anatomy of recreational learning. Anatomical Society and British Association of Clinical Anatomists joint summer meeting 'the anatomy of learning' Brighton and Sussex Medical School 19th-21st July 2016

Mahmud W, Hyder O, Butt J, Aftab A (2011) Dissection videos do not improve anatomy examination scores. Anat Sci Educ 4(1):16–21

Mayer RE (1989) Systematic thinking fostered by illustrations in scientific text. J Educ Psychol 81(2):240

Mayer RE (2002) Multimedia learning. In: Psychology of learning and motivation, vol 41. Academic, pp 85–139

Mayer RE, Gallini JK (1990) When is an illustration worth ten thousand words? J Educ Psychol 82(4):715

Mayer RE, Moreno R (1998) A cognitive theory of multimedia learning: implications for design principles. J Educ Psychol 91(2):358–368

Mayer RE, Moreno R (2002) Animation as an aid to multimedia learning. Educ Psychol Rev 14(1):87–99

Mayer RE, Moreno R (2003) Nine ways to reduce cognitive load in multimedia learning. Educ Psychol 38(1):43–52

Mayer RE, Heiser J, Lonn S (2001) Cognitive constraints on multimedia learning: when presenting more material results in less understanding. J Educ Psychol 93(1):187

McElligott S, Lowry A, Seaby E, Hall S, Stephens J, Sidebottom D, Pilborough E, Ahn M, Parton W, Border S (2016) Soton Anatomy Hub: an online educational platform produced by students for students. In: Anatomical Society and British Association of Clinical Anatomists joint summer meeting 'the anatomy of learning' Brighton and Sussex Medical School 19th–21st July 2016

McGarr O (2009) A review of podcasting in higher education: its influence on the traditional lecture. Australas J Educ Technol 25(3):309–321

Missildine K, Fountain R, Summers L, Gosselin K (2013) Flipping the classroom to improve student performance and satisfaction. J Nurs Educ 52(10):597–599

Mohorovičić S (2012) Creation and use of screencasts in higher education. In: MIPRO, 2012 proceedings of the 35th international convention. IEEE, Opatija, pp 1293–1298

Moreno R, (2004) Decreasing cognitive load for novice students: Effects of explanatory versus corrective feedback in discovery-based multimedia. Instructional science, 32(1–2), pp.99–113.

Moreno R (2007) Optimising learning from animations by minimising cognitive load: cognitive and affective consequences of signalling and segmentation methods. Appl Cognit Psychol Off J Soc Appl Res Mem Cognit 21(6):765–781

Morton S, Cecot T, Bayram-Weston Z, Border S, Paterson I, Skidmore J, O'Malley A (2016) using classic and technology based methods to enhance the student learning experience in histology. In: Anatomical society winter meeting Kings College London 19th–21st December 2016

Morris C, Chikwa G (2014) Screencasts: how effective are they and how do students engage with them? Act Learn High Educ 15(1):25–37

Mousavi SY, Low R, Sweller J (1995) Reducing cognitive load by mixing auditory and visual presentation modes. J Educ Psychol 87(2):319

Moxham BJ, Plaisant O (2014) The history of the teaching of gross anatomy-how we got to where we are. Eur J Anat 18(3):219–244

Mullamphy DF, Higgins PJ, Belward SR, Ward LM (2010) To screencast or not to screencast. Anziam J 51:C446–C460

Musallam R (2010) The effects of using screencasting as a multimedia pre-training tool to manage the intrinsic cognitive load of chemical equilibrium instruction for advanced high school chemistry students

Nieder GL, Nagy F (2002) Analysis of medical students' use of web-based resources for a gross anatomy and embryology course. Clin Anat Off J Am Assoc Clin Anatom Br Assoc Clin Anatom 15(6):409–418

Osguthorpe RT, Graham CR (2003) Blended learning environments: definitions and directions. Q Rev Dist Educ 4(3):227–233

Oud J (2009) Guidelines for effective online instruction using multimedia screencasts. Ref Serv Rev 37(2):164–177

Patel H, Pilborough E, Seaby E, Paterson S, Lowry A, Hall S, Stephens J, Border S (2017) Investigating student perceptions towards bespoke anatomy screencasts. Anatomical Society Summer Meeting at Brighton and Sussex Medical School. J Anat 230:354–372. https://doi.org/10.1111/joa.12558

Paterson S, Morton S, Bayram-Weston Z, Cecot T, O'Malley A, Border S, Skidmore J (2015) Flipping histology – a new approach to integrating anatomical sciences learning. Back to the future. Establishing a para-curriculum in anatomy. J Anat 230:165–195. https://doi.org/10.1111/joa.12488

Pereira JA, Pleguezuelos E, Merí A, Molina-Ros A, Molina-Tomás MC, Masdeu C (2007) Effectiveness of using blended learning strategies for teaching and learning human anatomy. Med Educ 41(2):189–195

Petherbridge D, Jordanova LJ, Gallery H, Gallery M (1997) The quick and the dead: artists and anatomy. Univ of California Press, Berkeley

Phillips JM, Billings DM (2007) Using webcasts for continuing education in nursing. J Contin Educ Nurs 38(4):152–153

Pickering JD (2015) Anatomy drawing screencasts: enabling flexible learning for medical students. Anat Sci Educ 8(3):249–257

Pickering JD (2017) Measuring learning gain: comparing anatomy drawing screencasts and paper-based resources. Anat Sci Educ 10(4):307–316

Pickering JD, Roberts DJ (2018) Flipped classroom or an active lecture? Clin Anat 31(1):118–121

Pilborough E, Patel H, Seaby E, Paterson S, Lowry A, Hall S, Stephens J, Border S (2015) Collaborative screen casting in anatomy: assessing attitudes and perceptions of educational resources made in partnership with medical students. Anatomical Society Winter Meeting, Cambridge. 14–16th December

Pilborough E, Patel H, Seaby E, Paterson S, Lowry A, Hall S, Stephens J, Border S (2017) Collaborative screen casting in anatomy: assessing attitudes and perceptions of educational resources made in partnership with medical students. Back to the future. Establishing a para-curriculum in anatomy. J Anat 230:165–195. https://doi.org/10.1111/joa.12488

Pinder-Grover T, Green KR, Millunchick JM (2011) The efficacy of screencasts to address the diverse academic needs of students in a large lecture course. Adv Eng Educ 2(3):3

Saxena V, Natarajan P, O'Sullivan PS, Jain S (2008) Effect of the use of instructional anatomy videos on student performance. Anat Sci Educ 1(4):159–165

Scantling-Birch Y, Morton S, Border S (2018) Do you see what I see? How histology videos can be used as an adjunct to traditional teaching. Anatomical Society Summer Meeting, University of Oxford, Oxford. J Anat. https://doi.org/10.1111/joa.12923

Seaby E, Lowry A, Hall S, Stephens J, Border S (2015) Collaboration between students and teaching fellows in medicine at the University of Southampton. In: Enhancing student learning through innovative scholarship conference, Durham University 16th/17th July

Sidebottom D, Lowry A, Parton W, Harrison C, Ahn M, Myers M, Elmansouri A, McElligott, Stephens J, Hall S, Seaby E, Carr N, Border S (2016) Blending near-peer teaching in anatomy education: a comparison of student attitudes towards integrated approaches. In: Anatomical society winter meeting Kings College London 19th-21st December

Smith CF, Border S (2019) The twelve cranial nerves of Christmas: mnemonics, rhyme, and anatomy – seeing the lighter side. Anat Sci Educ. https://doi.org/10.1002/ase.1846

Smith CF, Finn GM, Border S (2017) Learning clinical anatomy. Eur J Anat 21(4):269–278

Stephens JR, Hall S, Andrade MG, Border S (2016) Investigating the effect of distance between the teacher and learner on the student perception of a neuroanatomical near-peer teaching programme. Surg Radiol Anat 38(10):1217–1223

Stewart S, Choudhury B (2015) Mobile technology: creation and use of an iBook to teach the anatomy of the brachial plexus. Anat Sci Educ 8(5):429–437

Sugand K, Abrahams P, Khurana A (2010) The anatomy of anatomy: a review for its modernization. Anat Sci Educ 3(2):83–93

Sugar W, Brown A, Luterbach K (2010) Examining the anatomy of a screencast: uncovering common elements and instructional strategies. Int Rev Res Open Distrib Learn 11(3):1–20

Sweller J, Chandler P (1994) Why some material is difficult to learn. Cogn Instr 12(3):185–233

Swinnerton BJ, Morris NP, Hotchkiss S, Pickering JD (2017) The integration of an anatomy massive open online course (MOOC) into a medical anatomy curriculum. Anat Sci Educ 10(1):53–67

Tayler N, Hall S, Carr NJ, Stephens JR, Border S (2015) Near peer teaching in medical curricula: integrating student teachers in pathology tutorials. Med Educ Online 20(1):27921

Topping DB (2014) Gross anatomy videos: student satisfaction, usage, and effect on student performance in a condensed curriculum. Anat Sci Educ 7(4):273–279

Traser CJ, Hoffman LA, Seifert MF, Wilson AB (2015) Investigating the use of quick response codes in the gross anatomy laboratory. Anat Sci Educ 8(5):421–428

Trelease RB (2008) Diffusion of innovations: smartphones and wireless anatomy learning resources. Anat Sci Educ 1(6):233–239

Tsafrir J, Ohry A (2001) Medical illustration: from caves to cyberspace. Health Inf Libr J 18(2):99–109

Turney BW (2007) Anatomy in a modern medical curriculum. Ann R Coll Surg Engl 89(2):104–107

Valiathan P (2002) Blended learning models. Learning Circuits 3(8):50–59

Wakeman C (2013) The innovative use of screencasts in higher education. Innov Pract Higher Educ 1(3):1–20

Winterbottom S (2007) Virtual lecturing: delivering lectures using screencasting and podcasting technology. Plan Theory 18(1):6–8

2

Exploring the Role of xR in Visualisations for Use in Medical Education

Patrick Pennefather and Claudia Krebs

Abstract

Emerging technologies have the potential to transform our approach to medical education. A goal in this chapter is to inspire researchers, educators and scholars in the bio-medical visualisation field who can benefit from integrating wearable Augmented Reality (AR) technologies, like the HoloLens into their existing teaching and learning environments. We draw from case studies, existing research and the educational technology literature, to propose the design of purposeful learner-centered experiences that might benefit from wearable AR technologies in the classroom.

Keywords

Bio-medical visualisation · Wearable AR · Augmented Reality · xR · Emerging technologies · Pedagogy · Learner-centered

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2.1 Introduction

Emerging technologies have the potential to transform our approach to medical education. A goal in this chapter is to inspire researchers, educators and scholars in the bio-medical visualisation field who can benefit from integrating extended reality (xR) technologies into their existing teaching and learning environments. We draw from case studies, existing research and the educational technology literature, to propose the design of purposeful learner-centered experiences that might benefit from xR technologies in the classroom.

2.2 An Emerging Definition of xR

The term, xR (extended realities), is a fairly recent umbrella term which attempts to include and define Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) experiences. These emerging technologies are not only defined by the technical affordances of their hardware and software but by the experiences they offer learners. Virtual Reality experiences involve some type of wearable head mounted display that completely immerses a person in a different reality, while augmented reality can be experienced on your phone or through a wearable tech like the Microsoft HoloLens. The HoloLens is a wearable AR headset that has the power to

P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7_2

project a 3D image, superimposing it within a user's real-world environment. (Hanna et al. 2018). MR experiences like the HoloLens provide viewers the ability to interact with virtual objects within a familiar physical environment extending the perception of what is real (Spierling and Iurgel 2003).

2.3 A Focus on Wearable AR

Augmented reality technologies allow for different images and animations to be superimposed within, on, and around the physical environment. Wearable technology including the Microsoft HoloLens and most recently the Magic Leap are already being experimented with in classrooms and clinical settings across North America, Asia and Europe. Known as MR devices, they offer us a way to augment our current physical reality by superimposing 2D and, importantly, 3D interactive images onto it. Even more compelling, multiple devices can be digitally tethered and allow several individuals to see and interact with 3D digital objects and animations simultaneously in the same physical location or through remote telepresence.

2.4 A Multidisciplinary Approach

Work with these emergent technologies requires the assembly of a team that includes medical experts, computer scientists and engineers, as well as artists with a background in narrative and immersive education. Weyhe et al. (2018) studied the use of a VR anatomy atlas and while the students performed well on the post-test and were satisfied with the experience, the authors did comment on the need for better and more accurate 3D models. That accuracy can lead to a different creative process in which an MRI device was used to scan an accurate representation of the brain, which, served as the visual model for the 3D art team to build upon (Holman et al. 2018). This process is similar to the use of motion capture in 3D animation pipelines. Advantages of using an MRI or motion capture is that both processes more accurately represent a moving object, and save time for animators during the development process. In our own experience, the creation of the HoloBrain (Holman et al. 2018), required medical students and faculty to collaborate with programmers, 3D artists, industry experts in Mixed Reality HoloLens development, and user-experience designers. It is this combination of a seamless user experience (UX) and an intuitive user interface (UI) coupled with accurate renderings of the deep structures of the brain, that allowed for use of the HoloBrain in an educational setting.

The technology should not be more visible to the learner than the content and it should only be used to visualize structures that would otherwise remain elusive. User interfaces that act as mediators between the user and the virtual objects should be designed in such a way as to be "transparent" (Fishkin et al. 1998). User interactions with the virtual objects should rely on physical gestures that are familiar to users in real-world experiences.

Tepper et al. (2017) were among the first to demonstrate the use of the HoloLens in a surgical theatre setting and they found that this technology enabled the change from "pre-operative" planning that was virtual to "intraoperative" MR surgery. This technology can bridge the gap between the digital imaging technologies commonly used in clinical settings and the surgical intervention on a patient, where the operative window may be small and a fuller understanding can be achieved through an augmentation of reality with the digital imaging data. We propose a similar approach for medical education: The use of Augmented Reality devices in the classroom are meant to augment current educational experiences and contribute to a full educational ecosystem that spans the continuum of medical education from the undergraduate experience to postgraduate and continuing medical education. In the case of anatomy education, this is typically concentrated in the first years of a medical undergraduate programme, and yet it forms the foundation for clinical sciences and clinical practice. A recent study found that student anatomy knowledge in clinical years was below the expected standard (Brunk et al. 2017.) These senior students typically do not have access to the cadaver lab for regular classes anymore. Access to an augmented, digital lab would have the potential to bridge this knowledge gap and foster integration across the disciplines. Another study looked at the use of the HoloLens in a surgical simulation environment. In Logishetty et al.'s (2019) study, students that trained with the HoloLens performed as well as those trained by a surgeon. However, the qualitative data collected found that MR was a valuable addition to the learning ecosystem. A Mixed Reality tool like the HoloLens afforded "unsupervised" training that complemented what they learned with an "expert surgeon".

2.5 Augmented and Mixed Reality Wearables in the Classroom

In the development of xR technologies there is a persistent tension between developing an interactive experience with embedded learning opportunities and ensuring that we are considering the educational journey of those whom we are co-constructing it for. Empirical and qualitative oriented research discusses some key learning outcomes when AR wearables are integrated into the curriculum. These include immersion, spatial ability, contextualization, engagement and collaborative problem solving (Rosenbaum et al. 2007). Devices like the HoloLens afford authentic activities that model complex "real-world systems". These interactions offer learners the ability to manipulate "parameters" that control a 3D model or animation, and to contribute within a multi-player experience and observe others performing specific functions. Dunleavy et al. (2009) found that Augmented or Mixed Reality simulations are "highly engaging" and allow users an interactive medium to solve problems collaboratively. In some cases, AR "laboratories" have been found to afford students the ability to experience a type of learning that can be better than more traditional classes in laboratories (Andujar et al. 2011).

2.5.1 Addressing the Dilemma of Integrating Technology in the Classroom

Claims that the use of wearable AR can transform how people learn and how people learn together are met with a mixture of enthusiasm and skepticism. Like other technologies there is simply not enough research to make sweeping generalizations across learning contexts. To weigh the advantages and disadvantages of integrating new technologies in our curriculum, we need look at one of the earliest twentieth century media that integrated educational technology in the classroom; educational film. Paul Saettler's (2004) book <u>The Evolution of American Educational Technology</u>, makes mention that the role of educational film in learning environments developed from a meeting place of several factors, including technological advances, changes in pedagogy, and vested interest from government and technology manufacturers. Similar comments have been made over time of many educational technologies and their journeys of integration in the classroom. For xR we are now at a critical juncture where practitioners who want to integrate emerging technology in the classroom must conduct rigorous inquiry so that relevant communities of practice can understand their applicability in their own teaching and learning environments.

Creating rigorous inquiry that is trustworthy will help us transcend the tone of technological evangelism that has been persistent historical since one of its first evangelists, Thomas Edison. Edison was one of the first to produce educational films (Saettler 2004) for schools. A quote attributed to him regarding the obsolescence of books in schools (Smith 1913) has become one of the earliest reference points in the educational technology literature that highlights the danger of regarding any emerging technology as a cure-all for educational problems and "shortcomings" (Dent 1939). While 100 years later scholars are not exclusively instructed "through the eye", educational films are a mainstream tool in classrooms, in particular in sciences that require accurate visualisations. When we evaluate the adoption of visual media in the classroom over centuries, medical education has always relied on illustrations, photography, and video. While some consider that the adoption of xR will be the next step in this evolution (Vlada and Albeanu 2010), we need to research the best way to integrate xR into the ecosystem, carefully considering the advantages and disadvantages of this technology (Mitrousias et al. 2018). Part of the reason why skepticism is always present, is that not all emerging technologies will work in every learning context. This may be further amplified by an overall misunderstanding of how, when and why emerging technologies can be applied in the classroom, and whether or not they should.

2.5.2 How We Think Our Students Learn

How we think our students learn and how that informs our approach to teaching them is directly related to what we think the role of technology is in the classroom (Hannafin and Savenye 1993). Ertmer (2001) discusses how "teachers' beliefs" impact how, when and if technology is integrated into the design of instruction. Those beliefs may be influenced by how well teachers are able to manage the learning of emerging technologies. In addition, those educators who regularly interact with new technologies tend to have a greater capacity to quickly understand how to integrate them in their own teaching environments. Resistance to integrating emerging technologies may also be influenced by the teaching culture of the program, faculty, institution, and community of practice we belong to. Understanding these conditions may help educators make informed decisions as to the value of integrating emerging technologies in the classroom. Institutions are currently re-thinking their approached to medical education, in particular anatomy education (McMenamin et al. 2018) – these frameworks will inform how emerging technologies are integrated. As the hardware and the software development process can be expensive, it is difficult to support a more experimental learning environment where emerging technologies can be tried out and their effectiveness researched in the classroom.

While some assertions on the learning gains of the HoloLens AR can be made from Krebs' research (2017, 2018) and others (Barmaki et al. 2019), some medical educators (Wainman et al. 2018) may not be able to, nor want to, replicate the precise conditions that led to those assertions being made. It is up to each new teacher/practitioner to incorporate what they see as being relevant to the needs of their classroom, how relatable previous research might be to their own learning environment and the overall values and visions of their programs, and finally, to the design of their curriculum. Drawing from Stake's (1978) proposition of naturalistic generalizations in case study research, the contextual integration of xR in the classroom is a choice that medical educators need to consider when assessing the applicability of previously conducted research (Melrose 2009).

2.6 Why Do We Want Emerging Technologies in Our Classrooms and Labs?

Deeply questioning when, where, how and why integrating AR in the classroom will benefit educators in all disciplines. We need to task the tough questions of ourselves and our current pedagogy prior to following through on integrating emerging technologies in the classroom. The driver for the integration of technology must remain the pedagogy. The fundamental questions focus on what the added value is and how the use of xR technology will change our experience of reality. Some questions we have found helpful in answering include:

- How can we integrate wearable AR within existing pedagogical practice?
- How do we believe it will transform the learner-experience?

- What are the advantages of integrating wearable AR in the classroom and how will these contribute to learning outcomes?
- How adaptable is the program that I am in and how open are my colleagues to integrating emerging technologies in the classroom?
- How do we integrate training our faculty and students into the development pipeline?
- How long will it take to develop the technology and how much time am I willing to put into being part of the development team?
- Are there existing institutional resources, internal and external funding and partnerships that we can leverage?
- How do we test the learning gains from wearable AR?

2.7 Rethinking How We Integrate Augmented Reality in the Classroom

To articulate how wearable AR can be used in the classroom is to reinvent how we talk about its role in a teaching and learning situation. We can no longer use terms generally associated with quantitative research methods. Rather than discussing the 'effect' of AR or its 'impact' on learning, we need to reframe our linguistic orientation. This orientation might better prepare us for the types of research questions we ask. Instead of questions like "What are the learning effects of the Microsoft HoloLens?", we could ask, "How might the Microsoft HoloLens augment the learning experience of anatomy students in a neuroscience classroom? How might wearable AR differ in its use across disciplines, teaching environments and the types of learning interactions that are facilitated?

Typically, the questions we ask are an either/or proposition: Can xR replace cadaveric dissection/lectures/textbooks/videos? We propose a new avenue of inquiry where we look at the value added through these technologies. How can xR technologies help us to understand the physical reality of medical practice or the anatomy of the human body better?

2.7.1 Investing in Enhanced Learning Experiences Previously Not Possible

Our various experiences creating MR for the classroom had led us to believe that the HoloLens can offer teacher and learner interactions that would otherwise be more expensive, and in some cases impossible to achieve. Take the example of a HoloLens application (Bondoc et al. 2018), developed for an aerospace training facility to support teachers and students in the Avionics curriculum (British Columbia Institute of Technology). The HoloCopter project combined simple intuitive gestures and voice commands to afford users the ability to interact with a moving helicopter rotor, slowing down its speed and observing its working parts from any angle. Currently this type of interaction is not possible with conventional physical models as the moving blades of a helicopter would not be able to provide students with any safe close-up interactions.

In the case of augmenting the classroom with a giant working model of a 3D brain or other body parts, for example, we can selectively look at parts of the body, and importantly the 3D relationships of structures (see Fig. 2.1). Even though traditional pedagogical methods are still valid and have shown to be effective in teaching anatomy, AR affords different learning opportunities that were previously not possible. Expert anatomists can spend years building a conceptual 3D map of the body in the minds, with this technology this 3D map can now be shared easily with learners and interactions with these 3D models in an instructional setting are possible. We believe that one primary learning outcome for students is that it better prepares them and connects them to their subsequent roles as practitioners in the field.

2.7.2 Interaction and Collaboration Around 3D Anatomical Objects

One of the greatest benefits to learning in an xR environment is that it allows for new opportuni-

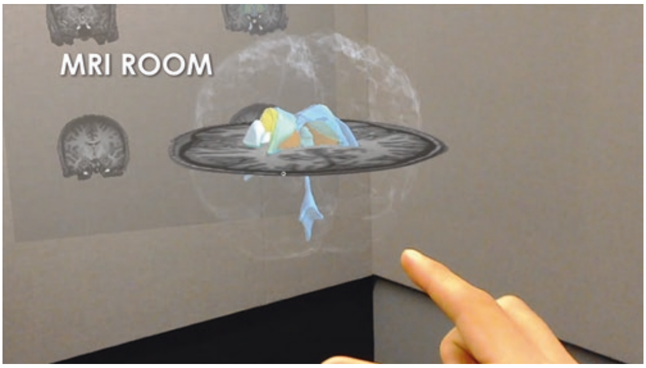

Fig. 2.1 HoloBrain in classroom use

ties for student to student and teacher to student collaboration and interaction. With several devices, students can see the same object simultaneously, interact with it and have discussions centered around the object itself. One could argue this is not very different than gathering around a 2D screen and looking at an object, but the devices such as the HoloLens place a virtual 3D object into the physical environment of the learning space, allowing for a 3D augmentation of reality. Learners can see from different angles, interact with it while others see those interactions, or interact with it simultaneously. As has been shown in clinical and nonclinical applications in pathology, the HoloLens is comfortable, has a small learning curve and is powerful enough to display high resolution 3D images, making it well suited for "digital pathology" and beneficial for autopsies and "microscopic examination" (Hanna et al. 2018).

2.7.3 Getting Closer to Realism and Reinventing the Artist's Role

The strength of xR is that it can provide an educational experience that transcends the limitations of reality – its main aim should not be to re-create reality. In education, as in art, we use a reductionist approach to help conceptualize and put the complex into context, to separate the signal from the noise. This is an extension of the thoughts put forward by Eric Kandel (2012) that in order to understand complex phenomena, science reduces them to "essential actions" while investigating the "interplay" of those essential actions. Kandel also proposes that this reductionist approach is exhibited in art as well. The role of artists in an xR environment is to assist experts in finding the right balance between the conceptual and the realistic. 3D reconstructions from clinical imaging (Binder et al. 2019), 3D models obtained from photogrammetry, 3D scanning (Dixit et al. 2019; Petriceks et al. 2018) or reconstructions from MRI scans (Zilverschoon et al. 2017) are all valuable tools in detailing the essential interactions that define complex scientific processes. It is the art of putting these objects into the context of xR, into a user-interface (UI) and user-experience (UX) that augments pedagogy, and becomes a qualitative measure that may well determine the success of one application over the other. Artists are essential in the process. Their focus is not to reinvent the wheel, it is to work with the existing scanned parts – balancing out the accuracy and the conceptual, integrating clinical pictures for the best immersion and authenticity. From the pedagogical point of view students are exposed early on to more accurate representations of what they might expect in real-world clinical scenarios.

2.7.4 The Learner Experience Needs to Be Front and Center

Content creators and educators need to spend more time considering how we can create wearable xR experiences that resonate with faculty and learners, require small learning curves to understand, are intuitive to work through, and are integrated into the curricular design – this requires a deep pedagogical understanding of learning goals and outcomes as well as the principles of good UI and UX.

Developing for wearable technologies challenges us to be co-designers of the experience itself. We need to collaborate and learn from user-experience designers and the field of UX design and improve the core experience from rigorous user-testing. This is because xR facilitates unfamiliar learning experiences that have to be considered when wanting to integrate them into pedagogy. Since our target users consist of students and teachers who may be more familiar with traditional media, we need to anticipate how they will use the device from the moment it is turned on and worn. This learning curve needs to considered and integrated into the overall UX of the teaching and learning experience. That includes the co-design of a user-friendly interface that is easy enough to use and understand, and flexible enough to afford new interactions that are unique to the medium.

2.8 Towards a UX of Emerging Technology in the Classroom

Educators across disciplines face tough choices when emerging technologies promise new transformative experiences for learners. Drawing from a specific tool commonly used in the field of UX design, defining the teacher/learner journey can be a powerful pedagogical tool that will shed light on the interaction points that learners have with all learning activities.

Prior to committing to integrating emerging technologies into the classroom we encourage educators to break down each interaction that they and their learners will have. This begins with a pre-classroom breakdown of the teacher journey, which, should detail the pedagogical reasoning and link the development cycle of an application for the HoloLens or other technology with specific curricular goals. A commitment to being present and active as a collaborator in the development of the application is crucial, including regular hypothesis testing of prototypes as the application develops. If the goal is to have other teachers also use the application on the HoloLens, then pre-class training should be integrated. Learning curves for the HoloLens need to be taken into account or the technology may not be integrated. Bringing in other teachers into the user-testing process should be considered high priority to ensure that their feedback is also accounted for. This will also make them stakeholders in the development process.

An in-class breakdown of the learner journey should be achieved during the development stage of the software application. An in-class breakdown details all the interaction points between the user (learner) and their use of the HoloLens. This would include in-class demonstrations of the HoloLens, a training period, a low-stakes experimental period with the HoloLens and its associated application covering how the learner will control the interactive 3D models and animations.

The post-application learner experiences should also be identified and integrated into the pedagogical intent of the class, the course and the future authentic practices of the learner beyond the course itself. We encourage the capture of student reflections prompted by their use of any emerging technology and how it supported their understanding of course content. Learner reflections are important to communicate internally to other faculty and University stakeholders to tell the story of its value.

2.9 Conclusions

We suggest that xR technology and its applications can be managed when they are considered pedagogically. That is, when all aspects of their management and the technical challenges of using them in the classroom, in addition to a consideration of the overall user-experience of teachers and learners are identified and resolved prior to their integration in curriculum. We also believe the use of mixed reality devices like the HoloLens challenges new modes of instruction to be designed, whose intentions are to shift away from pre-dominantly "teacher-directed" environments consisting primarily of rote memorization and reviewing case studies. An expanded view of learning that moves beyond acquiring "factual and procedural" knowledge (Suppes and Morningstar 1969) can lead to more rich interactions and problem-solving activities with complex scientific processes. Devices like the HoloLens offer us a future glimpse of learning in a different way with new affordances that are aligned with teaching complex scientific processes.

References

Andujar JM, Mejías A, Márquez MA (2011) Augmented reality for the improvement of remote laboratories: an augmented remote laboratory. IEEE Trans Educ 54(3):492–500

Barmaki R, Yu K, Pearlman R, Shingles R, Bork F, Osgood GM, Navab N (2019) Enhancement of anatomical education using augmented reality: an empirical study of body painting. Anat Sci Educ. https://doi.org/10.1002/ase.1858

Binder J, Krautz C, Engel K et al (2019) Leveraging medical imaging for medical education—a cinematic rendering-featured lecture. Ann Anat 222:159–165. https://doi.org/10.1016/j.aanat.2018.12.004

Bondoc J, Zhang J, Pennefather P (2018) Holocopter: an augmented reality project using the Microsoft Hololens. Unpublished Manuscript

Brunk I, Schauber S, Georg W (2017) Do they know too little ? An inter-institutional study on the anatomical knowledge of upper-year medical students based on multiple choice questions of a progress test. Ann Anat 209:93–100. https://doi.org/10.1016/j.aanat.2016.09.004

Dent EC (1939) The audio-visual handbook. Society for Visual Education Inc., Chicago, vol l039, 180p

Dixit I, Kennedy S, Piemontesi J, Kennedy B, Krebs C (2019) Which tool is best: 3D scanning or photogrammetry – it depends on the task. In: Rea P (ed) Biomedical visualisation. Advances in experimental medicine and biology, vol 1120. Springer, Cham

Dunleavy M, Dede C, Mitchell R (2009) Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. J Sci Educ Technol 18(1):7–22

Ertmer P (2001) Responsive instructional design: scaffolding the adoption and change process. Educ Technol 41(6):33–38. Retrieved from http://www.jstor.org.proxy.lib.sfu.ca/stable/44428707

Fishkin KP, Moran TP, Harrison BL (1998) Embodied user interfaces: towards invisible user interfaces. In: IFIP international conference on engineering for human-computer interaction. Springer, Boston, pp 1–18

Hanna MG, Ahmed I, Nine J, Prajapati S, Pantanowitz L (2018) Augmented reality technology using Microsoft HoloLens in anatomic pathology. Arch Pathol Lab Med 142(5):638–644

Hannafin RD, Savenye WC (1993) Technology in the classroom: the teacher's new role and resistance to it. Educ Technol 33(6):26–31

Holman P, Bodnar T, Ghomi M, Choi R, Moukhles H, Krebs C (2018) 3D neuroanatomy: using the HoloLens for an augmented reality approach in neuroanatomy education. FASEB J 32(suppl 1):25.3

Kandel ER (2012) The age of insight: the quest to understand the unconscious in art, mind, and brain : from Vienna 1900 to the present, 1st edn. Random House, New York

Logishetty K, Western L, Morgan R, Iranpour F, Cobb J, Auvinet E (2019) Can an augmented reality headset improve accuracy of acetabular cup orientation in simulated THA? A randomized trial. Clin Orthop Relat Res 1:1190–1199

McMenamin PG, McLachlan J, Wilson A et al (2018) Do we really need cadavers anymore to learn anatomy in undergraduate medicine? Med Teach 40:1020–1029. https://doi.org/10.1177/1744629509355751

Melrose S (2009) Naturalistic generalization. In: Mills AJ, Durepos G, Wiebe E (eds) Encyclopedia of case study research. Sage, Thousand Oaks

Mitrousias V, Varitimidis SE, Hantes ME et al (2018) Anatomy learning from prosected cadaveric specimens versus three-dimensional software: a comparative study of upper limb anatomy. Ann Anat 218:156–164. https://doi.org/10.1016/j.aanat.2018.02.015

Petriceks AH, Peterson AS, Angeles M et al (2018) Photogrammetry of human specimens: an innovation in anatomy education. J Med Educ Curric Dev. https://doi.org/10.1177/2382120518799356

Rosenbaum E, Klopfer E, Perry J (2007) On location learning: authentic applied science with networked augmented realities. J Sci Educ Technol 16(1):31–45

Saettler P (2004) The evolution of American educational technology. IAP, Greenwich

Smith FJ (1913) The evolution of the motion picture: VI–looking into the future with Thomas A. Edison. The New York Dramatic Mirror, 24

Spierling U, Iurgel I (2003) Just talking about art – creating virtual storytelling experiences in mixed reality. In: Balet O, Subsol G, Torguet P (eds) Virtual storytelling. Using virtual reality technologies for storytelling. ICVS 2003. Lecture notes in computer science, vol 2897. Springer, Berlin/Heidelberg

Stake RE (1978) The case study method in social inquiry. Educ Res 7(2):5–8

Suppes P, Morningstar M (1969) Computer-assisted instruction. Science 166(3903):343–350

Tepper OM, Hayeem LR, Lefkowitz A et al (2017) Mixed reality with HoloLens: where virtual. Plast Reconstr Surg:1066–1070. https://doi.org/10.1097/PRS.0000000000003802

Vlada M, Albeanu G (2010) The potential of collaborative augmented reality in education. In: The 5th international conference on virtual learning ICVL, vol. 2010. Bucharest University Press, Bucharest, pp 38–43

Wainman B, Pukas G, Wolak L, Zheng E, Norman G (2018) Virtual unreality – promise vs. performance of technology in anatomy education. FASEB J 32(suppl 1):91–92

Weyhe D, Uslar V, Weyhe F et al (2018) Immersive anatomy atlas—empirical study investigating the usability of a virtual reality environment as a learning tool for anatomy. Front Surg 5:1–8. https://doi.org/10.3389/fsurg.2018.00073

Zilverschoon M, Vincken KL, Bleys RLAW (2017) The virtual dissecting room : creating highly detailed anatomy models for educational purposes. J Biomed Inform 65:58–75. https://doi.org/10.1016/j.jbi.2016.11.005

3

Virtual Patients in Health Professions Education

Nathaniel Patrick Andrew Quail
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Abstract

Health care professionals must not only have knowledge, but also be able to organise, synthesise and apply this knowledge in such a way that it promotes the development of clinical reasoning. Panels of Virtual patients (VPs) are widely being used in health professions education to facilitate the development of clinical reasoning. VPs can also be used to teach wider educational outcomes such as communication skills, resource utilisation and longitudinal patient care. This chapter will define virtual patients and examine the evidence behind their use in health professions learning and teaching. The chapter will discuss virtual patient design, such as gamification. Finally, the chapter will discuss where this pedagogical innovation is best integrated into assessment and potential barriers to implementation into existing curricula.

Keywords

Virtual patient · Clinical reasoning · Virtual reality · Augmented reality · Health professions education

Abbreviations

VP	Virtual Patient
VPs	Virtual Patients

3.1 Introduction

By 2020, the doubling time of medical knowledge will be just 73 days (Denson 2018). Health care professionals must not only have knowledge, but also be able to organise, synthesise and apply this knowledge in such a way that it promotes the development of clinical reasoning (Eva 2005; Norman and Eva 2010). Clinical reasoning has been defined as the thinking and decision-making processes associated with clinical practice and is a critical capability in the health professions that forms their professional identity (Higgs et al. 2019). Traditional didactic pedagogical approaches do not allow the opportunity for the deliberate practice with real patients required to develop expertise in clinical reasoning (Boyle et al. 2016). While authentic, patient involvement in medical education has been become increasingly challenging because of the differentiated nature of patient case leading to increasing complexity with multiple morbidities that obscure the key clinical experience to be learned (Urresti-Gundlach et al. 2017), patient safety (Muller and Ornstein 2007), availability of student placements

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P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7_3

and willingness of patients to participate (Hardy and Brown 2010).

Panels of Virtual patients (VPs) are being increasingly being used in medical education to facilitate the development of clinical reasoning by overcoming reducing the randomness of patient cases as well as facilitating a cognitive apprenticeship through situated cognition as well as experiential learning in a safe and permanently stable learning environment (Brown et al. 1989; Consorti et al. 2012; Cook et al. 2010a, b; Kolb 1984; Lave and Wenger 1991). While VPs are widely used in health professions education, particularly in North America and Canada (Berman et al. 2016), barriers to implementation of VPs include resource, cost (Pantelidis et al. 2018), educator computer literacy (Berman et al. 2006), and uncertainty as to where exactly virtual patients are best integrated into the medical curriculum (Marei et al. 2018). VPs may also have a role in assessment in medical education, potentially eliminating some of the variables associated with standardised patients and actors in clinical examinations (Khan et al. 2013).

3.2 What Is a Virtual Patient?

The term "Virtual Patient" (VP) has been used extensively in publications in medical education. Indeed, the definition of VP has been heterogeneous leading to confusion about what constitutes a VP as well as their application in medical education. While the term VP generally refers to software facilitated case based learning, VPs has actually been applied to a wide range of technology, with the first virtual patient encounter being described in the 1960's with the PLATO computer system being used to teach nursing students about heart attack management (Bitzer 1966). The Association of American Medical Colleges (AAMC) makes three distinctions in terms of technology in medical education (Cook et al. 2007):

1. Computer-aided Instruction
2. Virtual Patients
3. Human Patient Simulations

While there is a large overlap between the three distinct groups suggested, the AAMC go further by describing VPs as "A specific type of computer-based program that simulates real-life clinical scenarios; learners emulate the roles of health care providers to obtain a history, conduct a physical exam, and make diagnostic and therapeutic decisions". Begg (2010) argues that a VP can in fact take many forms: "computer simulations of biochemical processes, physical simulators such as manikins, data sets representing actual patients (so that, in effect, we might ourselves conceivably be considered as virtual patients), and electronic case studies delivered via interactive computer applications" (Begg 2010).

Talbot et al. (2012) has subsequently suggested a more inclusive approach to the taxonomy for VPs consisting of several categories in which to group VPs. These include case presentations, interactive patient scenarios, games, high fidelity software simulations, human standardised patients, high fidelity manikins and virtual standardised patients. This classification was further refined when Kononowicz et al. (2015) linked each domain to the predominant competency, predominant technology and published research (Fig. 3.1). Both interactive patient scenarios and virtual patient game mapped to clinical reasoning with the largest body of published work focused on developing clinical reasoning using multimedia systems.

Such VPs generally include information about the patient such a history, examination findings and data from observations or investigations that may branch to different realistic paths and multiple outcomes depending on the learner interaction. Learner interaction can incorporate different components of clinical reasoning from information gathering, data interpretation, hypothesis generation, diagnostic justification, management and prognostication (Daniel et al. 2019). The learner then assesses the VP (typically multimedia software on a computer screen) by requesting information or selecting questions before being expected to make a commitment to diagnosis and management (Cook and Triola 2009).

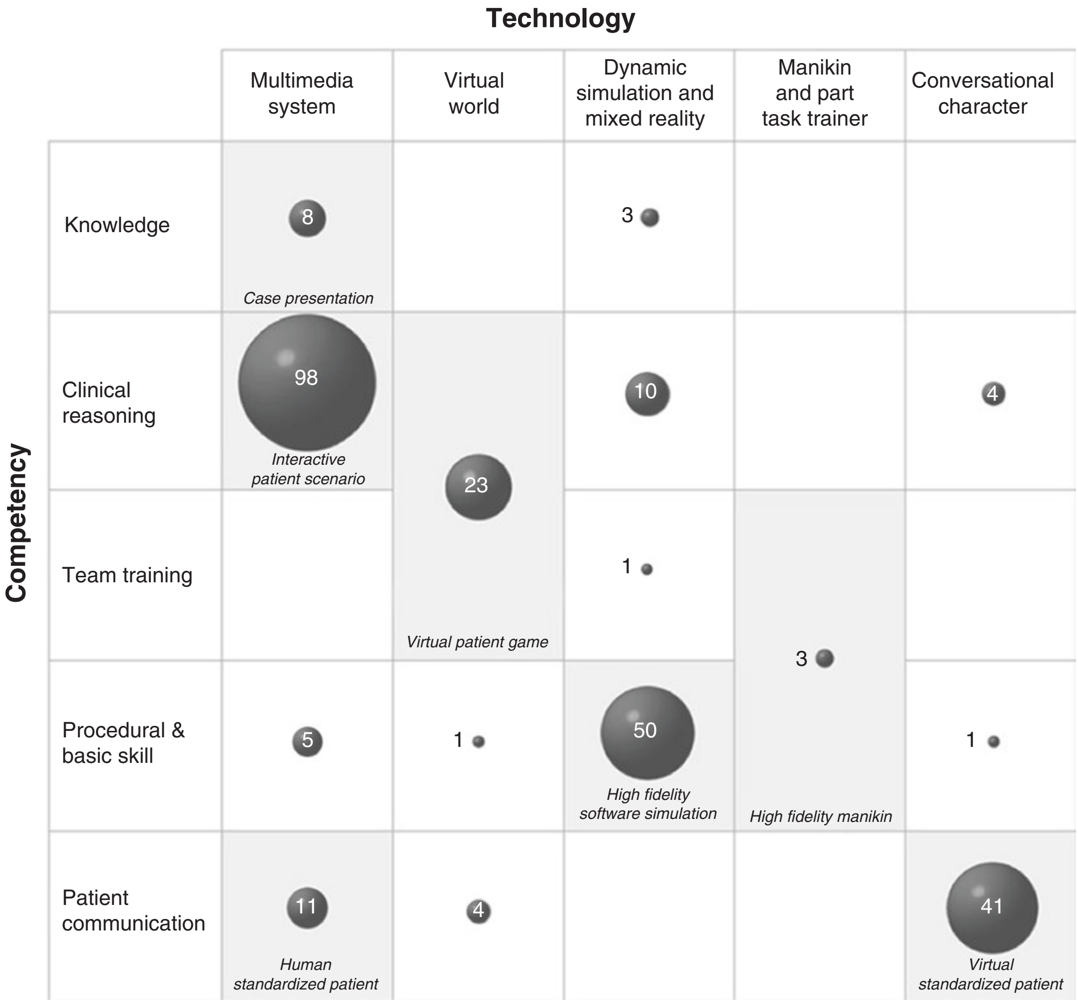

Fig. 3.1 The quantity of virtual patient studies grouped by the virtual patient technologies (columns) and the competency they are aiming to assess or develop (rows) as of 2015 (Kononowicz et al. 2015)

3.3 Virtual Patients in Learning & Teaching

The first question that must be asked is whether there is evidence for the use of VPs in learning and teaching in health professions education? Educators have used VPs in a variety of ways; core knowledge, clinical reasoning, communication skills and blended with simulation (Berman et al. 2016).

A pivotal critical literature review by Cook (2009) using the AAMC definition of VPs found indirect evidence that they were particularly suitable to the development of clinical reasoning skills. Cook (2009) VPs allow learners to participate in controlled immersion in a large number of different cases; with the opportunity to think and do in a variety of content areas and environmental contexts. Cook et al. argue that expertise in clinical reasoning is case specific and VPs allow the learner to develop expertise in clinical reasoning through deliberate practice by emphasising pattern recognition and the development of a library of rich and detailed “illness scripts” (Schmidt and Rikers 2007; Charlin et al. 2007).

Cook et al. subsequently completed a systematic review and meta-analysis of the effects of VPs on learning outcomes in health professions education (Cook et al. 2010a, b). This work found that, while there was a significant positive effect compared to no intervention, the effect compared with non-compute instruction was small. Limited by the quality and quantity of available studies, Cook et al. concluded that further work was required to clarify how to effectively implement VPs.

Again limited by the small number of cases, a subsequent meta-analysis by Consorti et al. (2012) focussing on VPs in medical education found a clear positive pooled effect when VPs were both compared to a traditional method or as an additive resource. When grouped for the type of outcome, the pooled effect size was greater for clinical reasoning when compared with communication skills and ethical reasoning. There were important methodological differences in the meta-analyses; Consorti et al. only selected papers from the year 2000 onwards, whereas the analysis by Cook et al. was performed on papers from all years, followed by a further analysis of papers from 1991 onwards only. The analysis by Consorti et al. was also limited to solely medical rather than healthcare professions education and their inclusion criteria as to what constituted a VP was more inclusive than that given by Cook et al.

Another important question is where are VPs best integrated into health professions education? This question remains largely unanswered. Cook et al. found that while students enjoy VPs they feel that they should not replace real patient encounters with the right balance of virtual to real unknown (Cook 2009). Ellaway et al. (2015) have suggested several broad ways in which VPs can be used in health professions education, such as synchronous group activities, or standalone reference activities. Berman et al. have recently shown that VPs can be integrated in massive online open course (Berman et al. 2017). A recent study of VP use on undergraduate dental students by Marei et al. (2018) separated undergraduate dental students into groups using a VP either before or after a traditional didactic lecture individually, or after the lecture in small groups. The collaborative deductive group had higher levels of knowledge acquisition and retention compared to other groups. These results have been replicated at the University of Dundee (Heng and Anbarasan 2018). Berman et al. (2009) have found that orientating students to VP cases, eliminating what redundant aspects of the curriculum and inclusion in assessment leads to a greater feeling of integration by students. Having trialled various integration strategies, Hege et al. have demonstrated that utilisation of VP cases was poor if they were introduced as independent and voluntary exercises, not mapped to examination content (Hege et al. 2007). Huwendiek et al. (2013) have also suggested the importance of aligning and sequencing VPs with other activities and assessments.

3.4 Virtual Patient Design

3.4.1 Extraneous Cognitive Load and Complexity of Cases

Extraneous cognitive load is the impedance to learning caused by excessive and unnecessary factors associated with the way in which information is presented to the learner (Marei et al. 2018). Essentially, the more of the working memory that is devoted to unravelling how information is presented, the less that is available to process the key learning points. Most textbook diagnoses are actually slightly more complex in day-to-day patients, with some tests and examination findings contradicting the correct final diagnosis. Moreover, many patients have more than one diagnosis, further complicating the picture. Such complexity can overwhelm novice students by producing an enormous amount of extraneous cognitive load. (Marei et al. 2018). Therefore, the majority of VPs involve a single, first presentation of illness (Urresti-Gundlach et al. 2017). These virtual patients may then have an advantage in that they can simulate textbook presentations of diseases, reducing extraneous cognitive load, and enabling novice students to learn easier than interacting with a complex, multi-morbid patient. A caveat to this is that, at some point, students must learn to engage in more complex patients they will encounter in clinical practice. VPs can therefore be tailored to their short, medium and long-term goals; providing uncomplicated history and examination findings to the novice student, whilst having a variability and complexity for developing skills over time.

3.4.2 Resource Utilisation and Gamification

Generally in order to obtain a blood result in hospital, the following must happen: a healthcare practitioner requests the blood using software that must be purchased and maintained; a phlebotomist is employed to take the blood sample, which can be painful for the patient and may require more than one attempt using a variety of disposable materials; the sample must then be delivered to the lab, analysed, and then interpreted by the clinician (Litchfield et al. 2015). It is now common practise to order routine tests for patients, regardless of the clinical question being asked and what value they may add to prognosis and treatment, due to availability of tests and a cultural practice of defensive medicine (Feldman et al. 2013). This is costly in terms of both materials and workforce time and can be termed as low-value care. Moreover, it can be a source of unnecessary pain to patients and, should results show incidental anomalies, can lead to unnecessary invasive investigations and delayed discharges, costing more money (Feldman et al. 2013). Promotions such as the International Choose Wisely Campaign aim to highlight low-value care (Levinson et al. 2015). Interestingly, unnecessary test ordering can be reduced when physicians are confronted with the cost of each test as they order it (Feldman et al. 2013).

VPs represent an interactive way in which healthcare professionals, and students in particular, can be taught the value of resource utilisation. Zhou et al. (2018) developed six VP scenarios concerning rheumatological diagnoses and resource utilisation. Some tests, for example a specialised antigen blood test HLA-B27, are expensive and only recommended to be performed when there is strong suspicion of specific pathology in the history and examination or radiologically. Students were tasked with reading a patient vignette and ordering the most appropriate tests given the history, examination, and investigation findings. Free-text criticism from participants was that, although it was valuable to receive feedback on what tests were unnecessary and expensive, there was no cost-limit for tests during the scenario and no penalty for over-ordering. Gamification is a way in which resource utilisation in VP scenarios can be rewarded. Gamification involves introducing aspects of games to VP scenarios, such as point scoring, rewards, and swift feedback, and can harness innate competitiveness in students and doctors in order to make the scenario more engaging. McCoy et al. (2016) detail several games relevant to health professions education in their review, categorising each for advantages such as real-world application and swift feedback. One interesting example, Septris, is a free online VP game developed and hosted by Stanford University, which tasks the player with the investigation and management of sepsis (Evans et al. 2015). Tests have a lag time between being ordered and results, and the patient's vital signs change in real-time, mimicking the time critical nature of sepsis management.

Foldit is an interesting online game where players are rewarded with points for realistically folding protein structures (Kleffner et al. 2017). Arguably, any software such as this, which mimics an aspect of human biology, can be considered a VP. This game is unique in that it is both useful for the user by visually demonstrating aspects of protein folding such as hydrogen bonding and to the developers in the sense that they can use data on how users attempt to fold proteins to better inform computer algorithms in modelling the process This can lead to improved insights into the educational needs of students. Moreover, the majority of research in health professionals education is conducted by single institutions with modest funding and no long-term follow up. Using data harvested from VPs, multi-institutional collaborations can produce more rigorous and longitudinal work (Cook et al. 2010a, b).

3.4.3 Clinical Reasoning and Diagnostic Error

Diagnostic error is a major cause of morbidity and mortality in all healthcare settings. (Singh et al. 2016). A number of factors contribute to diagnostic error, one of which is inadequate clinical reasoning (Singh et al. 2016). This is a concept of diagnostic skill which combines theoretical medical knowledge with clinical experience and is developed over the course of the professional career (Hege et al. 2018). VPs allow for autonomous practice and learning from diagnostic error in a safe environment (Hege et al. 2018).

In terms of developing virtual patients to fully enhance the development of clinical reasoning, realistic branch points are considered effective (Posel et al. 2014) (see Fig. 3.2). These are distinct junctions in the VP storyboard where the scenario can take several different directions depending on the user input. Klein et al. (2018) assessed whether prompts in the form of open-ended reflections or multiple-choice questions helped foster clinical reasoning. Interestingly, such prompts only stood to add extraneous cognitive load and so unsupported worked examples in VP games may be favoured, where the learner is simply informed of where they went wrong and why, rather than explicitly being tasked to reflect on their error.

Van Bruggen et al. (2012) have analysed the various question types that can be used in VP scenarios aimed at large groups of students and conclude that extended matching questions and comprehensive integrative puzzles are most useful in developing clinical reasoning skills. The latter involves students building a comprehensive patient history, examination and investigation results based on a final diagnosis, effectively working backwards from the end-point of the patient work-up.

3.4.4 Longitudinal Care and Combatting Clinical Inertia

As discussed, many VP scenarios focus primarily on the initial diagnosis and management of a condition, when patient management realistically involves dealing with more chronic conditions (Urresti-Gundlach et al. 2017). May branches of medicine a hospital consultant or involve the

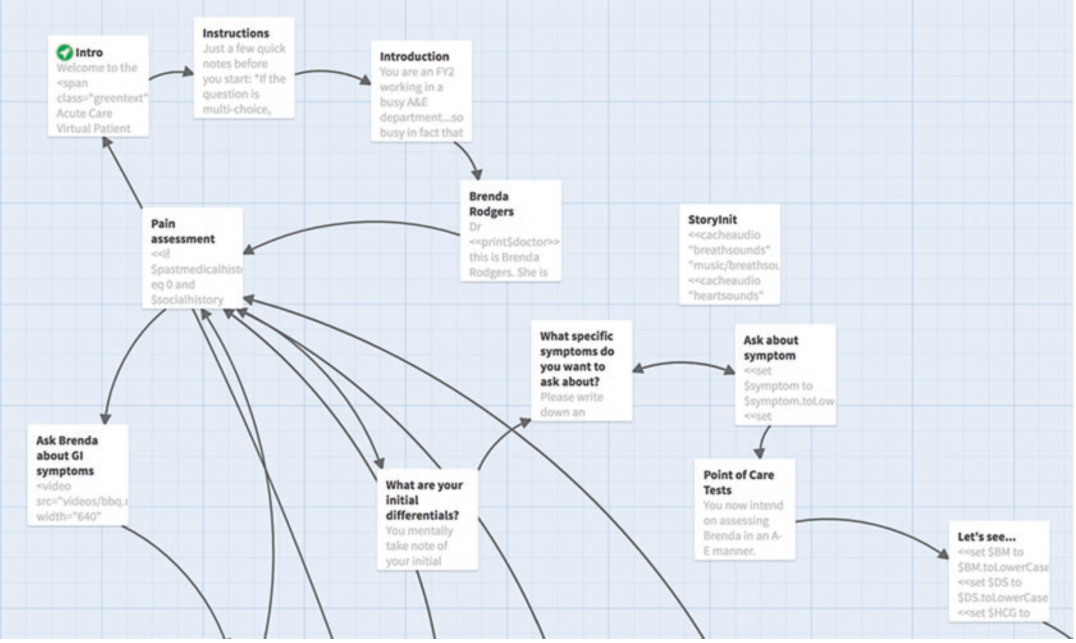

Fig. 3.2 A storyboard created using open-source Twine software shows a branching virtual patient scenario (Quail et al. 2018)

management of people with chronic conditions over a period of years. Junior doctors in the UK tend to rotate training posts every 4–6 months (Harries et al. 2016). Although this allows a multitude of skills to be built in different clinically settings, it does not afford much practise in managing chronic disease longitudinally learning from decisions made in this management. Sperl-Hillen et al. (2013) have piloted longitudinal VP in diabetes management where doctors can apply their treatment plan and follow up their VP over a 180-day period in an attempt to achieve physiological targets such as optimal blood pressure or blood glucose. Such VPs afford much needed practice in managing chronic illness and may also help combat clinical inertia.

3.4.5 Augmented and Virtual Reality in Skills Training

Augmented reality (AR) and virtual reality (VR) are two concepts that are becoming increasingly popular in health professions education (Pantelidis et al. 2018) and general popular culture with the advent of technologies such as smartphones. A notable example being the Pokémon Go worldwide phenomenon in 2016 (Marquet et al. 2017). AR differs from VR in that artificial images are layered over the natural environment of the user, rather than an entirely separate environment being created (Pantelidis et al. 2018). AR and VR lend themselves well to task-based training in health professions education. The philosophy of see one, do one, teach one, when it comes to clinical skills is one which is out-dated and unsafe (Seewoonarain and Barrett 2017). Satava (2006) suggests a multi-step process that could utilise VPs in order to teach clinical and surgical skills. This involves teaching the anatomy involved in the procedure didactically and through physical or even virtual models. Errors made while learning the task should also be explored, before learners test their psychomotor skills on the simulator. The progression from novice to expert can then be tracked using unique signatures created by the user each time they perform the task.

Pantelidis et al. (2018) have recently compiled a descriptive list of VR and AR simulators being used in speciality teaching, with more examples being published since their list was compiled. For example, a pelvic ultrasound VR simulator demonstrating pathology such as abnormal adnexal masses has recently been described (Arya et al. 2017). Although an exciting prospect, there are still several issues associated with implementing such technology in health professions education. The first is cost, although smartphones and tablets are making AR more readily accessible (Pantelidis et al. 2018). Physical reactions of users such as headaches and dizziness are common and limit usage time compared to traditional didactic teaching (Moro et al. 2017). A third potential issue is that any aspect of poor programming resulting in the simulator not reflecting real practice, or a lack of instruction as to correct technique, could lead to maladaptive skills being learned (Pantelidis et al. 2018). Finally, variability is key to mastering skills (Hatala et al. 2003). Simple variability in, for example, interpreting laboratory results can be introduced using very basic random number generation (Quail et al. 2018). More complex programming is needed to introduce the necessary variability in anatomical and pathological presentations in order for the user to begin to master the skill.

On the variability of simulations for skills, Norman (2014) discusses his thoughts from a recent hospital admission: "For IV insertion, you can run the gamut from a pig's foot, to a static plastic simulator, to a virtual reality simulator, to SimMan and its variants; the cost ranges over many orders of magnitude. But NONE of the simulators addresses the perceptual skill that the nurse displayed in scanning for veins… Similarly for heart sounds. A student has a vast choice of simulations, from free heart sounds downloaded from the Web, to Harvey (a heart murmur simulator), at $50,000…to achieve mastery he was going to have to listen to a great many heart sounds. Harvey has 29—one of each condition.

3.4.6 Virtual Patients and Communication Skills

VPs can also be used to teach communication skills. Although perhaps less effective than scenarios aimed at enhancing clinical reasoning (Consorti et al. 2012), scenarios can be tailored to teach specific points about communication, such as empathetic opportunities (Motz et al. 2018). If empathetic opportunities are acted upon in consultations, they can lead to a more thorough and accurate patient history being obtained. Since empathetic opportunities may very between custom and local dialect, VPs may represent a unique way in of training communication skills in a safe environment.

3.4.7 Collaborative Development of Virtual Patients

The Electronic Virtual Patients Programme is an online resource that is partially funded by the European Union (European Virtual Patient 2019). It combines submissions from various European medical schools to form a vast and varied learning resource. Collaborations such as this allow students to observe variations in practise between institution and, importantly, learn from presentations that may be rare in their own geographical area (Hardy and Brown 2010). As technology improves in real-time accurate translation in text, even audio description or video-based patients may be utilised by a variety of countries.

3.5 Virtual Patients in Assessment

Educators have used VPs to assess learners' progress. Using VPs as tools for assessment of basic theoretical and practical competencies is an interesting concept, bringing both advantages and disadvantages. Objective Structured Clinical Examinations (OSCEs) were introduced to healthcare professional assessment in order to eliminate variability between patients and examiners (Khan et al. 2013). A scenario with a script is constructed that a patient or actor will adhere to, and marks are awarded when the trainee either enquires about a specific point when taking a history, performs a certain examination technique, or answers a question correctly. There are several ways in which variability between stations can occur (Khan et al. 2013). For example, patients may have signs to find such as heart murmurs which are slightly easier to auscultate than others; patients may give a detailed history easily or only when asked very specific questions; or patients may take longer in answering questions, giving the trainee less time in the station. Variation may also occur between examiners when ambiguous answers are given to questions and they are tasked with deciding whether they award a mark or not. Various quality control steps aim to mitigate, but not eliminate, this potential for variability (Khan et al. 2013). Using VPs either in conjunction with, or in replacement of, OSCE scenarios may help eliminate some of the variability mentioned. A limited number of patients, actors, and examiners available for OSCEs can also cause several problems, which having standardised virtual patients may help solve. One of which is a difficulty in re-scheduling exams at short notice due to events such as adverse weather. Further, if large groups of students are to be examined, quarantining may be necessary in order to prevent collusion (Noonan et al. 2018). Fully converting OSCEs to VP assessment would be unwise, since OSCEs must assess real authentic patient scenarios (Khan et al. 2013). Lin et al. (2018) have successfully integrated VPs and regular human standardised patients into their OSCE for pharmacists, using standardised patients for communication stations and virtual patients for data-related scenarios. Assessing in this way can ensure graduates have a good degree of computer literacy, which is increasingly necessary for jobs in the healthcare sector.

3.6 Barriers to Integration

There are several barriers inhibiting the integration of virtual patients into health professions education. Cost of designing high fidelity simulators (Pantelidis et al. 2018) and computer literacy of designers and educators (Berman et al. 2006) are both important factors. Basic VP games can be created using open-source storyboard software such as Twine (Fig. 3.2) but this requires a great deal of computer literacy and time to complete. Conversely, outsourcing to create high fidelity VP is extremely costly (Quail et al. 2018). Open-source collaboration networks such as the European Electronic Virtual Patients Programme (Electronic Virtual Patients 2019) are useful in sharing resources between medical schools could make integration of VP into the curriculum far easier.

3.7 Conclusion

VPs play a useful role in medical education in developing skills such as clinical reasoning and practical skills. They may also be useful in substituting patient encounters in order to simplify and standardise encounters for novices, allow long-term follow-up to be practised virtually, or when patient availability or cost is a barrier to clinical experience. As technology and health professions education literature continues to advance and grow, VPs may play an increasing role in the learning, teaching and assessment of healthcare professions education. Future research should be focussed on how to fully integrate VPs within health professions curricula medical curriculum, and how best to design VP in order to maximise their use in acquiring and improving clinical reasoning. Collaboration is desirable, and perhaps essential; between academic centres both in the creation of VPs resources, and the collection and analysis of VP data in order to better understand educational needs.

References

Arya S, Mulla Z, Kupesic Plavsic S (2017) Role of pelvic ultrasound simulation. Clin Teach 15(6):457–461

Begg M (2010) Virtual patients: practical advice for clinical authors using labyrinth. Clin Teach 7(3):202–205

Berman A, Biguet G, Stathakarou N et al (2017) Virtual Patients in a behavioral medicine massive open online course (MOOC): a qualitative and quantitative analysis of participants' perceptions. Acad Psychiatry 41(5):631–641

Berman NB, Durning SJ, Fischer MR et al (2016) The role for virtual patients in the future of medical education. Acad Med 91(9):1217–1222

Berman N, Fall L, Maloney C, Levine D (2006) Computer-assisted instruction in clinical education: a roadmap to increasing CAI implementation. Adv Health Sci Educ 13(3):373–383

Berman N, Fall L, Smith S et al (2009) Integration strategies for using virtual Patients in clinical clerkships. Acad Med 84(7):942–949

Bitzer M (1966) Clinical nursing instruction via the PLATO simulated laboratory. Nurs Res 15(2):144–150

Boyle J, Quail N, Loo X, Linn A (2016) Flipping the classroom: is it worth the bother? Clin Teach 14(2):137–138

Brown JS, Collins A, Duguid P (1989) Situated cognition and the culture of learning. Educ Res 18:32–42

Charlin B, Boshuizen HPA, Custers EJ, Feltovich PJ (2007) Scripts and clinical reasoning. Med Educ 241:1178–1184

Consorti F, Mancuso R, Nocioni M, Piccolo A (2012) Efficacy of virtual patients in medical education: a meta-analysis of randomized studies. Comput Educ 59(3):1001–1008

Cook DA, Triola MM (2009) Virtual patients: a critical literature review and proposed next steps. Med Educ 43:303–311

Cook DA (2009) The failure of e-learning research to inform educational practice, and what we can do about it. Med Teach 31(2):158–162. https://doi.org/10.1080/01421590802691393

Cook D, Andriole D, Durning S, Roberts N, Triola M (2010a) Longitudinal research databases in medical education: facilitating the study of educational outcomes over time and across institutions. Acad Med 85(8):1340–1346

Cook D, Erwin P, Triola M (2010b) Computerized virtual patients in health professions education: a systematic review and meta-analysis. Acad Med 85(10):1589–1602

Cook D, Friedman C, Greene P et al (2007) Effective use of educational technology in medical education. AAMC Institute for Improving Medical Education. Available via: https://members.aamc.org/eweb/upload/Effective%20Use%20of%20Educational.pdf. Accessed 15 Jan 2019

Daniel M, Rencic J, Durning SJ et al (2019) Clinical reasoning assessment methods: a scoping review and practical guidance. Acad Med 94(6):902–912

Denson P (2018) Challenges and opportunities facing medical education. Trans Am Clin Climatol Assoc 122:48–58

Electronic Virtual Patients (2019) Electronic virtual Patients website. Available via https://virtualpatients.eu. Accessed 15 Jan 2019

Ellaway R, Topps D, Lee S, Armson H (2015) Virtual patient activity patterns for clinical learning. Clin Teach 12(4):267–271

Eva KW (2005) What every teacher needs to know about clinical reasoning. Med Educ 39(1):98–106

Evans K, Daines W, Tsui J, Strehlow M, Maggio P, Shieh L (2015) Septris: a novel, mobile, online, simulation game that improves sepsis recognition and management. Acad Med 90(2):180–184

Feldman L, Shihab H, Thiemann D et al (2013) Impact of providing fee data on laboratory test ordering. JAMA Intern Med 173(10):903–908

Hardy S, Brown G (2010) Virtual patients and online video resources: useful when patient availability is reduced? Clin Teach 7(4):292–293

Harries R, Rashid M, Smitham P et al (2016) What shape do UK trainees want their training to be? Results of a cross-sectional study. BMJ Open 6(10):e010461

Hatala R, Brooks L, Norman G (2003) Practice makes perfect: the critical role of mixed practice in the acquisition of ECG interpretation skills. Adv Health Sci Educ 8:17–26

Hege I, Kononowicz A, Kiesewetter J, Foster-Johnson L (2018) Uncovering the relation between clinical reasoning and diagnostic accuracy – an analysis of learner's clinical reasoning processes in virtual patients. PLoS One 13(10):e0204900

Hege I, Ropp V, Adler M et al (2007) Experiences with different integration strategies of case-based e-learning. Med Teach 29(8):791–797

Heng N, Anbarasan T (2018) Comments on: "collaborative use of virtual patients after a lecture enhances learning with minimal investment of cognitive load". Med Teach 41(1):118–119

Higgs J, Jensen GM (2019) Clinical reasoning. In: Higgs J, Jensen GM, Loftus S, Christensen N (eds) Clinical reasoning in the health professions, 4th edn. Elsevier, Edinburgh

Huwendiek S, Duncker C, Reichert F et al (2013) Learner preferences regarding integrating, sequencing and aligning virtual patients with other activities in the undergraduate medical curriculum: a focus group study. Med Teach 35:920–929

Khan K, Gaunt K, Ramachandran S, Pushkar P (2013) The objective structured clinical examination (OSCE): AMEE guide no. 81. Part II: organisation & administration. Med Teach 35(9):e1447–e1463

Kleffner R, Flatten J, Leaver-Fay A et al (2017) Foldit standalone: a video game-derived protein structure manipulation interface using Rosetta. Bioinformatics 33(17):2765–2767

Klein M, Otto B, Fischer M, Stark R (2018) Fostering medical students' clinical reasoning by learning from errors in clinical case vignettes: effects and conditions of additional prompting procedures to foster self-explanations. Adv Health Sci Educ 24:331–351. https://doi.org/10.1007/s10459-018-09870-5

Kolb D (1984) Experiential learning: experience as the source of learning and development. Prentice-Hall, Englewood Cliffs

Kononowicz A, Zary N, Edelbring S, Corral J, Hege I (2015) Virtual patients – what are we talking about? A framework to classify the meanings of the term in healthcare education. BMC Med Educ 15(1):11

Lave J, Wenger E (1991) Situated learning: legitimate peripheral participation. Cambridge University Press, New York

Levinson W, Kallewaard M, Bhatia RS (2015) On behalf of the choosing wisely international working group, et al 'choosing wisely': a growing international campaign. BMJ Qual Saf 24:167–174

Lin C, Chang E, Clinciu D et al (2018) Using modified information delivery to enhance the traditional pharmacy OSCE program at TMU – a pilot study. Comput Methods Prog Biomed 158:147–152

Litchfield I, Bentham L, Hill A, McManus R, Lilford R, Greenfield S (2015) Routine failures in the process for blood testing and the communication of results to patients in primary care in the UK: a qualitative exploration of patient and provider perspectives. BMJ Qual Saf 24(11):681–690

Marei H, Donkers J, Al-Eraky M, Van Merrienboer J (2018) Collaborative use of virtual patients after a lecture enhances learning with minimal investment of cognitive load. Med Teach 41:332–339. https://doi.org/10.1080/0142159X.2018.1472372

Marquet O, Alberico C, Adlakha D, Hipp J (2017) Examining motivations to play Pokémon GO and their influence on perceived outcomes and physical activity. JMIR Serious Games 5(4):e21

McCoy L, Lewis J, Dalton D (2016) Gamification and multimedia for medical education: a landscape review. J Am Osteopath Assoc 116(1):22–34

Moro C, Štromberga Z, Raikos A, Stirling A (2017) The effectiveness of virtual and augmented reality in health sciences and medical anatomy. Anat Sci Educ 10(6):549–559

Motz P, Gray M, Sawyer T et al (2018) Virtual antenatal encounter and standardized simulation assessment (VANESSA): pilot study. JMIR Serious Games 6(2):e8

Muller D, Ornstein K (2007) Perceptions of and attitudes towards medical errors among medical trainees. Med Educ 41(7):645–652

Noonan Z, Boyle J, Pope L, Ditchfield C, Leach J, McDowall S (2018) Quarantining the OSCE: reflections on the Glasgow experience. Clin Teach. https://doi.org/10.1111/tct.12993

Norman GR, Eva KW (2010) Diagnostic error and clinical reasoning. Med Educ 44(1):94–100

Norman G (2014) Research challenges in digital education. Perspect Med Educ 3(4):260–265

Pantelidis P, Chorti A, Papagiouvanni I et al (2018) Virtual and augmented reality in medical education. In: Tsoulfas G (ed) Medical and surgical education – past, present and future. IntechOpen, London, pp 77–97

Posel N, Mcgee J, Fleiszer D (2014) Twelve tips to support the development of clinical reasoning skills using virtual patient cases. Med Teach 37(9):813–818

Quail N, Holmes K, Linn A, Rea P, Livingstone D, Boyle J (2018) Serious digital games using virtual Patients and digital chalk-talk videos: a novel approach to teaching acute diabetes Care in the Undergraduate Medical Curriculum. Diabet Med 35(S1):112–135

Satava R (2006) Assessing surgery skills through simulation. Clin Teach 3(2):107–111

Schmidt HG, Rikers RMJP (2007) How expertise develops in medicine: knowledge encapsulation and illness script formation. Med Educ 41:1133–1139

Seewoonarain S, Barrett M (2017) The technological evolution in surgical skills. Clin Teach 14(5):370–371

Singh H, Onakpoya I, Thompson M (2016) Diagnostic errors. World Health Organization. Available via: http://apps.who.int/iris/bitstream/handle/10665/252410/9789241511636-eng.pdf;jsessionid=9BC584CFD622CF7ADC54D6BD7C9D915D?sequence=1. Accessed 15 Jan 2019

Sperl-Hillen J, O'Connor P, Ekstrom H et al (2013) Using simulation technology to teach diabetes care management skills to resident physicians. J Diabetes Sci Technol 7(5):1243–1254

Talbot T, Sagae K, John B, Rizzo A (2012) Sorting out the virtual patient. Int J Gaming Comput-Mediated Simul 4(3):1–19

Urresti-Gundlach M, Tolks D, Kiessling C, Wagner-Menghin M, Härtl A, Hege I (2017) Do virtual patients prepare medical students for the real world? Development and application of a framework to compare a virtual patient collection with population data. BMC Med Educ 17(1):174

Van Bruggen L, Manrique-van Woudenbergh M, Spierenburg E, Vos J (2012) Preferred question types for computer-based assessment of clinical reasoning: a literature study. Perspect Med Educ 1(4):162–171

Zhou L, Tait G, Sandhu S, Steiman A, Lake S (2018) Online virtual cases to teach resource stewardship. Clin Teach 16:220–225. https://doi.org/10.1111/tct.12804

4 Student-Created Online Teaching Resources for Students

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Abstract

Students have long been creating their own visualisations of concepts taught through presentations, posters, figures in essays etc. However, with the introduction of technology, the content created by students is now easily shared with future cohorts of students. This chapter explores the history and advantages of student-created resources for students, then describes the examples of e-tutorials and MOOCs in more detail. Finally, future challenges are identified and discussed.

Keywords

Student-created · E-tutorial · Online · MOOC · Student visualisation · Medicine

4.1 Introduction

In the current era of student-centred education, students are increasingly expected to actively participate in their learning, rather than act as mere passive recipients of information. Active participation in learning takes many forms, and occurs when learners engage with higher levels of cognitive processing in their learning (Chi and Wylie 2014). At lower cognitive levels, active learning consists of asking students to solve problems, answer questions, discuss topics, apply concepts to new scenarios, etc. In 2001, the concept of "create" appeared in Bloom's revised taxonomy of knowledge as the highest cognitive process in learning (Fig. 4.1) (Anderson and Krathwohl 2001). However, asking students to create materials was not a new idea; what was new was the recognition that for a long time, teachers have attempted to engage students in the learning process by asking them to create new materials. Student-created materials have historically included traditional presentations and posters, but have sometimes also included more imaginative creations such as plays, dances, songs, poems, images and paintings (Furman 2005; Raingruber 2009; Tieva and Malmros 2018).

It is now widely recognised that asking students to create new material improves student retention and critical processing and analysis of information, encourages utilization of a wider range of research materials, develops insight into question setting skills and improves communication skills (Owston et al. 2009; Armstrong et al. 2009). Furthermore, student creation of material improves engagement in the learning process, and allows students to establish ownership of their learning processes, both of the topic and of the resulting material (O'Neill and Barton 2005).

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P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7_4

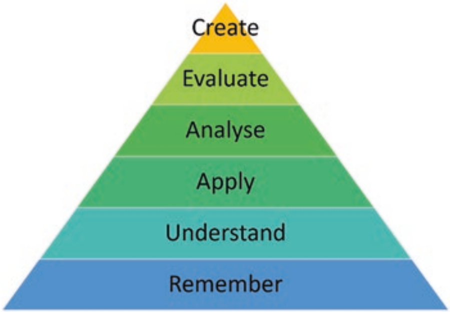


Fig. 4.1 Bloom's revised taxonomy of cognitive skills. (Adapted from Anderson and Krathwohl 2001)

While student visualisation of content has been facilitated through student-created materials for quite some time, the recent advances of technology have enabled the creation of an expanding range of materials. Students can now be asked to create videos, tutorials, MOOCs, games, podcasts, wikis, and an ever-increasing variety of others. The following examples illustrate the possibilities- whilst some are derived from out with the biomedical sciences, the approaches themselves are not disciplinary-specific, and have wider applicability.

Hamer (2006) has described his use of wikis and the 'contributing student' approach in computing classes, departing radically from traditional lecture-based teaching. This approach, developed by Collis and Moonen (2001), consists of students investigating one or two topics each, then sharing the results with the rest of the class. In Hamer's context, this was facilitated by the creation of a class wiki, and by transforming lectures into 'class meetings'. The student contributions were peer-assessed. This approach encouraged students to consider their readers, and how best to communicate with them – which information to include and which to omit, and how to keep the reader engaged. The use of the wiki also gave students an insight into the fact that the same topic can be viewed from different perspectives. As the wikis were undertaken in small groups, students also developed their team-working skills (Hamer 2006).

In a study by Owston et al. (2009), school students were assigned to groups which either followed the normal literacy curriculum, or a variation in which they also created computer games based around literacy skills. The games were created using a game development shell, and most of the content creation consisted of writing questions. Students who created games performed better on standardised literacy tests. A similar approach has been used in higher education, where collaborative question setting software such as Peerwise has been used to engage and motivate students, improve knowledge retention and encourage deep learning (Denny et al. 2008) in medicine (Walsh et al. 2015), veterinary students (Sykes et al. 2011) and biology (McQueen et al. 2014). Importantly, it has been noted that it is the setting of questions which improves student knowledge, rather than the more passive activity of answering questions (Rea and McClure 2012).

Armstrong et al. (2009) have used student-created podcasts in business education as an integral part of team-based research presentations. Students were tasked with, for example, interviewing a knowledgeable individual in their research topic area, allowing them to develop their professional communication and literacy skills. In an information technology classroom, Frydenberg (2006) noticed that his students were not engaging with the 60 minutes podcasts he provided after lectures. Realising that students wanted shorter resources, he challenged his students to create 6–10 min podcasts. This improved student engagement with the topics, as demonstrated by the dramatic increase in the number of podcast downloads.

All the above-mentioned examples demonstrate how student-created content can be used to increase ownership and engagement with learning for the student creators and their contemporary student cohorts. In addition, because these multimedia materials can easily be hosted online, the opportunity arises to share the materials with other students within and outwith the cohort, allowing them to be utilised by students in future cohorts or by learners outside the course itself. By asking students to create materials which can be used by other students for learning purposes, we essentially turn the students into asynchronous peer teachers. Peer teaching has been frequently used in physics lectures to engage students in active learning (Crouch and Mazur 2001), but has also been used in teaching anatomy (Evans and Cuffe 2009), medicine (Durning and Ten Cate 2007) and biology (Tessier 2007). Peer teachers have been found to communicate with their peers more effectively than teaching staff, leading to a better learning environment (Evans and Cuffe 2009). The success of peer teaching is thought to lie in the fact that students who do not yet understand a concept increase their understanding by explaining the concept to a student who is in earlier stages of their own comprehension (Nicol and Boyle 2003). Additionally, students are often more familiar with their courses than some teachers, and explain new learning experiences in the context of the whole curriculum (Field et al. 2007).

It is therefore a reasonable hypothesis that peer-teaching students will be able to create visualisations of concepts which are better targeted for their peer audience, and therefore may lead to better understanding than visualisations made by staff teachers. Furthermore, asking students to create content which is to be used by future students makes their work more meaningful, and gives students an awareness of the need for the factual accuracy of the content as well as creativity (Benedict and Pence 2012).

In recent years, a trend for student-staff partnerships and student engagement in shaping the curriculum has emerged in higher education (Bovill et al. 2011). Together with the wider use of online and blended learning, it is therefore not surprising to see the emergence of student-created content used for teaching future cohorts. In a 2008 review, Marc Prentsky lists many examples of games created by students for students. He explains that games created by teachers "*smell too much like school*", and are "*cute to the adults, but boring to the kids*". He describes the creation of mini-games, that is, games that typically take about an hour to complete and which can usually be created by a single team of student developers. Mini games are usually designed to develop a single skill, although they may contain several levels, which are essentially more difficult versions of the same game. Prentsky suggests that a curriculum can be split into individual skills, and a game developed for each skill. Of course, to cover a curriculum, several hundreds of simple games would need to be developed- a task impossibly large for teachers, but ideally suited to student creation (Prentsky 2008).

Benedict and Pence (2012) used student created videos and photo blogs to help college students in chemistry labs after finding that students were struggling to visualise how to perform certain procedures from written instructions in laboratory manuals. The videos and photo blogs created by students were linked to 2D barcodes, found in either the manuals or on scientific instruments. Using smart phones, students can easily access these resources, which help them visualise the instructions and understand how to use the equipment.

Nie et al. (2008) asked students to create podcasts as part of a genetics course for medical students at the University of Leicester. They showed that the student creators became more empowered, active and independent learners. In addition, the student creators were more engaged, motivated, and improved their cognitive learning and team-working skills. However, they did not evaluate the impact on the peer-learners to whom the podcasts were offered.

It is clear that student creation of materials to be used by future students has many benefits for the student creators, the student learners and the teachers themselves. Here we describe two recent projects from the School of Medicine, Dentistry & Nursing at the University of Glasgow, which have made use of student created content to teach future student cohorts and the general public. These projects required the creation of complex online resources, which combine a range of material and media.

4.1.1 Example 1: E-tutorials

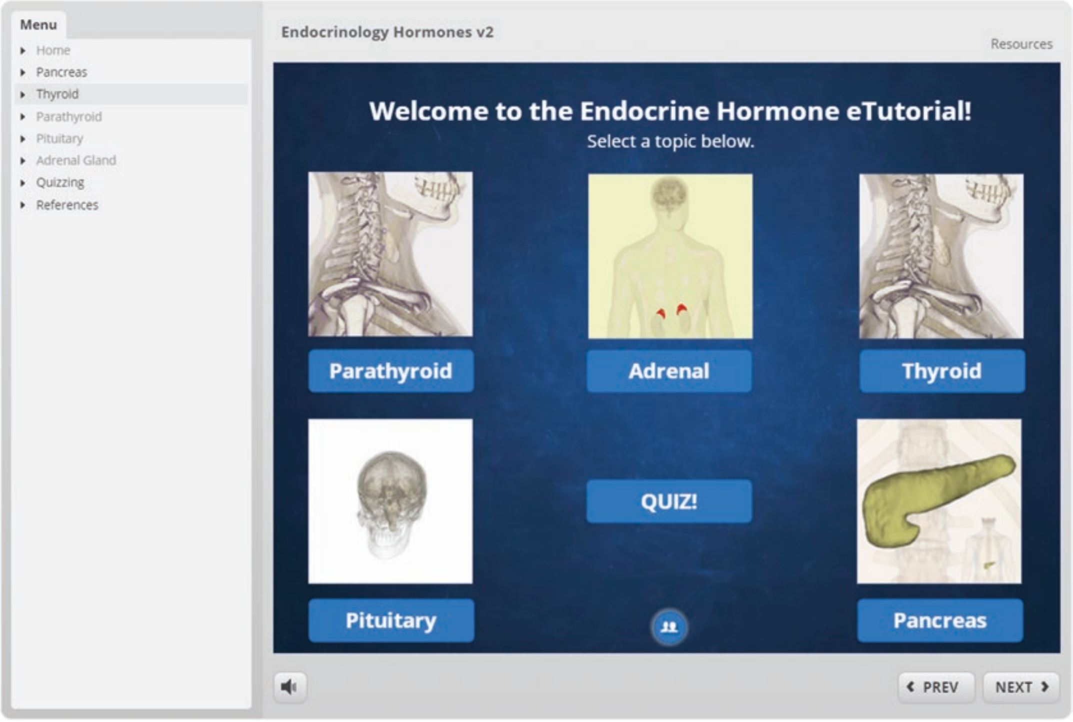
It has previously been reported that students find the visualisation of biological pathways difficult, especially as there are no standards for representation (dos Santos and Galembeck 2015). Visualisation of pathways is not a skill that is learned in higher education, but rather one that is learned informally through experience (dos Santos and Galembeck 2015). In some studies, students have shown a preference for online instruction for specific information, which they can engage with as and when required, the so-called 'just-in-time' teaching (Schimming 2008). With this in mind, pairs of students in the second year of their MBChB were asked to create online resources for their peers on endocrine anatomy and signalling, as part of a 5-week Student Selected Component (SSC). To maximise the student input in the creation of the e-tutorials, the students themselves performed the needs analysis, and determined the main topic of each tutorial, as well as the specific subtopics that would need to be covered- concepts that they or their peers found particularly challenging. The learning needs were cross-checked with the intended learning outcomes of the endocrine curriculum, to ensure the material covered in the tutorials would be relevant to the MBChB course. The students were then given a brief introduction to active learning teaching methods and to the Articulate Storyline 2 software, and asked to develop a plan for their e-tutorial. Using Articulate Storyline 2 allowed students to create a highly branched, personalised and engaging e-tutorial. They included quizzes which allowed students to test their understanding after each part of the tutorial, and a summary quiz to test their overall understanding after completing the tutorial. All quizzes included immediate feedback for correct and wrong answers. Quizzes maintained engagement by including MCQ questions, as well as drag and drop questions, matching, hotspot (identifying a specific area of a diagram for example), and short answer questions.

The students created e-tutorials with highly branched structures. On the home screen, learners must choose one of 5 different organs to focus on. For each organ, learners then need to select a further specific sub-topic to focus on (Fig. 4.2). As the layout is branched rather than linear, it allows the learner to choose a topic to focus on based on their own interest and learning needs, rather than what the teacher or creator thinks is the most logical approach.

In the endocrine anatomy tutorial, students drew their own diagrams, which they turned into interactive learning objects. Learners click on various areas of each organ, and when selected, the name of the area becomes visible and the area is highlighted in colour. This facilitates active learning, as learners must be engaged and click on each part of the organ to find out its correct name. It also helps learner visualisation- in classic textbook illustrations, arrows may denote a specific small area or to a large section of an organ. Using these interactive objects, it is immediately clear how much of the organ is associated with each label (Fig. 4.3). This technique was also used by the student creators to help learners understand and visualise histology sections of each organ.

In the endocrine signalling tutorial, student creators broke down signalling pathways into small segments, which they then built back up in successive layers. Each layer is accompanied by specific explanatory text, and is added actively by the learner through mouse clicks. This allows each learner to engage with the concept at their own pace, and helps visualisation by seeing the signalling pathways build slowly on their screen. Similarly, the student creators used the hovering functionality to add extra information for certain terms, which only appears when learners hover over the word. It therefore does not add complexity and cognitive load (Paas et al. 2003) to the concept being explained, but allows learners to look for extra information if they require it. Animated 3D images of the endocrine gland anatomy were also included in the e-tutorial to improve learner visualisation. Interestingly, the segmentation of the concept into smaller parts not only improved the student creator's own understanding of the topic, but also influenced their personal approach to learning, as evidenced in these reflections:

> *I had to break everything down in order to understand and explain it better … This helped, not only with endocrinology, but with all other aspects of my revision – I now break everything down so it is easier to explain and process.*



Welcome to the Endocrine Hormone eTutorial!
Select a topic below.

Fig. 4.2 Home screen for the Endocrine signalling e-tutorial. (Image courtesy of Roddy Grant and Naomi Dunphy)

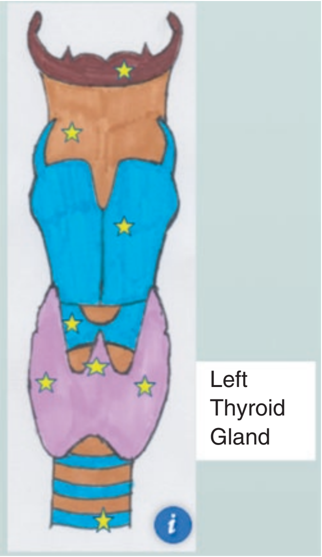


Fig. 4.3 Gross anatomy of the thyroid and associated structures, hand drawn by the student creators. Clicking on the stars makes the appropriate label pop up. (Image courtesy of Michaela Pishia and Monica Swinney)

> *I really struggled to put together all the different aspects of endocrinology and how they all worked together. Though the e-tutorial I was able to develop my understanding of the smaller aspects and then put these together in a big picture and see how they all interact.*
>
> *… I now break large complex pathways down into smaller chunks to learn in more reasonable sizes before gradually putting it back together to form the bigger picture clearly.*

Once built, the e-tutorials were content checked by the endocrinology block lead and co-ordinator, as well as by an expert anatomist. This was particularly important as the tutorials are to be used to teach future cohorts of students. The tutorials then underwent alpha testing using a concurrent think aloud (CTA) method (van den Haak et al. 2010). In CTA, a few student peers engaged with the tutorial while the student creators were in the room. They voiced their thoughts out loud while navigating through the tutorial, and their comments were used to improve the tutorial before beta testing. During beta testing, the whole year cohort was invited to engage with the tutorials, and fill out an online questionnaire before and after. Their comments were then used to make further adjustments and improvements to the e-tutorials.

The fact that the e-tutorials were created by students is clearly stated at the start of the tutorial. Following a pilot evaluation, user feedback was very positive:

> *I think it was excellent! It highlighted the key points and was highly structured; making it effective revision.*
>
> *Having extra questions to practice on is very much appreciated; the questions were well thought out and I could consolidate what I had learned so far.*

In addition, we expected student creators to have an increased interest, ownership and knowledge of the topics covered in their e-tutorials. Unsurprisingly, this was evidenced in their reflections:

> *It was definitely my strongest area of knowledge by the end of the year, and it helped me understand and enjoy the topic more afterwards.*

In the future, as a result of student demand, more student-created tutorials will be developed to support the MBChB, and when required older ones (Rea and Linn 2017) produced can be quickly up-dated to ensure continued alignment with the intended learning outcomes for the programme.

4.1.2 Example 2: MOOCs

Originating around 2008, Massive Open Online Courses (MOOCs) are accessible to anyone with an internet device, often attracting large number of participants. At least in their most basic forms, they are free to undertake. With SSCs being arguably one of the most creative aspects of the undergraduate medical curriculum (which inherently includes substantial 3-dimensional or visual material), it seemed natural to tie together these aspects, giving students the opportunity to create visual resources during the SSC period. MOOCs seemed a natural avenue to explore this aspect.

Having gained experience from our previous staff-led MOOC creation and the integration of this and other MOOCs into a 'blended' SSC, we have now offered a Medical Education SSC in MOOC creation in two academic sessions. We previously also had experience of working with a Life Science student to develop the 'So you want to Study Life Sciences?' MOOC. Contrary to our own expectations from anatomy-based MOOCs, and with freedom of choice in terms of content, our SSC students elected to develop more abstract concepts, opting for a First Aid MOOC and a Widening Participation MOOC. These were two- and three-week courses, respectively, with the former drawing almost exclusively on content created by the students, and the latter evolving into a wider staff-student partnership, due to the nature of the widening participation agenda.

While students are often encouraged to draw mind maps and other forms of visual stimulus to aid memory and integration of material, these forms of revision are inherently 2-dimensional. The concept of creating a timeline of content for another user adds the dimension of time to the process, a powerful concept and one which begs further investigation. The seemingly simple task of breaking content into several weeks and then further subdividing into coherent blocks may in itself give great understanding of the material.

Content in MOOCs varies greatly, from heavily text- and video-'lecture'-based, to highly creative and collaborative approaches. While much of the content of our student-created MOOCs is based on the written word, there are many examples of visual aspects which would not necessarily be used in more traditional forms of student work. Creation of a 'fun facts' visual, for example, requires students to focus on much more than just the words themselves, but rather on issues such as colour, spatial layout, text format and accessibility. One could argue that these aspects detract from content, but others have shown that visualization of complex concepts can assist students in conceptualization of the material (Wu et al. 2001).

The idea of students themselves 'becoming' the content is another novel aspect of using video within a MOOC setting. In our example, students demonstrated the recovery position with one playing the role of the patient and another the first aider. Creation of video content has previously been shown to promote a more 'authentic learning experience' (Kearney and Schuck 2004) as well as increasing motivation and engagement (Ryan 2002).

Opportunities such as these align well with learning objectives with adjectives such as 'describe', 'demonstrate' etc. This aspect is in some ways analogous to the 'signalling pathway' dance cited previously (Tieva and Malmros 2018), and is also familiar in simulation and virtual reality scenarios. For topics such as CPR, which perhaps involve a deeper grasp of the material than 'Fun Facts' might, it was interesting to see how the students visualized the topic in different ways, as was seen in the varied approaches taken to content development. In addition to more standard checklists of procedures to be followed, students also designed flowcharts and quizzes and linked to external content where relevant.

A further powerful aspect of MOOC creation lies in the audience itself. One of the first students to undertake these MOOC design projects in Glasgow commented that the visual map representation of the learners was a powerful motivator for both the quality and also the ownership of his work. Seeing potentially thousands of learners from over 100 countries engaging with his work (Fig. 4.4) was placed in stark comparison with the 'audience of 1' for whom he was used to writing for. The opportunity (as yet untapped) for student creators to engage with their learners through forum discussions is another potential motivator.

> *It's easy to become apathetic when completing extensive written work in University as at best two markers will read it, and at worst two will merely skim….It was really fulfilling initially sending out my (MOOC) into the world, but only became more exciting as people actively interacted with it….. helped to cement its value to me and also provided an opportunity to really evaluate its content. Putting it in the public sphere made the creation feel valuable and something I could be proud of*

In a similar manner to the e-tutorials, the content of the MOOCs was reviewed by staff before releasing it to a wider audience. The MOOC was also subject to stringent FutureLearn quality assurance checks, as is standard practice. As the work produced is representative of the University of Glasgow and may be used to inform practice, it is vital that these checks occur. However, rather than being viewed as negative 'correction' of student work, this process may rather be viewed as contributing to student professionalism learning, and part of key skills in receiving and responding to feedback.

The resultant First Aid MOOC may be viewed at: https://www.futurelearn.com/courses/basic-first-aid

A further course created by an undergraduate life sciences student has since been retired but basic information is available from: https://www.futurelearn.com/courses/so-you-want-to-study-life-science

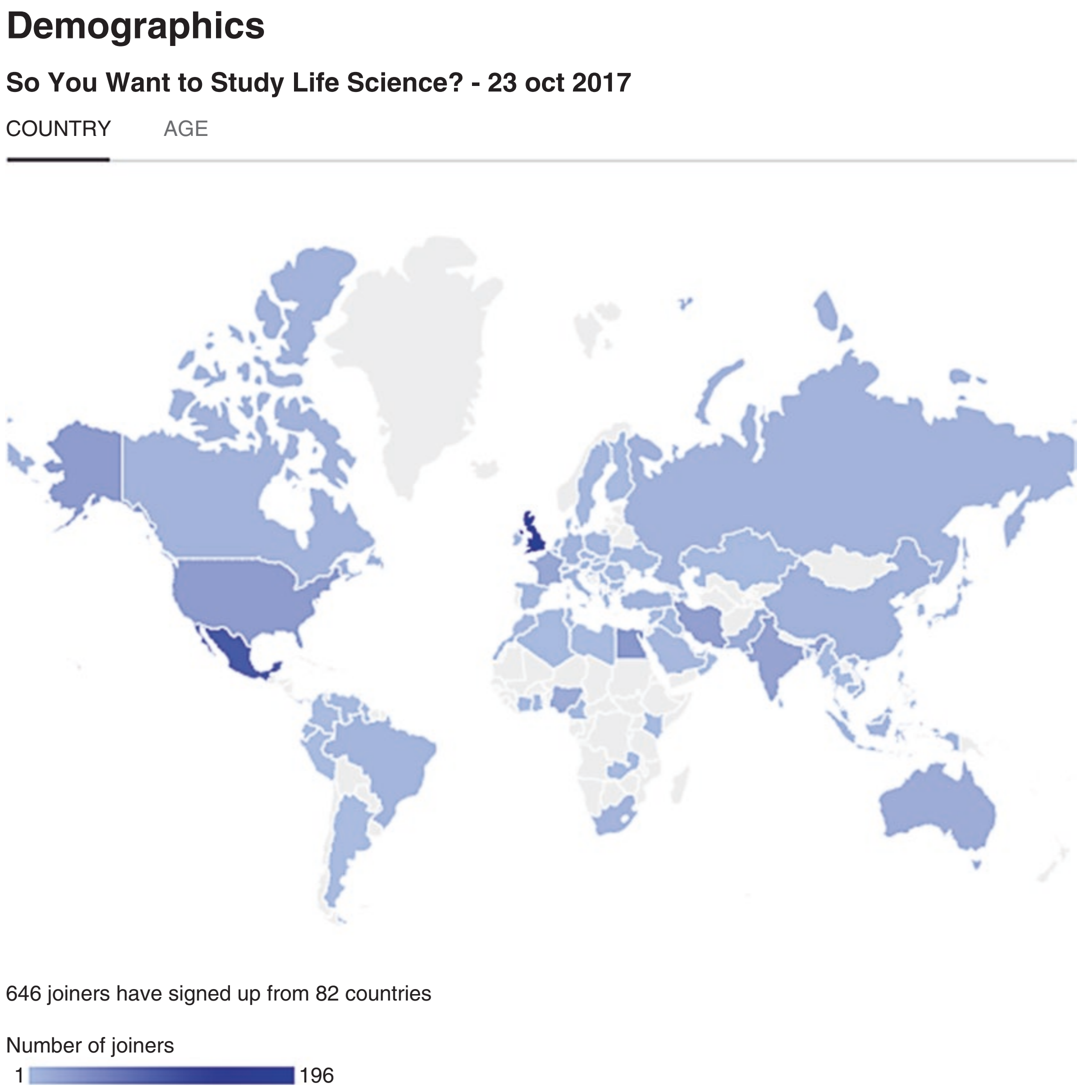
The Widening Participation MOOC is currently under development and registration will be open in the near future at https://www.futurelearn.com/

4.1.3 Future Directions

The rise of student-staff partnerships, and the drive to increase student engagement not only with taught material but also in shaping curriculum and assessment (Bovill et al. 2011), is likely to lead to a wider use of student-created content for teaching purposes. This new era will need to face and resolve some fresh educational challenges.

4.1.4 Technology or Education Led?

Firstly, as with more traditional forms of teaching, when asking students to create resources, it is important to avoid choosing a technology to use for teaching, but rather, ask student creators to establish the learning needs of their peers and then select the most appropriate technology to address those. For example, we must be mindful that videos do not in themselves stimulate active learning in their audience, and may not be ideal to promote deep understanding of topics. It is therefore vital to teach student creators about the



Demographics

So You Want to Study Life Science? - 23 oct 2017

646 joiners have signed up from 82 countries

Fig. 4.4 Worldwide reach of student developed MOOC

principles of active learning and how to design resources accordingly before they are asked to create any content to be used by their peers.

4.1.5 Quality Assurance

It is also of crucial importance that the materials created by students are of high quality, but how is that quality determined? Perez-Mateo et al. (2011) have proposed a framework to evaluate the quality of learner-generated content, which uses 19 criteria such as adequacy, reliability and clarity (Perez-Mateo et al. 2011). These criteria can be given to student creators to ensure that they aim for a high quality product, and can be used by teachers to assess the quality and utility of the created resources.

4.1.6 Accessibility

On a more practical level, as with any other type of visualisation, the challenge of accessibility will need to be overcome, to allow students with visual impediments to engage with the created resources. Interactive diagrams, animated 3D models and layered signalling pathways will be particularly challenging.

The student-created materials also need to be easily accessed in terms of time and space. This can be achieved using elegant virtual learning environment design, or through the use of 2D barcodes (Benedict and Pence 2012). It is also important that the materials are accessible through mobile technology, as desktop computer and even laptop use is starting to decrease (Benedict and Pence 2012).

As technology advances, it will become easier for students to create more complex resources, such as augmented reality and virtual reality resources. This is already done at the University of Glasgow (Medical Visualisation & Human Anatomy MSc), where some VR/AR resources have been created by students for use by other learners. However, these resources are currently only created by students studying visualisation techniques as part of a Masters degree. In future, we envisage that this technology will be used directly by undergraduate students from a wider range of subjects, to create learning resources for their peers.

4.1.7 Content Curation

As students create more and more resources for their peers, how will this content be managed and curated? What will happen to the content once such a volume has been created, that it cannot all be used by peers? Will it then be up to the teachers to select which should be prioritised, or will that be another task for students themselves to decide? Will students use this material to build their own learning communities? Will student motivation to create new materials decline, once they know that suitable resources already exist?

The hypothesis made earlier in the chapter (that peer-teaching students will be able to create visualisations of concepts which are better targeted for their peer audience, and therefore may lead to better understanding than visualisations made by staff teachers) remains to be thoroughly tested. But if it turns out to be correct, will students be able to create learning resources that are of such quality that they replace some or even all core teaching? How would that be viewed by regulatory bodies, and what happens to the role of the teacher? Does the teacher then truly become the ‘guide on the side’, helping students create and edit learning resources, rather than directly transferring knowledge?

These scenarios may seem a little far-fetched, but increased peer-created visualisation seems likely to be the future of sharing of information, as evidenced by the existence of a journal which, rather than publishing written articles, publishes videos of scientific experiments: The Journal of Visualized Experiments (JoVE) Homepage. http://www.jove.com/

References

Anderson LW, Krathwohl DR (2001) A taxonomy for learning, teaching and assessing: a revision of bloom’s taxonomy of educational objectives: complete edition. Longman, New York

Armstrong G, Tucker J, Massad V (2009) Achieving learning goals with student-created podcasts. Decis Sci J Innov Educ 7(1):149–154

Benedict L, Pence H (2012) Teaching chemistry using student-created videos and photo blogs accessed with smartphones and two-dimensional barcodes. J Chem Educ 89:492–496. https://doi.org/10.1021/ed2005399

Bovill C, Cook-Sather A, Felten P (2011) Students as co-creators of teaching approaches, course design and curricula: implications for academic developers. Int J Acad Dev 16(2):133–145. ISSN 1360-144X

Collis B, Moonen J (2001) Flexible learning in a digital world: experiences and expectations. Kogan Page, London, p 2001

Chi M, Wylie R (2014) The ICAP framework: linking cognitive engagement to active learning outcomes. Educ Psychol 49(4):219–243. https://doi.org/10.1080/00461520.2014.965823

Crouch C, Mazur E (2001) Peer instruction: ten years of experience and results. Am J Phys 69:970–977. https://doi.org/10.1119/1.1374249

Denny P, Hamer J, Luxton-Reilly A, Purchase H (2008) PeerWise: students sharing their multiple choice questions. ICER’08, September 6–7, 2008, Sydney, Australia

Dos Santos V, Galembeck E (2015) Metabolic pathways visualization skills development by undergraduate students. Int Union Biochem Mol Biol 43(3):162–167. https://doi.org/10.1002/bmb.20858

Durning S, ten Cate O (2007) Peer teaching in medical education. Med Teach 29(6):523–524. https://doi.org/10.1080/01421590701683160

Evans D, Cuffe T (2009) Near-peer teaching in anatomy: an approach for deeper learning. Anat Sci Educ 2:227–233. https://doi.org/10.1002/ase.110

Field M, Burke J, McAllister D, Lloyd D (2007) Peer-assisted learning: a novel approach to clinical skills learning for medical students. Med Educ 41:411–418. https://doi.org/10.1111/j.1365-2929.2007.02713.x

Frydenberg M (2006) Principles and pedagogy: the two P’s of podcasting in the information technology classroom. Proc ISECON 23:1–10

Furman R (2005) Using poetry and written exercises to teach empathy. J Poet Ther 18(2):103–110. https://doi.org/10.1080/08893670500140549

Hamer J (2006) Some experiences with the “contributing student approach”. ITiCSE’06, June 26–28, 2006, Bologna, Italy, pp 68–72

Kearney MD, Schuck SR (2004) Authentic learning through the use of digital video. Research, reform, realise the potential? In: Au W, White B (eds) ACEC2004. Australian Council for Computers in Education, Adelaide, pp 1–7

McQueen HA, Shields C, Finnegan DJ, Higham J, Simmen MW (2014) PeerWise provides significant academic benefits to biological science students across diverse learning tasks, but with minimal instructor intervention. Biochem Mol Biol Educ 42(5):371–381. https://doi.org/10.1002/bmb.20806

Nicol D, Boyle J (2003) Peer instruction versus class-wide discussion in large classes: a comparison of two interaction methods in the wired classroom. Stud High Educ 28(4):457–473. https://doi.org/10.1080/0307507032000122297

Nie M, Cashmore A, Cane C (2008) The educational value of student-generated podcasts. In: ALT-C 2008 research proceedings, pp 15–26

O’Neill T, Barton A (2005) Uncovering student ownership in science learning: the making of a student created mini-documentary. Sch Sci Math 105(6):292–301

Owston R, Wideman H, Sinitskaya Ronda N, Brown C (2009) Computer game development as a literacy activity. Comput Educ 53:977–989

Paas F, Renkl A, Sweller J (2003) Cognitive load theory and instructional design: recent developments. Educ Psychol 38(1):1–4. https://doi.org/10.1207/S15326985EP3801_1

Perez-Mateo M, Maina M, Guitert M, Romero M (2011) Learner generated content: quality criteria in online collaborative learning. Eur J Open Dist e-Learn: 1–12. ISSN: 1027-5207

Prentsky M (2008) Students as designers and creators of educational computer games: Who else? Br J Educ Technol 39(6):1004–1019. https://doi.org/10.1111/j.1467-8535.2008.00823_2.x

Raingruber B (2009) Assigning poetry reading as a way of introducing studentsto qualitative data analysis. J Adv Nurs 65(8):1753–1761. https://doi.org/10.1111/j.1365-2648.2009.05025.x

Rea P, McClure J (2012) The use of peerwise in a student selected component within the medical curriculum led to improvement in examination performance. In: 5th annual university of Glasgow learning and teaching conference: empowering student learners in higher education, Glasgow, Scotland, 17th Apr 2012

Rea P, Linn A (2017) Creation of e-tutorials to enhance medical students anatomy learning experience using articulate storyline. In: Ma M, Oikonomou A (eds) Serious games and edutainment applications, vol 2, 2nd edn. Springer, London, pp 203–221. ISBN 9783319516431

Ryan S (2002) Digital video: using technology to improve learner motivation. Mod Engl Teach 11(2):72–75

Schimming L (2008) Measuring medical student preference: a comparison of classroom versus online instruction for teaching PubMed. J Med Libr Assoc 96(3):217–222

Sykes A, Denny P, Nicolson L (2011) PeerWise – the marmite of veterinary student learning. In: 10th European conference on e-learning, Brighton Business School, University of Brighton, UK, 10–11 Nov 2011, pp 820–830. ISBN: 9781908272232

Tessier J (2007) Small-group peer teaching in an introductory biology classroom. J Coll Sci Teach 2007:64–69

Tieva A, Malmros B (2018) What could teachers learn from catching sight of students understanding? In: International society for the scholarship of teaching and learning. I.3.2. 24–27 October 2018 Bergen, Norway. https://issotl18.w.uib.no/friday/friday-psi/#psi

Van de Haak M, De Jong M, Schellens PJ (2010) Retrospective vs. concurrent think-aloud protocols: testing the usability of an online library catalogue. Behav Inform Technol 22:339–351

Walsh J, Denny P, Smith P (2015) Encouraging maximal learning with minimal effort using PeerWise. Med Educ 49:513–541

Wu HK, Krajcik JS, Soloway E (2001) Promoting understanding of chemical representations: students’ use of a visualization tool in the classroom. J Res Sci Teach 38(7):821–842. https://doi.org/10.1002/tea.1033

5

Massive Open Online Courses: Current and Future Trends in Biomedical Sciences

Jo-Anne Murray

Abstract

The first massive open online courses or MOOCs were offered in 2008 in the USA, since then MOOCs have hit the higher education (HE) section by storm and have continued to grow rapidly since 2012, with hundreds of HE establishments across the globe engaged in providing MOOCs. MOOCs are online courses that are open to everyone and anyone to join with typically no limits to the number of participants or prerequisite qualifications. In some MOOCs there is an option to pay for a certificate upon completion. This chapter captures the use and future of MOOCs in the biomedical sciences. As the number of MOOCs available in biomedical subject areas grow, so do the number of participants taking these courses, with many of these learners and professionals looking to update their knowledge in the biomedical sciences.

There is also a growing use of MOOCs in higher education as a recourse for campus degree programmes, known as hybrid MOOCs, where the MOOC provides the learning and the assessment is undertaken by the educational institution. The growing number of MOOCs available for credit is changing the way some learners are accessing higher education and the development of micro degrees obtained through the completion of a number of MOOCs may potentially change the way higher education is provided in the future. Finally, the potential of artificial intelligence to provide virtual classroom assistants is also a possible game changer, allowing more personalised learning to be delivered at scale.

Keywords

Open online courses (MOOC) · Biomedical

5.1 Introduction

Massive open online courses (MOOCs) are a relatively recent addition to what can be described as a rapidly expanding set of open educational resources. The first massive open online courses or MOOCs were offered in 2008 in the USA, since then MOOCs have hit the higher education (HE) section by storm and have continued to grow rapidly since 2012, with over 900 hundred (by 2018) HE establishments across the globe engaged in providing over eleven thousand MOOCs collectively (Shah 2018), with some course enrolments in the six figures.

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P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7_5

Since 2012, over 100 million learners have taken a MOOC. MOOCs are online courses that are open to everyone and anyone to join with typically no limits to the number of participants or prerequisite qualifications. MOOCs were launched by Stanford University professors as an extension of offering open and free online versions of their campus-based courses. Therefore, as their name suggests, MOOCs typically attract thousands of participants permitted by the online delivery method, which negates the spatial limitations of the traditional classroom. In fact, this mass education approach has received considerable media attention, resulting in some academics almost becoming celebrities. However, more importantly, MOOCs permit access to quality education for learners across the globe from diverse backgrounds. In fact, the initial MOOC concept was to democratise education and inform the world on the quality of education provided by institutions.

MOOCS were, to an extent, vilified due to their potential to disrupt education and damage the HE sector. However, along with a better understanding of MOOCs that has been developed over time, the reality is that the impact of MOOCs is more nuanced than these early extreme views. Most early MOOCs had no entry requirements and were offered free of charge, with little or no interaction with the instructors. MOOCs were and still are, to an extent, designed for the lifelong learning market. Most MOOCs have a start and end date, but generally remain open for registration after the course has started and participants usually have access to the course for a considerable period of time after the course has ended. MOOCs utilise the internet to deliver education, in part using a similar approach to social-networking sites. MOOCs have the potential to be a very valuable source of learning in the biomedical sciences due to their accessibility and global reach, with anyone, anywhere being able to participate as long as they have internet access. There are a number of platforms that institutions can engage with to deliver MOOCs, with some universities delivering MOOCs with multiple providers. Moreover, there are millions of participants from across the globe participating in MOOCs. In some MOOCs, there is an option to pay for a certificate upon completion.

5.2 MOOC Pedagogy

One of the great benefits of MOOCs is that they offer the potential to widen participation in education, in particular allowing learners across the globe to participate when historically they have been unable to (Lane 2013). MOOCs are based on building connections, supporting collaboration and sharing resources, and are modelled on a delivery mechanism that requires little or no tutor input. Therefore, MOOCs require instructional design that facilitates large-scale feedback and interaction. MOOCs could be described as being the ultimate in flexible education, with participants being able to study almost anything, anytime and anywhere. MOOC learners can also choose whether to complete the assessments or indeed continue with the course if it is not suited to them. However, the term “MOOC” encompasses a wide range of course formats.

Some MOOCs rely heavily on peer-review and collaboration and are therefore considered to be *connectivist* MOOCs (Kop 2011) and often referred to as “cMOOCs”, and many of the early MOOCs were delivered in this way. In fact, cMOOCs were an extension of the open educational resource movement, but also incorporated highly distributed peer learning. Connectivist MOOCs are linked to the notion of social learning with others, with emphasis placed on learning through interaction with others. Connectivism is based on the philosophy of a network-based pedagogy (Siemens 2005). Another approach to MOOCs incorporates the use of automated feedback mechanisms through objective online assessments and these have been described as *broadcast* MOOCs or “xMOOCS”. xMOOCs are generally structured in the same way as traditional lecture formats and usually delivered through a proprietary learning management platform that MOOC providers have developed for the specific use. xMOOCs concentrate on content, scalability and automation to facilitate mass education, and the main MOOC providers

(Coursera, EdX and Futurelearn) all offer xMOOCs. Most xMOOC models are designed as a short course with video presentations, quizzes and discussions. They are generally time limited, typically running over a period of between 2 and 10 weeks with emphasis on self-directed learning and some light-touch tutoring. The main difference between a MOOC and a traditional online course is the scale, structure and level of academic input when the course is running.

Most MOOCs are generally organised around a weekly structure where learners can access the learning materials at a time that suits them. Over time, the quality of the learning materials has improved, mostly in relation to the video content, with today's videos being of professional quality with animations and simulations. These videos take various formats, but talking heads are the most common. The main difference between a MOOC and other online courses is the length of the lecture videos, which are usually between 5 and 10 min in length and have in-video quizzes embedded. In fact, this practice has informed online learning in general, with HE institutions reducing the length of video learning materials. The benefit of these short video lectures is that learners can spend as much time on each segment as they need, providing greater flexibility to their learning. In addition to the videos, participants are encouraged to participate in discussions on the course forum areas.

The main difference between MOOCs and online degree courses is the level of interaction from the course instructor. In MOOCs, instructor input is significantly lower than in an online degree course, and peer discussions predominate. Assessments are primarily though the use of automated multiple-choice questions or peer review, where the learners evaluate, and grade assignments based on a defined rubric. Some MOOCs also offer learners the option to participate in live video sessions run by the course instructor and participants can also be encouraged to continue their discussions on social media platforms, such as Facebook. There have been MOOCs where students from specific areas of the world have formed their own discussion groups and have also arranged to meet face to face.

5.3 Biomedical Sciences MOOCs

A number of higher education institutions have developed MOOCs in the biomedical sciences, ranging from biomedical big data to MOOCs on specific aspects of health and disease. Indeed, there are hundreds of MOOCs available in bioscience subjects across the various MOOC platforms. In fact, there are six biomedical MOOCs in the top 50 MOOCs of all time (as at 2018) in dementia, clinical statistics, mindfulness, the musculoskeletal system and the body's vital signs. Many of these MOOC participants are healthcare professionals looking to update their knowledge in a specific area, indeed there is evidence to suggest that clinical practice has improved following the completion of a MOOC course, particularly in developing countries (Albrechestsen et al. 2017).

MOOCs allow working professionals to participate in self-directed study and are playing a role in supporting continuous education and ongoing professional development (Dhanani et al. 2016). In fact, the majority of learners enrolled in Coursera MOOCs in 2013 (Sandeen 2013) had already obtained one or more degrees. Furthermore, the optional assessment and completion certificate that many MOOC courses provide allows participants to evidence their learning for continual professional development purposes. Another aspect of MOOCs is that they bring together learners from a wide variety of backgrounds; for example, healthcare professionals can interact with the public and better appreciate public perception and understanding of various subject areas.

Some MOOCs are developed to increase public awareness of a topic, often with the aim of improving health and wellbeing; for example, a MOOC on human nutrition was reported to significantly improve eating behaviours and meal composition in participants (Adam et al. 2015). A MOOC designed to raise awareness of Animal Welfare also reported an improvement in participants' understanding of animal welfare and the scientific research behind it (Mackay et al. 2016). MOOCs have also been used to disseminate research findings and to facilitate a flipped classroom approach to research by a global cohort (de Castaneda et al. 2018). Indeed, many grant awarding agencies request that a MOOC is developed to disseminate the research findings. A criticism of biomedical research has been the lack of knowledge exchange and dissemination, and MOOCs are one way of addressing this.

MOOCs have also been used as a tool to help students decide upon and transition into a biomedical sciences degree; for example, the MOOCs “So you want to study life science?”, “do you have what it takes to be a vet?” and “So you want to become a surgeon?”. These are in addition to the many MOOCs that have been developed to help students prepare for university. The “do you have what it takes to be a vet?” MOOC attracted a large proportion of leaners that hoped the course would help them decide whether a career in veterinary medicine was something worth considering, with many stating that it definitely helped with their decision making and others changing their mind (Paterson et al. 2017).

5.4 Participation and Retention

Despite the growing popularity of MOOCs, retention rates overall are typically very low, with less than 10% completing the full course (Hone and El Said 2016), which appears to be attributable to lack of time and motivation to study, as well as feeling isolated when interaction on the MOOC is low. Studies have also reported course instructor to have the largest positive effect on completion rate (Adampoulos 2013). Indeed, some MOOCs have reported completion rates of 30% and above (Murray 2014).

In terms of online distance learning, evidence from the wider literature can be used to evaluate MOOC provision. Peltier et al. (2003) report six constructs that affect the online educational experience: three in relation to interaction and communication (student-to-student interaction, student-instructor interactions and instructor support) and three that focus on course design (content, structure and technology). The forgoing have also been identified as key factors affecting MOOC retention rates and participant experience. Later work by Peltier et al. (2007) suggested that course content was the most important factor in determining the quality of the online learning experience.

In terms of MOOC content, it is generally the case that learning materials are high quality and developed by academics that are experts in their area. Whilst the total number of people taking a MOOC increased to over 100 million in 2018, the number of new learners signing up decreased. However, the number of participants that paid for a completion certificate increased and as a result MOOC provider revenues are at a record level, with Coursera reporting income of over 140 million in 2018 (Shah 2018). Studies suggest that most of the MOOC learners enrol on the basis of their professional objectives; however, a substantial number also participate as hobby learners (Batuaray 2014).

In 2013, Universities UK reported learner backgrounds to fall into five main groups: vocational learners (professionals looking to update their knowledge), educators and researchers (education professionals using MOOCs as open educational resources (OERs)), HE students (taking MOOCs as part of an existing campus course), hobby learners (adults engaging in self-directed study for interest) and prospective students (looking to explore course options and subjects). HE institutions have capitalised on the latter, using MOOCs as recruitment tools for on-campus and online degrees. In fact, there appears to be a shift in search patterns over the last few years, with more and more prospective students searching for universities with online offerings rather than their reputation. In terms of demographics, as mentioned previously, the majority of MOOC learners have one or more degrees, with just over 5% also having a doctoral level qualification.

5.5 MOOCs in Higher Education

Many educational institutions have begun to experiment with integrating MOOCs into the curriculum. Some institutions have directed their students to either their own institutional MOOCs or MOOCs delivered by other HE establishments. This integration of MOOCs into the traditional curriculum has been referred to as the “hybrid MOOC” or hMOOCs (Sandeen 2013). This can be as simple as providing students with a list of relevant MOOCs to augment their learning, or can involve using some, or all, of the MOOC content in a flipped classroom model. In fact, some institutions have used a full MOOC to deliver the complete course content. There is evidence to suggest that online learning in this way promotes independent learning (Garrison 2017), which is essential to promote life-long learning, and directing students towards MOOCs can encourage the development of these skills. Moreover, where academics have engaged in MOOC provision there is evidence of this increasing their awareness and understanding of online learning and incorporating this into other areas of their teaching.

MOOCs also provide the opportunity for students to study certain topics in more depth than their curriculum permits, particularly in the medical and veterinary degree programmes, as well as facilitating communication between them and other MOOC participants from across the globe with diverse backgrounds. Indeed, some MOOC providers, for example Futurelearn, have developed learning analytics that allow HE institutions to track their students within a MOOC course. In fact, some MOOC platforms are capable of providing more sophisticated learning analytics than the intuition’s own virtual learning environment, providing valuable insights into the learner behaviours. This information can inform course design and be used to support learners to achieve better outcomes. Learning analytics also offers instructors a comprehensive assessment of how a learner is performing; thus, allowing the instructor to direct any additional the support required. The foregoing allows HE institutions to provide learners with a more personalised leaning experience. There is also growing evidence that retention rates in online learning can be improved using learning analytics. If a learner is not performing well during the course then they are more likely to drop out, whereas if additional support is provided and motivation to study improves as a result then the learner is less likely to leave the course.

However, in MOOCs with thousands of students, the ability to support individual students in this way is impossible. Artificial intelligence (AI) offers a solution to this problem. AI provides an opportunity to include customised learning paths for individuals by data mining information on a student’s previous learning experiences. AI can also use data to predict the likelihood of a student passing or failing a course, which in principle could be used to alert a student at an early stage when an intervention could still be made. MOOC design and delivery provides the opportunity to capture millions of data on each individual student that could be used to allow for richer learning experiences through more personalised provision. Indeed, this approach could be used more widely in HE, the challenge is getting the humans to agree to share the information to allow these developments.

Once aspect that AI can be extremely valuable at addressing is the lack of instructor presence on discussion areas. Most MOOCs have human teaching assistant moderating the discussion areas; however, this is time consuming and costly. Georgia Tech utilised an AI teaching assistant to answer questions from students in online discussions, which resulted in increased student engagement, in fact students were unaware that the teaching assistant was not a real person. The use of AI teaching assistants in MOOCs is a step towards virtual learning companions being more widely available (Yu et al. 2017). However, in order to provide authentic interactions, these virtual learning companions need to have human-like characteristics. To address this, curious companions have been proposed as a means of providing personalised support and guidance in virtual learning environments (Wu and Miao 2013). By continually monitoring a learner’s progress, the curious companion can identify and suggest additional learning materials to maintain the learner's interest and motivation for study. To support learners to recall previously acquired information related to a current learning task, a remembrance companion, modelled on how humans recall information, was used (Wu et al. 2013). To avoid over-reliance on the remembrance companion it worked in a way that provided the learner with progressive more explicit hints. A teachable learning companion has also been shown to help learners consolidate knowledge (Biswas et al. 2016). Therefore, there is scope for virtual learning companions to address the issue of supporting large scale MOOCs, the limitation is their ability to support learners comprehend complex topics. Currently, virtual learning companions can answer questions, but cannot have meaningful conversations, which is a difficult aspect to develop.

In recent years, some universities have offered MOOCs for credit, although the debate of MOOCs and academic credit began very early on in the MOOC era. Even without credits being awarded, many undergraduate students have cited having completed a MOOC relevant to the degree they have applied to undertake at university and report further value if this could be formally recognised for credit. Moreover, MOOCs delivered by elite universities attracted learners looking for high-level professional development and some of these participants began to look for validation and recognition for successfully completing the course (Sandeen 2013). The University of Finland was one of the first institutions to offer MOOCs for credit, closely followed by Georgia State University who also decided to accept MOOCs as a from of credit transfer (Jaschik 2013). Generally, the model for this is that learners must complete a series of MOOCs and purchase the completion certificate and the university will provide a number of credits, which can be transferred to any other university and used as accredited prior learning for an appropriate degree programme. In addition to this, most universities offering MOOCs for credit require learners to complete an additional assessment to ensure that standards are being met as well as requiring authentication of identity in some way.

In addition to the above, there has been the recent emergence and growth of micro credentials, where a number of MOOCs can be taken to enable the learner to attain a degree-level qualification. This approach, which some refer to as "unbundling" HE is believed by MOOC enthusiasts to have the ability to revolutionise HE (McCowan 2017); however, this development is still in its infancy. In this model, a collection of MOOCs can be taken as individual components of a degree. This unbundling degree through a series of small courses is offered by several MOOC providers referred to as "Nanodegrees" and "MicroMasters". Whilst the names and approaches differ between MOOC providers, the one common theme is that they all offer a group of courses around a common subject to allow the learner to achieve a degree upon completion.

5.6 Conclusion

MOOCs have raised the awareness of the potential of online learning and teaching across the higher education sector and beyond. MOOCs are also ideal test environments for advancing educational research and one of the main benefits of MOOCs has been in the increased use of online learning in on campus courses. MOOCs offer the potential for learners to access professional development, allow students to get a feel for a particular subject area applying for a university degree in that area, can support students transition to university, and can also expand the range of options and subject available to students within their campus-based degree programme. In fact, students can achieve credits towards their campus-based degree by completing a MOOC and can even complete their entire degree through completing a series of small MOOCs. Artificial intelligence and learning analytics offer the potential for more personalised learner support and the era of MOOC 3.0 offers many opportunities and possibilities for online learning in the future.

References

Adam M, Young-Wolff KC, Konar E, Winkleby M (2015) Massive open online nutrition and cooking course for improved eating behaviours and meal composition. Int J Behav Nutr Phys Act 12:143–152

Adampoulos P (2013) What makes a great MOOC? An interdisciplinary analysis of student retention in online courses. In: Proceedings of the international conference on information systems

Albrechesten NJW, Poulsen KW, Svensson L, Jensen L, Holst JJ, Torekov SS (2017) Healthcare professionals form developing countries report educational benefits after an online diabetes course. BMC Med Educ 17:97

Batuaray MH (2014) An overview of the world of MOOCs. Procedia Soc Behav Sci 174:427–433

Biswas G, Segedy JR, Leelawang K (2016) From design to practice – a learning by teaching system: Betty's brain. Int J Artif Intell Educ 26:350–364

de Castaneda RR, Garrison A, Haeberli P, Crump L, Zinsstag J, Ravel A, Flahault A, Bolon I (2018) First "global flipped classroom in one health": from MOOCs to research on real world challenges. One Health 5:37–39

Dhanani J, Chavda N, Patel N, Tandel K (2016) Awareness and utilisation of massive open online course (MOOC) and videos series as continuous learning tools for facilities. Int J Med Sci Public Health 5(8):1540

Garrison DR (2017) E-learning in the 21st century: a framework for research and practice. Routledge, New York

Hone KS, El Said GR (2016) Exploring the factors affecting MOOC retention: a survey study. Comput Educ 98:157–168

Jaschik S (2013) MOOCs for credit. Inside Higher Ed. http://www.insidehighered. Last accessed 18th Jan 2019

Kop R (2011) The challenges to connectivist learning on open online networks: learning experiences during a massive open online course. Int Rev Res Open Dist Learn 12(3):19–38

Lane A (2013) The potential of MOOCs to widen access to, and success in, higher education study. In: Proceedings to the open and flexible higher education conference, pp 189–203

MacKay JR, Lanford F, Waran N (2016) Massive open online courses as a tool for global animal welfare education. J Vet Med Educ 43(2):287–301

McCowan T (2017) Higher education unbundling, and the end of the university as we know it. Oxf Rev Educ 43(6):733–748

Murray JMD (2014) Participants' perceptions of a massive open online course. Insights: UKSG J 27(2):154–159

Paterson J, Hughes K, Steer L, Das Gupta M, Boyd S, Bell C, Rhind S (2017) Massive open online courses (MOOCs) as a window into the veterinary profession. Vet Rec 180(7):179–183

Peltier JW, Drago W, Schibrowskt JA (2003) Virtual communities and the assessment of online marketing education. J Mark Educ 25(3):260–276

Peltier JW, Schibrowskt JA, Drago W (2007) The interdependence of factors influencing perceived quality of the online learning experience: a casual model. J Mark Educ 29(2):140–153

Sandeen C (2013) Integrating MOOCs into traditional higher education: the merging "MOOC 3.0" era. Chang: Mag High Learn 45(6):34–39

Shah D (2018) By the numbers: MOOCs in 2018. https://www.class-central.com/report/moocstats-2018/. Last accessed 18th Jan 2019

Siemens G (2005) Connectivism: a learning theory for the digital age. Int J Instr Technol Dist Learn 2(1):3–10

Wu Q, Miao C (2013) Modelling curiosity-related emotions for virtual peer learners. IEEE Comput Intell Mag 8:50–62

Wu Q, Han X, Yu H, Miao C, Shen Z (2013) The innovative applications of learning companions in virtual singapura. In: Proceedings of the international conference on autonomous agents and multiagent systems, pp 1171–1172

Yu H, Miao C, Leung C, White TJ (2017) Towards AI-powered personalisation in MOOC learning. NPJ Sci Learn 2:15

6 Applying Geometric Morphometrics to Digital Reconstruction and Anatomical Investigation

Federica Landi and Paul O'Higgins

Abstract

Virtual imaging, image manipulation and morphometric methods are increasingly used in medicine and the natural sciences. Virtual imaging hardware and image manipulation software allows us to readily visualise, explore, alter, repair and study digital objects. This suite of equipment and tools combined with statistical tools for the study of form variation and covariation using Procrustes based analyses of landmark coordinates, geometric morphometrics, makes possible a wide range of studies of human variation pertinent to biomedicine. These tools for imaging, quantifying and analysing form have already led to new insights into organismal growth, development and evolution and offer exciting prospects in future biomedical applications. This chapter presents a review of commonly used methods for digital acquisition, extraction and landmarking of anatomical structures and of the common geometric morphometric statistical methods applied to investigate them: generalised Procrustes analysis to derive shape variables, principal component analysis to examine patterns of variation, multivariate regression to examine how form is influenced by meaningful factors and partial least squares analysis to examine associations among structures or between these and other interesting variables. An example study of human facial and maxillary sinus ontogeny illustrates these approaches.

Keywords

Virtual imaging · Geometric morphometrics · Medical investigation · Maxillary sinuses · Procrustes shape analysis

6.1 Introduction

6.1.1 Imaging 3D Anatomy

Virtual study of the anatomy of living and extinct species, our natural heritage, and that of our cultural products, such as artefacts and buildings, is dependent on the methodologies available to image, reconstruct and investigate them (Bourne 2010; Weber and Bookstein 2011; Profico et al. 2018). The digital revolution has provided a series of innovative and non-invasive tools for the study of objects and biological structures. In the past 20 years, through advances in mathematics, computer science and physics, digital acquisition of data representing the 3D form of objects has become cheap and readily available. Disciplines such as palaeontology (Sutton et al. 2016),

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P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7_6

anthropology (Weber 2014), forensics, medicine (Howerton Jr and Mora 2008), archaeology (Luhmann et al. 2006) and geography (Smith et al. 2016) apply these techniques to questions in evolutionary biology, functional morphology, biological anthropology, medicine, ancient artefacts, geomorphology and to teaching. The advent of modern digital technologies has made it possible to easily visualize, manipulate, alter and explore objects in fine detail and extract information that would hardly be accessible without damaging specimens. Additionally, they allow us to process large datasets and perform complex analyses very rapidly (Bruner and Manzi 2006).

As digital image acquisition has become readily available and increasingly applied in science, the technologies and methods that facilitate the study of these images have also expanded (Goel et al. 2016; Toennies 2017; Sadler 2018). Computerised tomography (CT-scanning) is an important and commonly used imaging modality applied to the study of internal and external form. In acquiring images the object is exposed to x-rays from different directions (e.g. by rotating the x-ray source or object) while multiple x-ray detectors capture the data required to reconstruct a contiguous series of slices. These can then be reconstructed as a volume or a 3D surface mesh (Brenner and Hall 2007; Mettler Jr et al. 2000). The resulting volume is rendered as voxels with shades (levels) of grey reflecting the degree of attenuation and so, the radiodensity of each tissue, measured in Hounsfield units (Razi et al. 2014; Hounsfield 1973; Mah et al. 2010). CT scanning is widely applied in medicine and biomedical research. It produces detailed volumetrically accurate images of internal and external structures but presents a few issues with regard to image quality. One such issue is that CT scans may contain artefacts, defined as any systematic discrepancy between the CT reconstruction and the true attenuation coefficients of the object (Barrett and Keat 2004). Physics-based artefacts result from the physical processes of beam hardening involved in the acquisition of CT data. Patient-based artefacts can be caused by the presence of high-density material such as metal. The CT-scan device can cause ring artefacts, due to imperfections in the detector elements such as a calibration error in the detector array, while helical and multisection artefacts are caused by the helical interpolation and reconstruction process. Whatever their nature, artefact presence can damage the final resolution of the slices and therefore impact segmentation, anatomical investigation and clinical diagnosis (Goerres et al. 2002; Sijbers and Postnov 2004; Barrett and Keat 2004). However, with modern hospital CT scanners and software good quality reconstructions, useful in many scientific and clinical contexts can readily be made (Fig. 6.1).

Micro CT scanning is an increasingly common technique in biological work and is comparable to medical CT-scanning but uses a more focussed x-ray beam and detectors with small pixel patches to image on a smaller scale and at much higher resolution (Ritman 2004). With current, commonly available microCT scanners objects as large as 200 millimetres in diameter can be scanned with pixel sizes as small as 100 nanometres. Feldkamp et al. (1989) noted that micro-CT offers advantages over histology in preserving sample integrity, being less time consuming and in readily allowing 3D structure to be appraised. However, exposure to high levels of ionizing radiation in micro-CT means that this approach is unsuitable for *in vivo* biological work (Willekens et al. 2010). In the study of fossils and archeological material, micro-CT has largely replaced older and more invasive approaches used to remove sediment or isolate fragments (Cunningham et al. 2014).

Magnetic resonance imaging (MRI) is a cross-sectional imaging technique that uses the magnetic properties of materials to visualize structures in the body (Van Der Straeten 2013). In brief, it differs from CT scanning in that no ionising radiation is used, rather, in medicine images are created using a strong magnetic field and radio frequency energy to visualise water content throughout the volume of the body region. In contrast to CT, MRI results in detailed images of soft tissues. Both CT and MRI techniques are volumetric methods, capturing internal

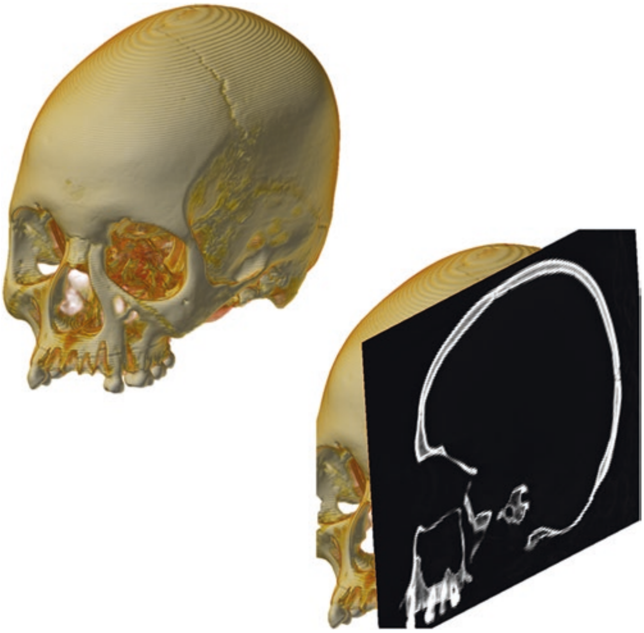

Fig. 6.1 Volume rendering of a human skull from a stack of CT-scans. An orthoslice is shown in the sagittal plane. Internal cavities and bone densities are clearly visible

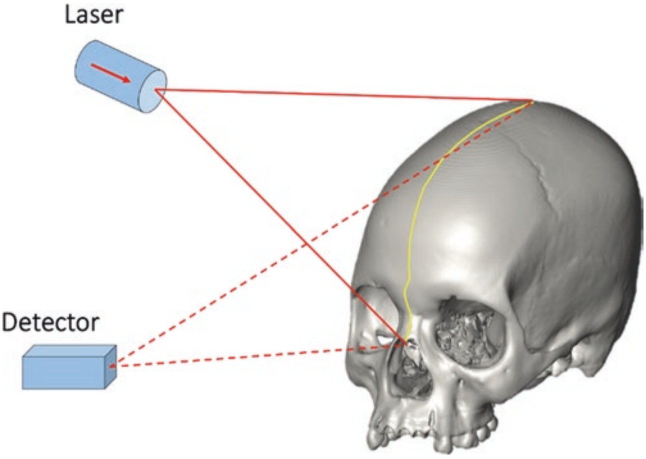

Fig. 6.2 Schematic illustration of the principles of a laser scanner: a single line of laser light is projected on the surface of interest, reflected and received by the detector. This operation is repeated from multiple angles until the whole surface is scanned

morphology and allowing exploration of the internal anatomy of animals, organs and tissues.

Rather than the volume of an object, the form of the external surface is all that is required for many studies. One of the most commonly used approaches to surface digitisation is through the reconstruction of a 3D surface from a series of images in which the surface is illuminated by projection of either a single line of illumination (e.g. from a laser; Fig. 6.2) or a more complex pattern (stereoscopic structured light scanning) onto the surface. Both of these use one or multiple cameras to capture images of the projection, which appears distorted according to surface topography. A function is then used to reconstruct surface topography from these images and to represent it as a 3D polygon mesh. The camera and light source are placed asymmetrically so that the device can assess depth as the bands of the light curve over the surface of the scanned item (Weber and Bookstein 2011). Stereoscopic structured light scanning can be used to rapidly and non-invasively generate surface meshes of single objects (Niven et al. 2009). It is used in a wide range of research and museum applications to accurately record surface morphology (McPherron et al. 2009). However, it has limitations. If the object is reflective or lacking in surface texture, scanners will often fail to acquire and perform an accurate rendering of the surface (Gupta et al. 2011; Slizewski and Semal 2009). Further, stereoscopic structured light scanning is very sensitive to lighting conditions, camera placement and the number of images used to acquire the surface, which means that acquisition may need to be repeated several times until the right conditions for a particular object are found.

Photogrammetry shares with light projection methods the capturing of a series of images from varying viewpoints as the basis for reconstructing three-dimensional 3D surface topology. It is not a new technique but has recently seen a substantial revival of interest in applications within the natural sciences (Bates et al. 2010; Falkingham 2011; Evin et al. 2016; Buzi et al. 2018; Sadler 2018). Photogrammetry technology comes from computer science and uses stereo-reconstruction techniques to transform images (taken from multiple viewpoints, by moving the camera around the object or by rotating the object itself) in two to three dimensions (Fig. 6.3). Photogrammetry identifies matching points between overlapping images taken from different viewpoints and uses the apparent movement of these points between images to reconstruct 3D surface topography (Verhoeven 2011). It is not as accurate as projection methods (Katz and Friess 2014), but Evin et al. (2016) show that it can produce results of acceptable accuracy and it has the benefit that by capturing surface texture maps photorealistic colour renderings can be generated.

Photogrammetry has wide applicability and offers portability and low equipment costs. It permits rapid data collection in the field due to its ease of use and allows the reproduction not only of isolated bones and archaeological artefacts but also of entire excavation sites as well as geo-referenced data for topographical, ecological and archaeological studies (Sapirstein 2016). These factors and the fact that all that is needed is a good camera and software (e.g. Agisoft 2014, and increasing numbers of mobile phone apps) to capture and process the images and obtain coloured textured meshes add to its utility and applicability.

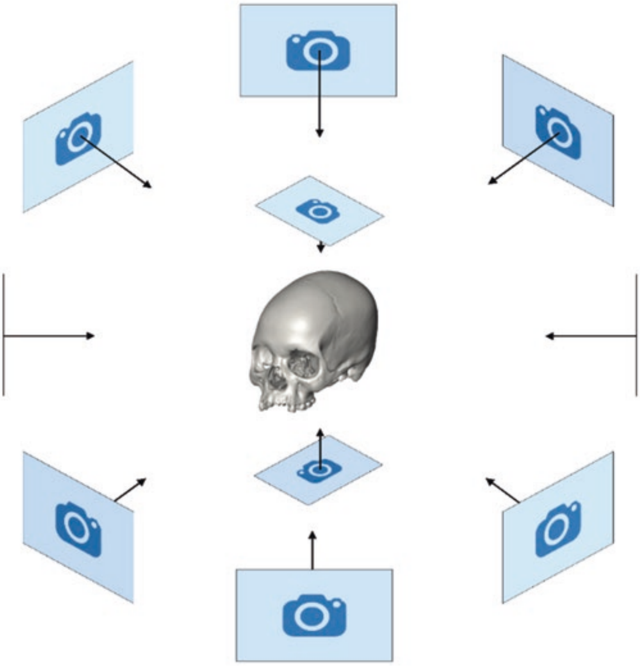

Fig. 6.3 The construction of a photogrammetry model of a human skull. Pictures are taken around the object and from at least two different perspectives

In photogrammetry, meticulous planning (and testing) of lighting conditions and of the scheme of photography are vital to ensure precise rather than simply aesthetically pleasing topographic reconstructions (Dellepiane et al. 2013). It is vital that lighting is even, to avoid blind spots and so, errors in the final 3D surface. In addition, a good camera with appropriate lens and settings are important to ensure accuracy (Nicolae et al. 2014).

6.1.2 Potential of 3D Imaging in Medical Diagnosis and Anatomical Investigation

3D Medical imaging has evolved dramatically in the past few decades and is applied widely in detection and differential analysis of pathology and abnormalities (Doi 2007; Sun 2007; Chhabra et al. 2013; Schmidle et al. 2014). High-resolution, three-dimensional volumetric image data can be rapidly acquired and 3D visualization, multiplanar reformation and navigation through image volumes and surfaces underpins diagnosis in many fields of medicine. Digital imaging applications have impacted care across a range of medical specialisations (e.g. Heiland et al. 2004; Joel et al. 2004; Bradley 2008; Norouzi et al. 2014). Virtual methods of surgical simulation based on imaging data facilitate pre-operative experimentation, improving planning of surgical treatment and potentially reducing patient risk (Meehan et al. 2003).

An emerging technique, rapid prototyping, can 3D print anatomical objects from 3D models. Physical printed models can be useful for surgeons in planning treatment as well as for training and teaching. Patients can also benefit from rapid prototyping by touching and looking at a physical model to improve their understanding of both the condition and the planned surgical intervention (Rengier et al. 2010). Thus, at present we are in the middle of a major transformation of how imaging is applied in medicine, through developments in virtual and physical reconstruction and modelling. These developments are opening up new possibilities for anatomical and medical investigation, detection and treatment (Tzou and Frey 2011).

6.1.3 Quantification of Morphology and Analyses of Variation: Geometric Morphometrics

Quantification of the form of virtual representations of anatomy, no matter how acquired, is necessary if we are to compare them in the context of diagnosis, planning and review. In this section we describe how the use of linear and angular measurements to study form variation has been superseded in many applications in organismal biology by landmark based, geometric morphometric, methods. We illustrate how these landmark based approaches can be employed in biomedicine by applying them to the study of craniofacial growth in humans. We show how segmented images of human crania are reconstructed, landmarked and semilandmarked, and then how a model of maxillary growth can be derived from these data through a principal component analysis (PCA) and multivariate regression of form on centroid size. Further, we describe the application of 2-block partial least squares analysis (PLS) to assessment of the strength and nature of association between two related anatomical structures, and illustrate this by investigating how maxillary sinus form covaries with the form of the facial skeleton.

The sample comprises CT-scans of an ontogenetic series of modern humans (N = 60). These were segmented semi-automatically using the software tool Avizo 9.0 (FEI Visualization). Because these scans are of dry bones, contrast is good between skull and air. Therefore, the initial segmentation was performed using a single global threshold, estimated by the histogram method (Pun 1980) to maximize the inclusion of bone material in the resulting virtual reconstruction of the skulls. A second global threshold was applied to segment the maxillary sinus bone material. This semi-automatic segmentation often resulted in errors in the reconstruction of the orbital and nasal walls of the sinuses. This is because, when CT-scanning, the acquired signal

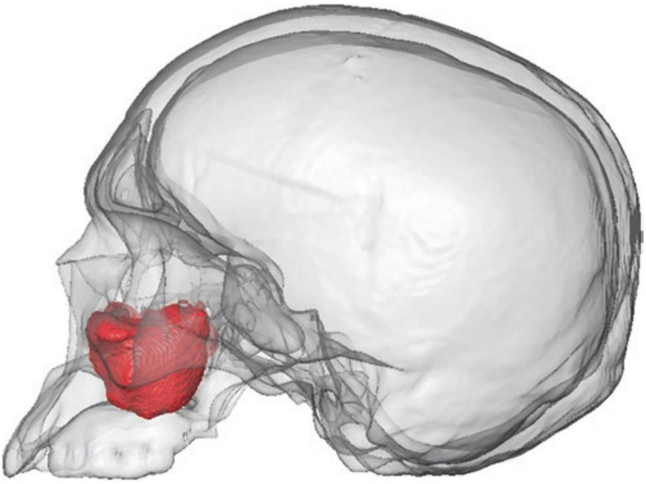

Fig. 6.4 Mesh rendering of a maxillary sinus in a modern human adult specimen after segmentation and reconstruction

is sampled and not continuous and the effect of partial volume averaging becomes apparent after thresholding (Spoor et al. 1993). Therefore, thresholding of both cranium and sinuses was reviewed, slice by slice, so that the presence of unwanted elements (such as the scanning bed) and errors in segmentation (small holes in thin-bone structures such as the eye sockets and sinus medial walls) were manually fixed using the brush-tool available in Avizo 9.0. An example reconstructed cranium with highlighted maxillary sinus is shown in Fig. 6.4.

Comparative morphological analysis has always played a central role in biological and medical studies (Adams et al. 2004). Qualitative descriptions of morphology have utility and a long-established history of application but are inherently subjective and lack repeatability. With the advent of multivariate statistical approaches in the mid-twentieth century, sets of linear measurements, indices and angles were used to explore shape variations and evaluate morphological differences between taxa (Sneath and Sokal 1962; Blackith and Reyment 1971; Bookstein 1998).

Linear measurements between anatomical points (landmarks) individually describe the distance between them, while more than two measurements begin to describe the form, defined as the size and shape of an object. Multiple measurements taken on a sample can be submitted to multivariate analysis to assess and describe form variation. The use of linear measurements is well established and, with angular measurements formed the basis what became known as multivariate morphometrics (Blackith and Reyment 1971; Mardia et al. 1979). If we are interested in shape, measurements can be scaled before further analysis. Visualisation of the results of multivariate morphometric analyses of form or shape based on linear measurements is possible if the measurements are designed in such a way that the original geometry of the object can be reconstructed (e.g in Euclidean Distance Matrix Analysis, EDMA; Lele and Richtsmeier 1991; Richtsmeier et al. 1993a, b; Adams et al. 2004; and truss measures, Strauss and Bookstein 1982).

However, the use of linear measurements or angles to describe shape is problematic. The key issue is that after scaling of interlandmark distances or using angles, the resulting shape spaces have undesirable statistical properties (independent isotropic error at landmarks does not result in isotropic distributions in the resulting shape spaces) and are a poor choice for statistical analysis (Rohlf 2000).

The issue of how to compare objects based on landmark coordinates was the subject of intense debate and discovery in the 1980's and 1990's (Bookstein 1982, 1991, 1996; O'Higgins and Dryden 1992, 1993; Richtsmeier and Lele 1993; Marcus and Corti 1996; Dryden and Mardia 1998; Rohlf 1999) and led to the advent of geometric morphometrics (GM), a set of morphometric methods that caused a shift in the way in which biological structures were measured and investigated in many disciplines (Rohlf and Marcus 1993; Slice 2007). Thus, the statistical foundations of geometric morphometrics (GM) led to the development of a powerful set of tools for the investigation of shape variation and covariation that have been widely applied to the study of organismal growth, development and evolution (Roth and Mercer 2000; Cobb and O'Higgins 2004; Mitteroecker et al. 2004; Goergen et al. 2017).

Increasing numbers of clinical and surgical studies have applied GM to study morphological changes in development, growth or pathology, to identify associations among skeletal units and between them and related soft tissues, to recognise proper and abnormal growth and development and to document variation in anatomical structures (Hajeer et al. 2004; Singh et al. 2004).

In GM the geometry of an object, its form, is described using the landmark coordinates themselves, rather than measurements taken between them (Zelditch et al. 2012). To be comparable, these coordinates have to be equivalent in some sense, which means that they must correspond to points that are believed to have 'the same' developmental, evolutionary or functional significance (whichever is pertinent to the question) in different organisms (O'Higgins 1997; Bookstein, 1997 a; Oxnard and O'Higgins 2009).

Landmarks can be placed on 2D (X-rays, pictures) and 3D surfaces (mesh rendering from CT-scan, laser scan or photogrammetry) and should be chosen to provide an adequate representation of the object under study in relation to the question at hand (O'Higgins 1997; Lele and Richtsmeier 2001; Oxnard and O'Higgins 2009). When equivalent points between specimens are scarce, semilandmarks (defined as those that lie on curves or surfaces but with ill defined exact location on the curve or surface; Bookstein 1997b; Mitteroecker and Gunz 2009) can be applied, as long as a sufficient number of equivalent landmarks can be used as a fixed reference to control subsequent sliding over surfaces and curves to minimise error in the location of semilandmarks. The sliding procedure iteratively adjusts the positions of the semilandmarks until either the Procrustes distance or bending energy between the reference specimen (also estimated iteratively) and that being landmarked is minimal. Minimisation of Procrustes distances takes the locations of all fixed landmarks equally into account (global form) to guide the sliding, whereas the minimisation of bending energy gives greater weight to landmarks near the surface or curve on which they are to be slid. The choice of Procrustes distance or bending energy leads to different eventual semilandmark positions and so, different estimates of differences among specimens. The choice should be guided by which criterion seems most appropriate to the question. Most often in applications to crania, minimisation of bending energy (see warping, below) has been preferred because this slides semilandmarks based on local rather than global aspects of form (Gunz et al. 2005). After sliding, landmarks and semilandmarks each have the same weight in subsequent statistical analyses (Gunz and Mitteroecker 2013).

Figure 6.5 illustrates the landmarks and semilandmarks recorded on the 3D surface mesh of each cranium from the ontogenetic series described above. These cover the external and internal surfaces of the face, base and cranial vault. Six landmarks were also located on the surface of each maxillary sinus. Since the sinuses almost totally lack identifiable equivalent anatomical landmarks, five of these were defined with respect to the Frankfurt plane (most lateral, inferior, superior, anterior and posterior). The sixth is an anatomical landmark, at the ostium.

Once landmarks have been collected the form of specimens can be compared pairwise, visually, in terms of warpings between them, or patterns of variation within the entire sample can be assessed using Procrustes based statistical analyses.

Warping of meshes representing surfaces or of volumes of specimens involves interpolation of differences in landmark configurations to the space in the vicinity of the landmarks, occupied by virtual objects representing surfaces or volumes. Thus, differences between two landmark configurations are used to smoothly warp surface meshes or volumes representing the anatomical

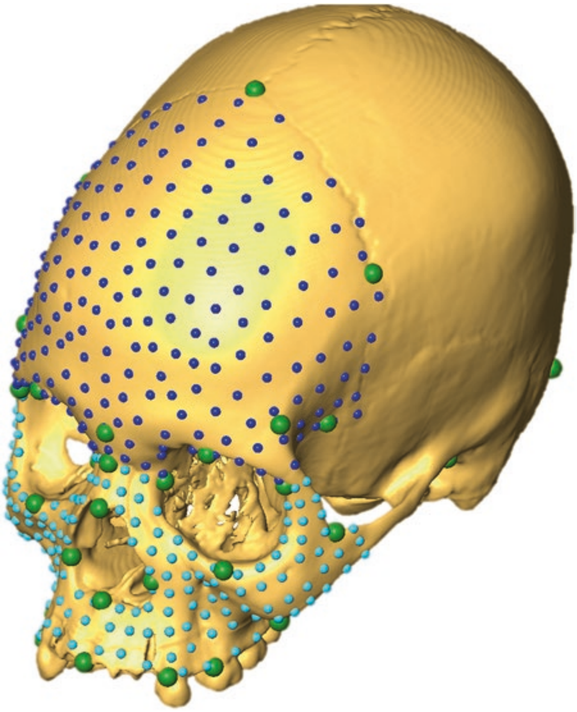

Fig. 6.5 Landmark (green) and semilandmark configuration (light blue for the facial skeleton and dark blue for the frontal bone) used for the study of midfacial and sinus morphology shown on a human skull

structure on which the landmark configurations were taken. The two configurations are termed the reference configuration (the original object surface or volume) and the target configuration (into which the object will be warped). They could be two specimens or represent objects at opposite poles of a vector of interest arising from statistical analyses, as described below.

In GM, warping is most commonly achieved using two (for 2D) or three (for 3D) thin plate splines (TPS) as interpolating functions. The thin plate spline comprises a uniform (uniform stretchings and shears) and a non-uniform component. It interpolates differences in relative landmark locations to the space between them, minimising a quantity from the non-uniform component known as the bending energy, analogised as the energy required to deform a thin, uniform metal sheet. The 'metal sheet' is constrained at landmark coordinates but otherwise free to adopt the form that requires the minimum bending energy. This leads to a smooth interpolation of the space between landmarks (Mitteroecker and Gunz 2009). As noted above bending energy is commonly minimized by the algorithm used to slide semilandmarks. This is because bending energy is larger for localised deformations than global ones of the same magnitude. Thus, so sliding of semilandmarks based on minimization of bending energy gives greater weight to minimization of localized 'errors' in their initial locations.

Transformation grids (Thompson 1917) are often used to visualise local variations in shape differences between two landmark configurations as a deformation (Fig. 6.6). They are calculated using one thin plate spline per dimension (2, for 2D or 3 for 3D data). The grids can be interpreted as indicating how the space in the region of a reference shape might be deformed into that in the region of the target such that landmarks in the reference map exactly into those of the target. The graphical representation of shape differences resulting from these approaches is readily interpretable in 2D but less so in 3D, where warping of a surface or volume as a movie or a series of 'stills' may lead to better understanding of the nature and degree of form differences between configurations. Care should be taken, in balancing the visual appeal of transformation grids

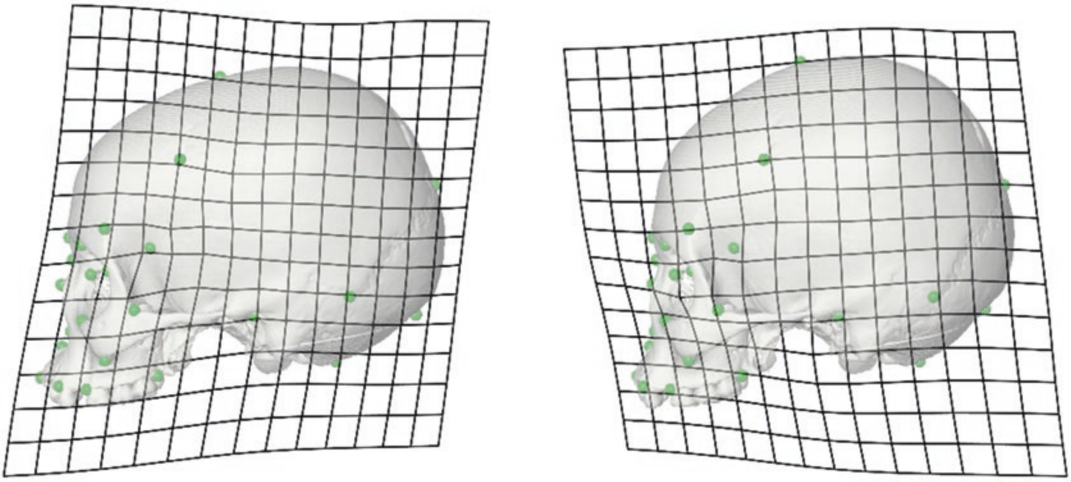

Fig. 6.6 Transformation grids showing shape differences between two human crania. The grids are sited in the sagittal plane and the skulls are rendered semi-transparent so the grids can be viewed. A regular square grid was drawn over the mean (reference) of the two skulls and then it was deformed into each of them (targets). Thus, it shows equal and opposite deformations in each that indicate the local and global differences in shape between the two landmark configurations

against the underlying assumptions (e.g. smooth interpolation) in their construction. From a biological perspective it is important to bear in mind that this mapping is purely mathematical, and it is based only on the locations of the original landmarks (O'Higgins 2000).

Beyond visually comparing differences between pairs of landmark configurations, GM methods allow statistical analyses of variation and of covariation among different configurations of landmarks or between a configuration and other variables of interest. Landmark configurations differ among objects in form (size and shape) and in location and orientation. Geometric morphometric analyses aim to investigate the shape of objects, regardless of 'size' (specifically, centroid size, see below), location and orientation in space. As such GM relies on the computation of shape differences among objects, expressed as Procrustes distances. These distances are estimated through generalized Procrustes analysis (GPA; Gower 1975; Kendall 1984; Rohlf and Slice 1990; Goodall 1991; Dryden and Mardia 1993). This proceeds by standardising centroid size (the square root of the sum of squared distances of a set of landmarks from their centroid), position and orientation of the landmark configurations through registration. Squared distances between equivalent landmarks taken on all specimens are minimized by scaling, translating and rotating the individual's landmark configurations. Scaling is carried out such that the centroid size of each configuration is scaled to 1 by dividing the raw landmarks by the original configuration centroid size. Configurations are then superimposed at their centroids (the arithmetic mean of all landmark coordinates) and iteratively rotated with respect to each other to minimize the sum of squared distances of the specimens from the mean shape. In the first iteration, the specimens are aligned to an arbitrarily chosen one, normally the first, and once all configurations are best fitted to this, the sample mean of each coordinate is computed. In subsequent iterations the configurations are best fitted to the mean, which is recomputed and used in the next iteration. The algorithm stops when the sum of residuals from the mean reaches a minimum, usually after 3–5 iterations. The resulting registered landmark coordinates are known as 'shape coordinates' and can be submitted to subsequent statistical analysis.

Kendall's shape space (Kendall 1984; Goodall 1991; Dryden and Mardia 1993) is the shape space that would arise from full Procrustes fitting (scaling translation and rotation of a pair of configurations) of every specimen to every other one. For triangles it has the form of the manifold of a sphere of diameter 1, and for higher dimensions is a hypersphere. Kendall's shape is discussed at length in statistical texts (Dryden and Mardia 1993; Weber and Bookstein 2011).

In practice, such a registration is not used often because it does not lend itself to visualisation of shape differences among a sample. Instead, GPA is carried out, as described above because this incorporates calculation of the mean shape, which can be warped to visualise results of statistical analyses. After GPA, specimens come to lie on the manifold of a hemisphere with radius = 1, known as the hemisphere of GPA aligned coordinates (Rohlf and Slice 1990). As long as variations are small, the scatter of points over this manifold will be concentrated and, for practical purposes, very similar to that on the manifold of Kendall's shape space. The region of (Kendall's or GPA) shape space that they occupy can be considered approximately linear and so, suitable for multivariate analyses using linear models (Dryden and Mardia 1993). However, it is common to formally linearise the region of shape space occupied by the specimens under study by carrying out a tangent projection (Dryden and Mardia 1993; Kent 1994). This is rather like what cartographers do, when drawing maps on flat sheets of paper, and like maps, they do not distort distances much over small areas near the point of tangency (the mean) but more so for distances at the periphery of a distribution.

The tangent projected shape variables are then submitted to statistical analyses pertinent to the question at hand. Centroid size differences are also of interest and these can be used to examine how shape covaries with centroid size in studies of allometry or combined with the shape data, as an extra column in the shape coordinate data matrix (Mitteroecker et al. 2004; Mitteroecker et al. 2013), allowing analyses of form (size and shape) differences or covariances with other factors using standard multivariate methods.

Ordination methods are often used to visualise the scatter of points representing specimens within the shape space. They allow groupings and modes of variation among specimens to be visualised. The most commonly applied ordination method in GM studies is principal component analysis (PCA). In this, new orthogonal (therefore independent and uncorrelated) variables, the principal components (PCs), are extracted from the matrix of shape variables previously computed using GPA (see above). These are linear combinations, (rotations of axes within the space) of the original variables, sorted by decreasing variance (Rohlf 1986; Mitteroecker and Gunz 2009; Zelditch et al. 2012; Klingenberg 2013; Mitteroecker et al. 2013) and retain the relationships (distances) among points. They allow the scatter of points in the high dimensional space defined by the original correlated variables to be appreciated in fewer dimensions defined by the first few uncorrelated PCs, while retaining as much as possible of the variance of the original dataset (Jolliffe 2011). The modes of shape variation represented by the PCs can readily be visualised as warpings of points, transformation grids, surfaces or volumes as described above.

The plot in Fig. 6.7 shows the first two principal components from an analysis of right sided maxillary sinus form in modern humans (60 specimens ranging from 0 to 60 years). GPA and PCA were performed using the R package Morpho (Schlager 2013). PC1 accounts for 80% of the total variance in form of the sample and this represents a large change in size and a change in shape with increasing age, while PC2 accounts for 6% of the total variance and does not order specimens by age. Warpings of landmarks and meshes representing the maxillary sinus surface drawn in position within example crania show that infant sinuses are narrow medio-laterally and elongated antero-posteriorly and that they mainly expand in the vertical dimension during ontogeny, paralleling the large increase in facial height that occurs during the same period.

Multivariate regression treats e.g. shape as being dependent on another variable of interest (such as size, time, diet etc), resulting in a vector of regression coefficients that indicates the change of shape per unit of change in the independent variable (Drake and Klingenberg 2007;

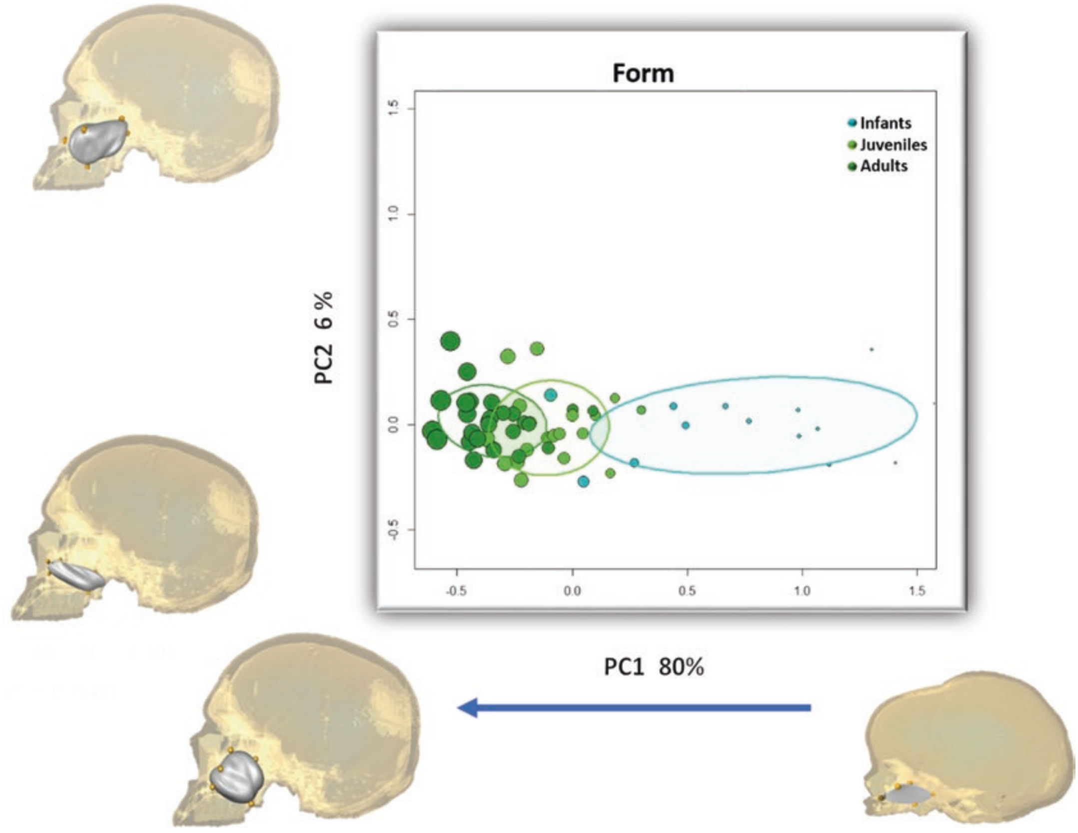

Fig. 6.7 Principal component analysis. Plot of the first two principal components (86% of the total variance) of maxillary sinus form in a modern human sample. Age stages are indicated by colours: “light cyan” for infants up to the age of 6 years, “light green” for juveniles up to the age of 18 years and “dark green” for adults over the age of 18 years. The size of each point is proportional to the centroid size of each individual. The modes of sinus form variation represented by each principal component are shown (in grey) adjacent to each axis. These were drawn by warping the mean sinus to each extreme of each principal component, after which they were superimposed on representations of adult and infant skulls to indicate their position and relative size

Klingenberg 2013). Multivariate regression allows prediction of specimen shape for a given value of the independent variable and allows computation of the proportion of total shape variance explained by the independent variable. By predicting shapes at extremes of the regression vector and computing transformation grids, warped surfaces or object volumes as described above, the shape changes along a regression vector can be visualised.

A multivariate regression of sinus shape on centroid size, a study of ontogenetic allometry, was carried out using the sample of modern humans described above. The results show a significant ($p < 0.001$) association between sinus shape and sinus size, but this is weak ($R^2 = 0.18$), indicating that factors other than allometry are important in shaping sinus morphology during ontogeny. Visualisations of the shape differences between small and large sinuses are more or less identical to those shown in Fig. 6.7 along PC1.

Where the association between one form and another or between a form and a set of interesting variables (e.g describing climate, ecology, behaviour) is of interest partial least squares analysis (PLS) is an appropriate method. Two-block partial least squares analysis (PLS) allows the covariation between two blocks of variables to be quantified and visualised. It differs from regression analysis in that the two sets of variables are treated symmetrically rather than as one set of variables being dependent on the other (Rohlf and Corti 2000). Two-block partial least squares analysis performed within a morphometric context is also called singular warp (SW) analysis (Bookstein et al. 2003). It computes the linear combination of two sets or "blocks" of shape variables (two landmark sets) that maximise explained covariance between blocks. It results in pairs of singular axes (also known as singular warps, singular vectors, singular axes or PLS axes) which maximise explained covariance and which, when plotted against each other, visualise the associations between blocks. The strength of the association between blocks can be quantified for each pair of axes by computing Pearson's correlation coefficient between the scores of each block (Hollander et al. 2013). To calculate the significance of this, a permutation test is used.

The proportion of total covariance explained by each pair of axes is also calculated. Beyond this, PLS allows the calculation of the proportion of total variance in each block explained by each singular axis for that block (Cardini 2018). In reporting the results of PLS analyses, it is important to consider the strength and significance of correlations, the proportion of the total covariance explained by pairs of singular axes and the proportion of total variance in each block explained by each singular axis. This is because a strong association between blocks does not necessarily indicate that a large proportion of the variance of each block is explained by the analysis. Thus, blocks can be strongly associated, but this association may account for a large or a small proportion of the total variance in each block. A strong and highly significant association that accounts for a very small proportion of the total variance, might have little real morphological or biological meaning. For visualization of the patterns of association in PLS analyses, the mean of each block (assuming both represent shape) is warped along each singular axis and the two warpings are presented, one for each block.

PLS was used to examine the association between maxillary sinus form and the form of the face during growth and development using the data described earlier. The 3D coordinates for each structure were first transformed to shape variables using GPA and, together with the ln of their centroid sizes, were submitted to a PLS. Figure 6.8 shows a plot of specimen scores on the first singular warps (SW1) of the sinus and the midface.

The correlation coefficient between the scores of each block on their respective SW1 is 0.94, $p < 0.001$. 80% of the total variance in sinus form is associated with facial form and 81% of the total variance in facial form is associated with maxillary sinus form. Visualisations of the modes of associated form variation in each structure show similar changes to those observed in the PCA of Fig. 6.7: the sinus transforms from a relatively flat narrow structure to a vertically taller one while the face shows a degree of orbital enlargement, supero-inferior expansion of the zygomatico-maxillary region, an increase in nasal aperture and facial height.

6.1.4 Conclusions

The foregoing description of methods for imaging, reconstruction, visualisation and analysis of patterns of variation and covariation of anatomical structures reflects the fact that we are entering an exciting period in the development of the anatomical sciences. By taking up the opportunities offered by the readily available state of the art hardware and software necessary to carry out this work, anatomical studies in relation to medicine can extend beyond the study of form to that of form variation and covariation and thus provide important data and tools for clinical assessment. By applying geometric morphometric methods, patterns of anatomical form variation and covariation can be quantified and used to assess pathology, patterns of normal and abnormal growth, development, and covariation of skeletal and soft tissue structures.

Thus, in this chapter, we illustrate the potential of modern imaging tools combined with GM by characterising normal ontogeny and ontogenetic interactions in the human craniofacial skeleton between the first few months of life and adulthood. This kind of study, carried out on extensive data, such as are held in the imaging

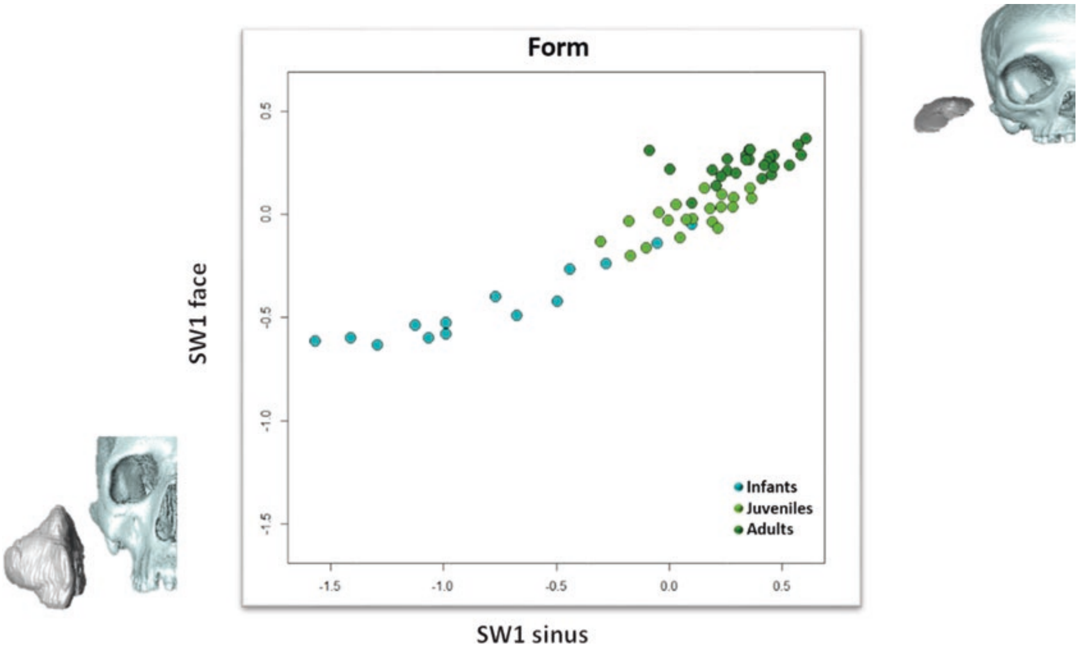

Fig. 6.8 Partial least squares: a plot of the first pair of singular warps (SWs) from a PLS analysis of right sided maxillary sinus and facial form. Age stages are indicated by colours: "light cyan" for infants up to the age of 6 years, "light green" for juveniles up to the age of 18 years and "dark green" for adults over the age of 18 years. The inset figures to bottom left and upper right show warpings of the mean maxillary sinus and facial forms to the minimum and maximum limits of the scatter of points on each SW

departments of all major hospitals, could provide a modern equivalent of the growth standards developed by Tanner and co-workers in the middle of the last century (Tanner and Whitehouse 1976). Furthermore, statistical models of variation can support the development of diagnostic and prognostic tools that facilitate identification of pathological form or form change. Thus Hajeer et al. (2004) used bilateral landmarks to study facial asymmetry caused by dentofacial deformities. They assessed the magnitude of 3D asymmetry of facial soft tissues before and after orthognathic surgery. 3D geometric morphometrics has also been used to evaluate three-dimensional changes in nasal morphology in patients with unilateral cleft lip and palate, treated to correct naso-labio-alveolar deformities (Singh et al. 2005; Bugaighis et al. 2010). Further examples of applications include morphological analysis of neuroanatomical structures among adults (e.g. Free et al. 2001) or in a developmental context (e.g. Bookstein et al. 2001) to identify prenatal brain damage from alcohol and studies of thoracic volumes and breathing (Bastir et al. 2013, 2017).

In this chapter we focussed on long term changes in form due to growth and development but much shorter period changes in form, such as those due to motion, are also of interest clinically, and these too are amenable to GM analyses. Taking the heart as an example, its form alters with failure and its cyclic motion changes post myocardial infarction. A potentially useful application of GM is in the assessment of changes with failure or alterations in its cyclic motion as are being explored by Piras and co-workers (Piras et al. 2015).

Clearly the virtual domain presents many opportunities. We are just at the beginning of a phase of development of tools for imaging and analysis of images that promises practical technologies and applications with the potential to make a marked contribution in medical assessment, diagnosis, planning, and review.

References

Adams DC, Rohlf FJ, Slice DE (2004) Geometric morphometrics: ten years of progress following the 'revolution'. Ital J Zool 71(1):5–16

Agisoft LLC (2014) Agisoft photoscan. Professional Edition, St Petersburg

Barrett JF, Keat N (2004) Artifacts in CT: recognition and avoidance. Radiographics 24(6):1679–1691

Bastir M, Martínez DG, Recheis W, Barash A, Coquerelle M, Rios L et al (2013) Differential growth and development of the upper and lower human thorax. PLoS One 8(9):e75128

Bastir M, García-Martínez D, Torres-Tamayo N, Sanchis-Gimeno JA, O'Higgins P, Utrilla C, García Río F (2017) In vivo 3D a nalysis of thoracic kinematics: changes in size and shape during breathing and their implications for respiratory function in recent humans and fossil hominins. Anat Rec 300(2):255–264

Bates KT, Falkingham PL, Rarity F, Hodgetts D, Purslow A, Manning PL (2010) Application of high-resolution laser scanning and photogrammetric techniques to data acquisition, analysis and interpretation in palaeontology. Int Arch Photogramm, Remote Sens, Spat Inf Sci 38:68–73

Blackith RE, Reyment RA (1971) Multivariate morphometrics. Academic Press, New York

Bookstein FL (1982) Foundations of morphometrics. Annu Rev Ecol Syst 13(1):451–470

Bookstein FL (1991) Morphometric tools for landmark data: geometry and biology. Cambridge University Press, Cambridge

Bookstein FL (1996) Combining the tools of geometric morphometrics. In: Advances in morphometrics. Springer, Boston, pp 131–151

Bookstein FL (1997a) Landmark methods for forms without landmarks: morphometrics of group differences in outline shape. Med Image Anal 1(3):225–243

Bookstein FL (1997b) Morphometric tools for landmark data: geometry and biology. Cambridge University Press, Cambridge

Bookstein FL (1998) A hundred years of morphometrics. Acta Zool Acad Sci Hung 44:7–59

Bookstein FL, Sampson PD, Streissguth AP, Connor PD (2001) Geometric morphometrics of corpus callosum and subcortical structures in the fetal-alcohol-affected brain. Teratology 64(1):4–32

Bookstein FL, Gunz P, Mitteroecker P, Prossinger H, Schaefer K, Seidler H (2003) Cranial integration in Homo: singular warps analysis of the midsagittal plane in ontogeny and evolution. J Hum Evol 44(2):167–187

Bourne R (2010) Fundamentals of digital imaging in medicine. Med Phys 37(7Part1):3882–3882

Bradley WG (2008) History of medical imaging. Proc Am Philos Soc 152(3):349–361

Brenner DJ, Hall EJ (2007) Computed tomography—an increasing source of radiation exposure. N Engl J Med 357(22):2277–2284

Bruner E, Manzi G (2006) Digital tools for the preservation of the human fossil heritage: Ceprano, Saccopastore, and other case studies. Hum Evol 21(1):33–44

Bugaighis I, O'higgins P, Tiddeman B, Mattick C, Ben Ali O, Hobson R (2010) Three-dimensional geometric morphometrics applied to the study of children with cleft lip and/or palate from the North East of England. Eur J Orthod 32(5):514–521

Buzi C, Micarelli I, Profico A, Conti J, Grassetti R, Cristiano W et al (2018) Measuring the shape: performance evaluation of a photogrammetry improvement applied to the Neanderthal skull Saccopastore 1. ACTA IMEKO 7(3):79–85

Cardini A (2018) Integration and modularity in Procrustes shape data: is there a risk of spurious results? Evol Biol 46:1–16

Chhabra A, Thawait GK, Soldatos T, Thakkar RS, Del Grande F, Chalian M, Carrino JA (2013) High-resolution 3T MR neurography of the brachial plexus and its branches, with emphasis on 3D imaging. Am J Neuroradiol 34(3):486–497

Cobb SN, O'Higgins P (2004) Hominins do not share a common postnatal facial ontogenetic shape trajectory. J Exp Zool B Mol Dev Evol 302(3):302–321

Cunningham JA, Rahman IA, Lautenschlager S, Rayfield EJ, Donoghue PC (2014) A virtual world of paleontology. Trends Ecol Evol 29(6):347–357

Dellepiane M, Dell'Unto N, Callieri M, Lindgren S, Scopigno R (2013) Archeological excavation monitoring using dense stereo matching techniques. J Cult Herit 14(3):201–210

Doi K (2007) Computer-aided diagnosis in medical imaging: historical review, current status and future potential. Comput Med Imaging Graph 31(4–5):198–211

Drake AG, Klingenberg CP (2007) The pace of morphological change: historical transformation of skull shape in St Bernard dogs. Proc R Soc B Biol Sci 275(1630):71–76

Dryden IL, Mardia KV (1993) Multivariate shape analysis. Sankhyā. Ind J Stat, Ser A 55:460–480

Dryden IL, Mardia KV (1998) Statistical shape analysis. John Wiley & Sons, New York

Evin A, Souter T, Hulme-Beaman A, Ameen C, Allen R, Viacava P, Dobney K (2016) The use of close-range photogrammetry in zooarchaeology: creating accurate 3D models of wolf crania to study dog domestication. J Archaeol Sci Rep 9:87–93

Falkingham PL (2011) Acquisition of high resolution three-dimensional models using free, open-source, photogrammetric software. Palaeontol Electron 15(1):1–15

Feldkamp LA, Goldstein SA, Parfitt MA, Jesion G, Kleerekoper M (1989) The direct examination of three-dimensional bone architecture in vitro by computed tomography. J Bone Miner Res 4(1):3–11

Free SL, O'Higgins P, Maudgil DD, Dryden IL, Lemieux L, Fish DR, Shorvon SD (2001) Landmark-based morphometrics of the normal adult brain using MRI. Neuroimage 13(5)801–813

Goel N, Yadav A, Singh BM (2016) Medical image processing: a review. In: Computational intelligence on power, energy and controls with their impact on humanity (CIPECH), pp 57–62

Goergen MJ, Holton NE, Grünheid T (2017) Morphological interaction between the nasal septum and nasofacial skeleton during human ontogeny. J Anat 230(5):689–700

Goerres GW, Kamel E, Heidelberg TNH, Schwitter MR, Burger C, von Schulthess GK (2002) PET-CT image co-registration in the thorax: influence of respiration. Eur J Nucl Med Mol Imaging 29(3):351–360

Goodall C (1991) Procrustes methods in the statistical analysis of shape. J R Stat Soc, Ser B (Methodological) 53:285–339

Gower JC (1975) Generalized procrustes analysis. Psychometrika 40(1):33–51

Gunz P, Mitteroecker P (2013) Semilandmarks: a method for quantifying curves and surfaces. Hystrix, Ital J Mammal 24(1):103–109

Gunz P, Mitteroecker P, Bookstein FL (2005) Semilandmarks in three dimensions. In: Modern morphometrics in physical anthropology. Springer, Boston, pp 73–98

Gupta M, Agrawal A, Veeraraghavan A, Narasimhan SG (2011) Structured light 3D scanning in the presence of global illumination. In: Computer vision and pattern recognition (CVPR), pp 713–720

Hajeer MY, Ayoub AF, Millett DT (2004) Three-dimensional assessment of facial soft-tissue asymmetry before and after orthognathic surgery. Br J Oral Maxillofac Surg 42(5):396–404

Heiland M, Schulze D, Rother U, Schmelzle R (2004) Postoperative imaging of zygomaticomaxillary complex fractures using digital volume tomography. J Oral Maxillofac Surg 62(11):1387–1391

Hollander M, Wolfe DA, Chicken E (2013) Nonparametric statistical methods. Wiley & Sons, New York

Hounsfield GN (1973) Computerized transverse axial scanning (tomography): part 1. Description of system. Br J Radiol 46(552):1016–1022

Howerton WB Jr, Mora MA (2008) Advancements in digital imaging: what is new and on the horizon? J Am Dent Assoc 139:S20–S24

Joel F, Leong WM, Leong ASY (2004) Digital imaging in pathology: theoretical and practical considerations, and applications. Pathology 36(3):234–241

Jolliffe I (2011) Principal component analysis. In: International encyclopedia of statistical science. Springer, Berlin, pp 1094–1096

Katz D, Friess M (2014) 3D from standard digital photography of human crania—a preliminary assessment. Am J Phys Anthropol 154(1):152–158

Kendall DG (1984) Shape manifolds, procrustean metrics, and complex projective spaces. Bull Lond Math Soc 16(2):81–121

Kent JT (1994) The complex Bingham distribution and shape analysis. J R Stat Soc, Ser B (Methodological) 56:285–299

Klingenberg CP (2013) Visualizations in geometric morphometrics: how to read and how to make graphs showing shape changes. Hystrix, Ital J Mammal 24(1):15–24

Lele S, Richtsmeier JT (1991) Euclidean distance matrix analysis: a coordinate-free approach for comparing biological shapes using landmark data. Am J Phys Anthropol 86(3):415–427

Lele SR, Richtsmeier JT (2001) An invariant approach to statistical analysis of shapes. Chapman and Hall/CRC, New York

Luhmann T, Robson S, Kyle SA, Harley IA (2006) Close range photogrammetry: principles, techniques and applications. Whittles, Scotland

Mah P, Reeves TE, McDavid WD (2010) Deriving Hounsfield units using grey levels in cone beam computed tomography. Dentomaxillofac Radiol 39(6):323–335

Marcus LF, Corti M (1996) Overview of the new, or geometric morphometrics. In: Advances in morphometrics. Springer, Boston, pp 1–13

Mardia KV, Kent JT, Bibby JM (1979) Multivariate analysis. Academic Press Inc., London

McPherron SP, Gernat T, Hublin JJ (2009) Structured light scanning for high-resolution documentation of in situ archaeological finds. J Archaeol Sci 36(1):19–24

Meehan M, Teschner M, Girod S (2003) Three-dimensional simulation and prediction of craniofacial surgery. Orthod Craniofac Res 6:102–107

Mettler FA Jr, Wiest PW, Locken JA, Kelsey CA (2000) CT scanning: patterns of use and dose. J Radiol Prot 20(4):353

Mitteroecker P, Gunz P (2009) Advances in geometric morphometrics. Evol Biol 36(2):235–247

Mitteroecker P, Gunz P, Bernhard M, Schaefer K, Bookstein FL (2004) Comparison of cranial ontogenetic trajectories among great apes and humans. J Hum Evol 46(6):679–698

Mitteroecker P, Gunz P, Windhager S, Schaefer K (2013) A brief review of shape, form, and allometry in geometric morphometrics, with applications to human facial morphology. Hystrix, Ital J Mammal 24(1):59–66

Nicolae C, Nocerino E, Menna F, Remondino F (2014) Photogrammetry applied to problematic artefacts. Int Arch Photogramm, Remote Sens Spat Inf Sci 40(5):451

Niven L, Steele TE, Finke H, Gernat T, Hublin JJ (2009) Virtual skeletons: using a structured light scanner to create a 3D faunal comparative collection. J Archaeol Sci 36(9):2018–2023

Norouzi A, Rahim MSM, Altameem A, Saba T, Rad AE, Rehman A, Uddin M (2014) Medical image segmentation methods, algorithms, and applications. IETE Tech Rev 31(3):199–213

O'Higgins P (1997) Methodological issues in the description of forms. In: Fourier descriptors and their applications in biology. Cambridge University Press, Cambridge, pp 74–105

O'Higgins P (2000) The study of morphological variation in the hominid fossil record: biology, landmarks and geometry. J Anat 197(1):103–120

O'Higgins P, Dryden IL (1992) Studies of craniofacial development and evolution. Archaeol Ocean 27(3):105–112

O'Higgins P, Dryden IL (1993) Sexual dimorphism in hominoids: further studies of craniofacial shape differences in Pan, Gorilla and Pongo. J Hum Evol 24(3):183–205

Oxnard CE, O'Higgins P (2009) Biology clearly needs morphometrics. Does morphometrics need biology? Biol Theory 4(1):1–14

Piras P, Teresi L, Gabriele S, Evangelista A, Esposito G, Varano V, Puddu PE (2015) Systo-diastolic lv shape analysis by geometric morphometrics and parallel transport highly discriminates myocardial infarction. In: International workshop on statistical atlases and computational models of the heart. Springer, Cham, pp 119–129

Profico A, Bellucci L, Buzi C, Di Vincenzo F, Micarelli I, Strani F, Manzi G (2018) Virtual anthropology and its application in cultural heritage studies. Stud Conserv 7:1–14

Pun T (1980) A new method for grey-level picture thresholding using the entropy of the histogram. Signal Process 2(3):223–237

Razi T, Niknami M, Ghazani FA (2014) Relationship between Hounsfield unit in CT scan and gray scale in CBCT. J Dent Res, Dent Clin, Dent Prosp 8(2):107

Rengier F, Mehndiratta A, Von Tengg-Kobligk H, Zechmann CM, Unterhinninghofen R, Kauczor HU, Giesel FL (2010) 3D printing based on imaging data: review of medical applications. Int J Comput Assist Radiol Surg 5(4):335–341

Richtsmeier JT, Lele S (1993) A coordinate-free approach to the analysis of growth patterns: models and theoretical considerations. Biol Rev 68(3):381–411

Richtsmeier JT, Cheverud JM, Danahey SE, Corner BD, Lele S (1993a) Sexual dimorphism of ontogeny in the crab-eating macaque (Macaca fascicularis). J Hum Evol 25(1):1–30

Richtsmeier JT, Corner BD, Grausz HM, Cheverud JM, Danahey SE (1993b) The role of postnatal growth pattern in the production of facial morphology. Syst Biol 42(3):307–330

Ritman EL (2004) Micro-computed tomography—current status and developments. Annu Rev Biomed Eng 6:185–208

Rohlf FJ (1986) Relationships among eigenshape analysis, Fourier analysis, and analysis of coordinates. Math Geol 18(8):845–854

Rohlf FJ (1999) Shape statistics: Procrustes superimpositions and tangent spaces. J Classif 16(2):197–223

Rohlf FJ (2000) On the use of shape spaces to compare morphometric methods. Hystrix, Ital J Mammal 11:1

Rohlf FJ, Corti M (2000) Use of two-block partial least-squares to study covariation in shape. Syst Biol 49(4):740–753

Rohlf FJ, Marcus LF (1993) A revolution morphometrics. Trends Ecol Evol 8(4):129–132

Rohlf FJ, Slice D (1990) Extensions of the Procrustes method for the optimal superimposition of landmarks. Syst Biol 39(1):40–59

Roth VL, Mercer JM (2000) Morphometrics in development and evolution. Am Zool 40(5):801–810

Sadler J (2018) Capturing morphology. Master thesis (unpublished), Hull York Medical School York (UK)

Sapirstein P (2016) Accurate measurement with photogrammetry at large sites. J Archaeol Sci 66:137–145

Schlager S (2013) Morpho: calculations and visualisations related to geometric morphometrics. R package version 0.23.3

Schmidle G, Rieger M, Klauser AS, Thauerer M, Hoermann R, Gabl M (2014) Intraosseous rotation of the scaphoid: assessment by using a 3D CT model—an anatomic study. Eur Radiol 24(6):1357–1365

Sijbers J, Postnov A (2004) Reduction of ring artefacts in high resolution micro-CT reconstructions. Phys Med Biol 49(14):N247

Singh GD, Levy-Bercowski D, Santiago PE (2005) Three-dimensional nasal changes following nasoalveolar molding in patients with unilateral cleft lip and palate: geometric morphometrics. Cleft Palate Craniofac J 42(4):403–409

Singh GD, Rivera-Robles J, de Jesus-Vinas J (2004) Longitudinal craniofacial growth patterns in patients with orofacial clefts: geometric morphometrics. Cleft Palate Craniofac J 41(2):136–143

Slice DE (2007) Geometric morphometrics. Annu Rev Anthropol 36:261–281

Slizewski A, Semal P (2009) Experiences with low and high cost 3D surface scanner. Quartär 56:131–138

Smith MW, Carrivick JL, Quincey DJ (2016) Structure from motion photogrammetry in physical geography. Prog Phys Geogr 40(2):247–275

Sneath PH, Sokal RR (1962) Numerical taxonomy. Nature 193(4818):855–860

Spoor CF, Zonneveld FW, Macho GA (1993) Linear measurements of cortical bone and dental enamel by computed tomography: applications and problems. Am J Phys Anthropol 91(4):469–484

Strauss RE, Bookstein FL (1982) The truss: body form reconstructions in morphometrics. Syst Biol 31(2):113–135

Sun Z (2007) Multislice CT angiography in abdominal aortic aneurysm treated with endovascular stent grafts: evaluation of 2D and 3D visualisations. Biomed Imaging Intervention J 3(4):e20

Sutton M, Rahman I, Garwood R (2016) Virtual paleontology—an overview. Paleontol Soc Pap 22:1–20

Tanner JM, Whitehouse RH (1976) Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. Arch Dis Child 51(3):170–179

Thompson DAW (1917) On growth and form. Cambridge Press, Cambridge

Toennies KD (2017) Guide to medical image analysis. Springer, London

Tzou CHJ, Frey M (2011) Evolution of 3D surface imaging systems in facial plastic surgery. Facial Plast Surg Clin 19(4):591–602

Van Der Straeten C (2013) The use of magnetic resonance imaging (MRI) to evaluate hip resurfacing. In: The hip resurfacing handbook. Elsevier, Amsterdam, pp 242–252

Verhoeven G (2011) Taking computer vision aloft–archaeological three-dimensional reconstructions from aerial photographs with photoscan. Archaeol Prospect 18(1):67–73

Weber GW (2014) Another link between archaeology and anthropology: virtual anthropology. Digit Appl Archaeol Cult Herit 1(1):3–11

Weber GW, Bookstein FL (2011) Virtual anthropology: a guide to a new interdisciplinary field. Springer, Vienna

Willekens I, Buls N, Lahoutte T, Baeyens L, Vanhove C, Caveliers V et al (2010) Evaluation of the radiation dose in micro-CT with optimization of the scan protocol. Contrast Media Mol Imaging 5(4):201–207

Zelditch ML, Swiderski DL, Sheets HD (2012) Geometric morphometrics for biologists: a primer. Academic, New York and London

7

Three-Dimensional Visualisation of Skeletal Cavities

Alessio Veneziano and Antonio Profico

Abstract

Bones contain spaces within them. The extraction and the analysis of those cavities are crucial in the study of bone tissue function and can inform about pathologies or past traumatic events. The use of medical imaging techniques allows a non-invasive visualisation of skeletal cavities opening a new frontier in medical inspection and diagnosis. Here, we report the application of a new mesh-based approach for the isolation of skeletal cavities of different size and geometrical structure. We apply a mesh-based approach to extract (i) the main virtual cavities inside the human skull, (ii) a complete human endocast, (iii) the inner vasculature of the malleus bone and (iv) the medullary of a human femur. The detailed description of the mesh-based isolation method and its pioneristic application to four different case-studies show the potential of this approach in medical visualisation.

Keywords

Medicine · Bones · Virtual anthropology · 3D-images · Computerized tomography · Malleus bone · Skull · Femur

7.1 Introduction

Besides the hard matrix of hydroxyapatite, the bones exhibit spaces that are part of their normal anatomical appearance. Those macroscopic and microscopic cavities are pivotal for fulfilling some of the primary purposes of the skeletal apparatus, such as resistance to biomechanical loadings, protection of organs and blood cell production. Skeletal cavities include ‘tracks’ accommodating vessels (e.g. bone vasculature), air spaces within bones (e.g. paranasal sinuses), spaces hosting organs (e.g. cranial cavity) and soft and semi-solid tissues (e.g. marrow bones within long and flat bones). Those cavities can be altered following pathological events: bone cysts (Jaffe and Lichtenstein 1942; Mankin et al. 2005), bone tumors (Miller 2008) and several other conditions (Amaral et al. 2003; Seeger et al. 1996) can determine a morphological deformation of the cavity in which they form in response to changes in the surrounding bone. Other alterations can result from fracture healing (Shapiro 2008; Morgan et al. 2009). Furthermore, changes in the morphological appearance of skeletal cavities can be attributed to prolonged nutri-

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P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7_7

tional deficiencies (Medeiros et al. 2002) or simply as the result of bone loss with aging (Ruff and Hayes 1982; Ahlborg et al. 2003). Therefore, understanding and visualising skeletal cavities can better inform about health status, past traumatic events and also about normal and pathological function of the cavity itself.

Since the morphology of skeletal cavities is defined by the surrounding bone, the study of such structures necessitates indirect methods of enquiry. Medical imaging is an ideal approach for analysing internal anatomy. The goal of medical imaging is to provide quantitative and qualitative information of the internal morphology of the body or its parts. That information can be used to improve diagnosis and to support the study of anatomy (Chen and Sontag 1989; Doi 2007; Bartrolí et al. 2001). Medical imaging techniques allow the digital rendering of internal structures and therefore provide a way to observe skeletal cavities in their anatomical context. For more than a century X-ray based methods have been applied to the medical field to better visualise bone fractures and anomalies (Feldman 1989). These methods allow exploring normal and pathological bone anatomy by reducing the risks and invasiveness of surgical examinations. The introduction of Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI), among other methods (Beutel et al. 2000), have favoured the rapid increase of medical applications and remarkably improved the quality of visualisation of skeletal elements. Imaging techniques allow visualising, manipulating and analysing three-dimensional anatomical structures (Udupa and Herman 1999). To do so, it is often necessary to isolate the target structures from the matrix in which they are enclosed. Once isolated, those structures can be rendered in 3D as single entities, separated from the complex anatomy in which they are naturally embedded.

In this chapter we describe a mesh-based approach to extract 3D surfaces of anatomical cavities. At first (7.2.1), we present the problem of visualising skeletal cavities and discuss the issues related to manual segmentation. Then we introduce the reader to a new mesh-based approach to isolate and visualise skeletal cavities and focus on the underlying methodological procedure (7.2.2). We describe the usage of the method and support its usefulness by presenting four case studies (7.3). Finally (7.4), we underline the importance of the method and its potential in contributing to medical visualisation.

7.2 Segmentation of Skeletal Cavities

7.2.1 Manual Segmentation

By their own nature, skeletal cavities are defined by the bone matrix that encloses them. The cavity is not characterised by a well-defined density but rather by the difference in density between the surrounding bone and the material filling the cavity itself. Therefore, the isolation of such spaces is usually possible only through Segmentation. Segmentation is the process of separating the voxels (volumetric pixels) constituting the CT scan between different regions of interest (ROIs) identifiable by common features or spatial positioning and orientation (Pham et al. 2000). This process usually needs working on the stack of 2D images constituting the 3D volume and selecting the ROIs using tools commonly embedded in software packages. Although some automatic tools exist for segmentation (Pham et al. 2000; Ma et al. 2010), this is often performed manually since most anatomical structures are too complex. Manual segmentation is very demanding in terms of time and energy and requires users to be well-trained in both anatomy and the usage of segmentation software. Furthermore, as any other manual operation, segmentation is prone to errors and, therefore, results may not be fully reproducible by different users. Automatic or semi-automatic methods have proven capable of reproducing the results obtained manually (Jones et al. 2005; Kaus et al. 2001; Chiu et al. 2010) but advances in this field are needed to provide a standardised and reliable procedure for segmentation.

7.2.2 Mesh-Based Approach

Here we present a mesh-based approach to isolation of skeletal cavities as an alternative way to manual segmentation and, in general, to segmentation based on volume selection. Our method (Profico et al. 2018a) uses the "Hidden Point Removal" (HPR) operator developed by Katz and colleagues (Katz et al. 2007) for purposes not related to segmentation. We repurpose the HPR operator to simulate virtually the action of a laser scanner.

HPR is an operator for identifying the vertices of a mesh as "visible" or "hidden" based on their position with respect to a reference Point Of View (POV). HPR involves two steps: spherical flipping and the construction of a convex hull. Spherical flipping (Katz et al. 2005, 2007) uses a sphere centred on a POV to "invert" the vertices of the mesh. Each vertex (internal to the sphere) is reflected and projected outside the sphere along the rays from the POV to the vertex itself. The radius of the sphere is constrained to be large enough so that the sphere includes all the vertices of the mesh. A convex hull is then built to enclose the POV, the vertices of the mesh inverted through spherical flipping (Fig. 7.1). The vertices of the original mesh are marked as visible from the POV if their inverted coordinates lie onto the convex hull.

In the case of skeletal cavity extraction, the user defines a number of POVs external to the object to be scanned. The vertices (and associated facets) identified as visible from the POVs will be removed. In this way, it is possible to visualise all those vertices that cannot be "seen" from the POVs because hidden by the external surface of the mesh. This approach can be used to extract and visualise internal anatomical elements such as the dental pulp chamber and the medullary cavity of long bones. At the same time, this procedure can be useful to isolate complex systems of microscopic cavities such as vascular networks, whose segmentation would be challenging, if not impossible, using a manual approach. Alternatively, a set of POVs can be defined and placed inside the cavity to be isolated (Fig. 7.2). In this way, each POV is used to identify those vertices of the mesh (the ones constituting the walls of the cavity) that are visible from the POV itself. This approach is conceived to isolate all those cavities composed of one unique, continuous, well-defined "empty" space.

A major advantage of processing 3D meshes is that the starting material (the mesh) can be cleaned and prepared preliminarily, for example by deleting unwanted regions through surface editing tools. In addition, the isosurfacing algorithms used to extrapolate a 3D mesh from an image stack (Newman and Yi 2006; Sutton et al.

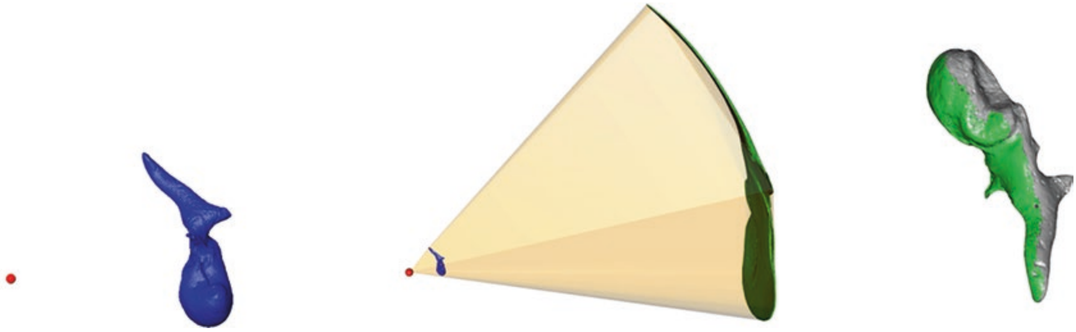

Fig. 7.1 The HPR operator applied on the 3D model of a human malleus bone. First, a Point Of View (POV, red) is positioned in the proximity of the 3D mesh (blue, left). The vertices of the mesh are inverted (green) through spherical flipping and projected outside a sphere enclosing the mesh (centre). A 3D convex hull enclosing the POV, the original vertices and the inverted ones is built (centre). The inverted vertices lying on the convex hull are identified as visible (green) from the POV (right)

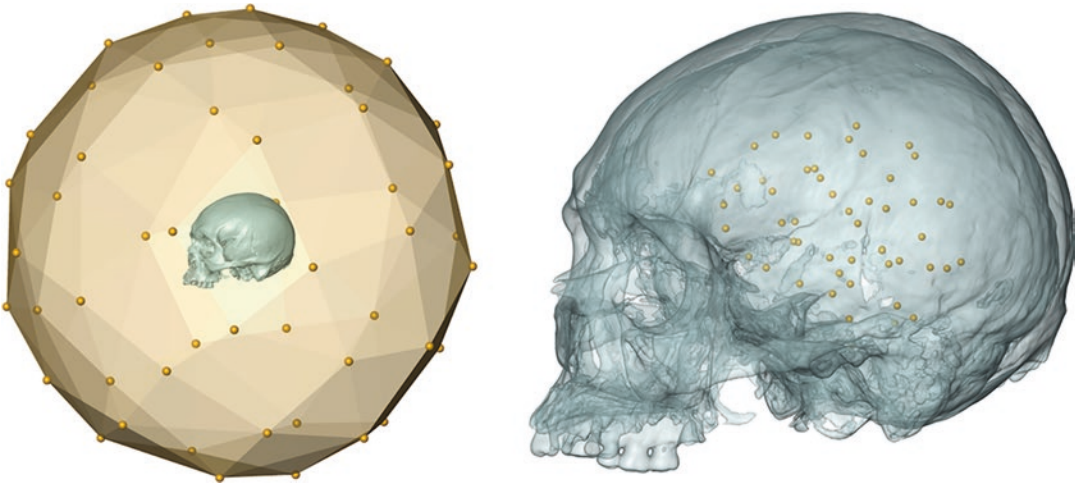

Fig. 7.2 Two different ways of applying the Hidden Point Removal (HPR) operator, shown on a human cranium. The ectocranial vertices can be detected using a set of Points Of View (POVs) surrounding the cranium (left). When marked as "visible" from the POVs, the external vertices can be removed to reveal the underlying cavities. Alternatively (right) the POVs can be placed within the cavity of interest. In this way, the only vertices visible from the POVs belong to the cavity itself and those can be isolated from the surrounding cranium and associated structures

2000) contribute largely to the standardisation of the isolation procedure. Indeed, in CT and MRI images, differences in density between contiguous materials are often fuzzy. Although such blurry boundaries can be resolved visually by a human operator, they can be interpreted differently by different users. Conversely, in the mesh-based approach, the selection of blurry boundaries is performed by isosurfacing algorithms such as the Marching Cubes (Newman and Yi 2006) and it is, therefore, less prone to accidental errors (although systematic biases can still occur).

In isolating skeletal cavities, the aim is to isolate a whole structure and, therefore, several POVs are needed. The definition of such set of POVs is crucial. Although the result will depend on the complexity of the cavity itself, the density of POVs placed around or inside the cavity is essential. At the same time, more POVs will translate in higher computational efforts. A mindful choice is needed to reach good results without increasing computing time.

Thanks to this novel approach, it is possible to “scan” a 3D mesh by placing the POVs respectively outside or inside the mesh. As a result, two meshes are obtained, formed respectively by areas that are visible or hidden from the POVs. The detection of the visible surface is directly obtained by applying the HPR operator (Katz et al. 2007). The hidden surface is obtained via subtraction of the visible vertices from the original 3D model. This method was developed in the R environment (Team 2015) and it is available in the R package “Arothron” (Profico et al. 2018b).

7.3 Case Studies

Here we report four case studies highlighting the potential applications of the method presented above. These examples also clarify the correct usage of the method with regards to the different types of skeletal elements to which it could be applied. The first two case studies deal with the visualisation of anatomical cavities within the human skull, with particular emphasis on the brain endocast. In another example, we apply the method for isolating vascular networks. Finally, the cavity extraction is performed on a human femur to isolate and visualise its endosteal and periosteal components.

7.3.1 Hidden Skeletal Cavities of the Human Skull

The human cranium hosts several cavities of high functional importance such as the nasal cavity, paranasal sinuses and ear canals. Some regions of the skull exhibit pneumatized areas where air-filled spaces are embedded within the hard bone matrix. In addition, a large portion of the whole cranial volume is occupied by the most impressive of all human skeletal cavities: the brain endocast. Some of those spaces, such as the nasal cavity and the ear canal, are partly visible from the outside but most cavities are concealed by the ectocranial surface. The visible part of the cranium can be removed using the HPR operator.

Here the HPR operator is applied on the cranium of a Fuegian individual from South America (FUE 3115), part of the anthropological collection of the Natural History Museum at the University of Florence, Italy. The 3D mesh of the cranium was obtained from a medical CT-scan (voxel size: 0.57 × 0.57 × 0.9 mm) by applying the Marching Cubes algorithm (Newman and Yi 2006) for Isosurfacing. We define a set of 50 POVs external to the 3D model and lying on a sphere surrounding the object (Fig. 7.2). The sphere is centered on the barycenter of the mesh. The goal is to remove all the facets visible from the outside of the skull to reveal its internal anatomy. Because the POVs lie outside the cranium, the HPR operator scans the whole ectocranial surface whose vertices are visible from the POVs. We then subtract the visible vertices and facets from the entire mesh obtaining the 3D model reported in Fig. 7.3.

The removal of the visible vertices highlights the internal morphology of the human cranium and emphasises the volume of the cavities there enclosed. Parts usually hidden below the ectocranial surface become visible and reveal details that are difficult to fully appreciate in 2D CT images. The visualisation of such structures is usually possible only through manual segmentation. A large part of the nasal fossae is now visible and the volume, position and orientation of the paranasal sinuses can be observed in their anatomical context. The pneumatized regions of the cranium are revealed, for example in the mastoid area (Fig. 7.3). The advantages of the HPR operator are particularly underlined by the brain endocast. Indeed, the removal of the ectocranial surface brings to light anatomical details of the brain vasculature, whose 3D orientation and position can be easily appreciated (Fig. 7.3).

7.3.2 The Brain Endocast

The major cavity in the human cranium, the brain endocast, holds a special meaning for those who study the uniqueness of our species among animals. The enlargement of our braincase is probably the most remarkable trait observed during human evolution (Schoenemann 2006) and the endocast provides information about the changes of the hominin brain over time (Radinsky 2017; Holloway et al. 2009). Besides its palaeoanthropological importance, the brain endocast can inform on the vascularisation of the brain and the tissues around it in normal and pathological conditions (Bruner et al. 2011; Bruner and Sherkat 2008; Dean O'Loughlin 1996).

By using the specimen in 7.3.1, we isolated the brain endocast by means of the HPR operator. We designed a set of 30 POVs placed inside the endocast cavity (Fig. 7.2). POVs placed internally are necessary to avoid other endocranial structures to be included in the result. In this way, we are able to "scan" the brain endocast as if a flexible laser scanner was introduced in the cranium through the foramen magnum. The 3D virtual rendering of the resulting endocast is shown in Fig. 7.4. The brain endocast reproduces the superficial anatomy of the Dura Mater and reveals the general brain shape as well as details of the associated vasculature, cranial nerves, and cranial sutures. The middle meningeal artery is clearly visible in its anatomical position and the extension of the different lobes can be observed. Part of the brain convolutions are also visible and some patterns of the sulci are recognisable, although not clearly marked.

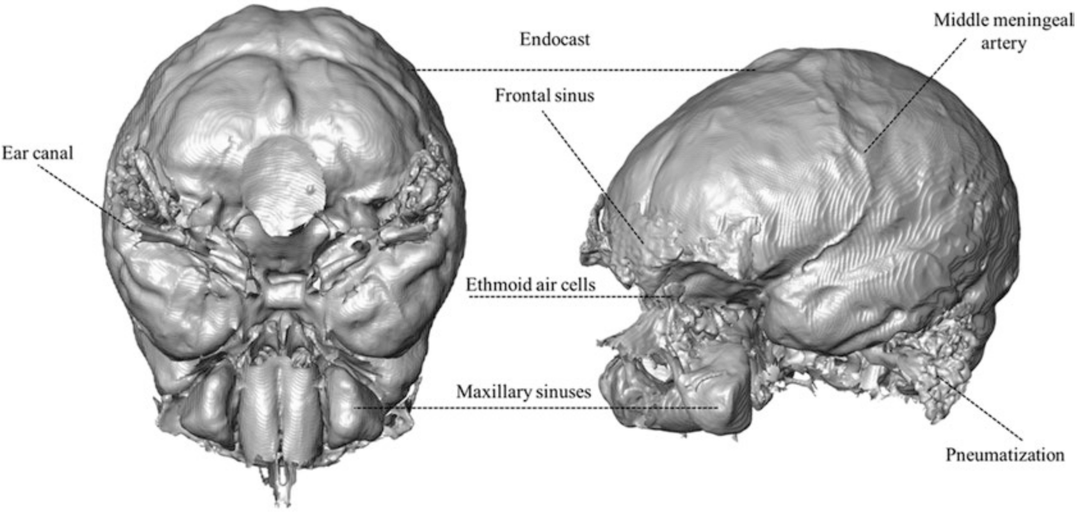

Fig. 7.3 Cranial cavities revealed by subtracting the vertices of the ectocranial surface from the 3D mesh. The recognition of the external surface of the cranium is performed using the Hidden Point Removal (HPR) operator applied on a 3D mesh. The removal of the ectocranial surface highlights several cavities whose virtual visualisation usually requires manual segmentation. The internal anatomy of the human cranium is shown on a Fuegian specimen (FUE 3115) of the Natural History Museum at the University of Florence, Italy

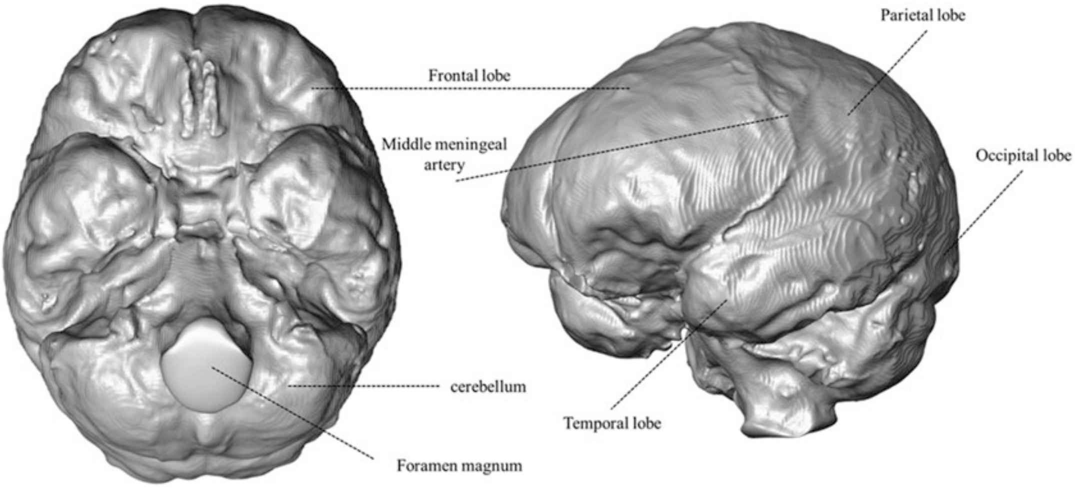

Fig. 7.4 The human brain endocast isolated using the Hidden Point Removal (HPR) operator applied on the 3D mesh of a cranium. The brain endocast represents the impression of the Dura Mater onto the internal surface of the cranium. Although it does not represent the brain directly, the extension of the different lobes are visible. Part of the meningeal vasculature and the different lobes can be observed. The endocast is obtained from a Fuegian cranium (FUE 3115) of the Natural History Museum at the University of Florence, Italy

7.3.3 Vascular Network of the Malleus Bone

The internal anatomy of the middle-ear ossicles is accessible through histology and microscopy (Nager and Nager 1953; Chien et al. 2009; Farahani and Nooranipour 2008). By dissecting single slices of the malleus, incus and stapes it is possible to gain insights on the spatial distribution of the blood vessels running through these bones. Visualising the network of vessels can be very informative about the volume and distribution of blood supply and its relevance for the function of the auditory ossicles. Disorders of the circulation of the inner ear have been indeed reported as causes of impaired hearing or hearing loss (Nadol Jr 1993). In addition, the design of prosthetic replacements of auditory ossicles would benefit from understanding the distribution of vessels inside the stapes, incus and malleus. In fact, the conversion from vibration to auditory stimuli is closely dependent on the structure of the ossicles (Kanzaki et al. 2011; Daniel et al. 2001; Raveh et al. 2002) and blood vessels occupy a relevant fraction of the volume of auditory ossicles. Nevertheless, a 2D analysis under a microscope does not do justice to the complex network formed by those vessels. CT-scan technology provides a great opportunity for clarifying the internal anatomy of the auditory ossicles (Decraemer et al. 2003; Sim and Puria 2008) but segmentation is needed to obtain a 3D rendering of their vascular system. Being a very intricate network, the manual segmentation of the vessels of the ear ossicles can be quite challenging and time-consuming, even for a skilled user.

Here we present the application of the method described in 7.2.2 to the isolation and visualisation of the vascular system of the human malleus bone. We apply the HPR operator to a human malleus belonged to a subadult individual from the Middle Ages of Portico D'Ottavia, Rome (XI century A.D.). The original specimen (PO 2010 US 23) is stored at the laboratory of Anthropology at the Department of Biology of the University of Florence, Italy. The specimen was digitally acquired with a Skyscan 1172 micro-CT scanner (Bruker microCT, Kontich, Belgium) in microCT format (voxel size: 0.01 × 0.01 × 0.03 mm). To obtain the inner cavities located inside the malleus bone, we define a set of 50 POVs lying on a sphere surrounding the 3D mesh. In this way, we find the vertices visible from the POVs and, by subtraction, we isolate the vascular system inside the malleus bone (Fig. 7.5).

By applying the HPR operator to the malleus bone, we obtain a 3D mesh of the complex network of blood vessels hidden below the external surface of this ossicle (Fig. 7.5). The removal of the external surface of the ossicle reveals a major, bifurcating branch, which is connected to the superior branch of the anterior tympanic artery through the nutrient foramen (Hamberger et al. 1963). The differential density of blood vessels is visible, the network being more intricate on the head, where the malleus articulates with the incus. This example demonstrates the feasibility of a mesh-based approach to isolate and visualise complex skeletal cavities.

7.3.4 The Medullary Cavity of Long Bones

The whole length of long bones is characterised by the presence of a large cavity delimited by compact bone along the shaft and by trabecular bone at the proximal and distal ends. This central cavity, also known as medullary cavity or medulla, acts as a storage space for bone marrow and is home to blood cell production. In addition, the shape and thickness of the compact bone surrounding the medulla are important to resist biomechanical stress (Currey and Alexander 1985; Zdero et al. 2010). The morphology of the medullary cavity can be altered following healing of fractures (McKibbin 1978), osteonecrosis (Saini and Saifuddin 2004), arthroplasty (D'antonio et al. 1993) or simply as an effect of aging (Parfitt 1984). Another common source of alteration is osteoporosis, which causes the expansion of the medulla because of cortical bone thinning (Keshawarz and Recker 1984). The visualisation of the medullary cavity in its 3D appearance can be highly useful to analyse the effects of fractures or osteoporosis and also for the design of prosthetic devices (Powlan 1989).

Here we show the isolation of the medullary cavity of a human femur using the HPR operator. The specimen used (FUE 0805) belongs to a Fuegian individual and is part of the skeletal collection of the "Anthropology Museum G. Sergi" at the Sapienza University of Rome, Italy. The specimen was CT-scanned (voxel

Fig. 7.5 The human malleus bone and its internal vascular network. The Hidden Point Removal (HPR) operator is used to scan the external surface (centre) of the original mesh (top). When the visible vertices are subtracted from the 3D mesh, the vascular network is revealed (bottom). The blood vessels of the malleus bone are shown on a specimen from a Middle Ages individual of Portico D'Ottavia, Rome (PO 2010 US 23), and stored at the laboratory of Anthropology at the Department of Biology of the University of Florence, Italy

size: 0.625 × 0.625 × 1.25 mm^3) to obtain its digital reconstruction and a mesh obtained through isosurfacing. To isolate the medullary cavity, 50 POVs lying on a sphere were placed around the femur. The vertices of the periosteal surface of the femur are recognised as "visible" from the POVs and are then subtracted from the 3D mesh to reveal the endosteal surface (Fig. 7.6).

7.4 Final Remarks

As for most anatomical regions, the complexity of several skeletal cavities makes their virtual isolation very demanding. The 3D visualisation of such structures is therefore challenging and often hard to reproduce accurately. Operators performing segmentation must be well-trained in medical imaging techniques as well as confident with the anatomy of interest. Nevertheless, in

Fig. 7.6 Isolation of the medullary cavity of a human femur. The 3D mesh of the femur (top) is fed to the Hidden Point Removal (HPR) operator, which recognises the vertices of the periosteal surface (transparent in middle image) as "visible". The subtraction of the periosteal vertices from the mesh leaves the endosteal surface uncovered. The surface of the medullary cavity is revealed and part of the spaces within the trabecular bone are also rendered as part of the resulting mesh. The original specimen (FUE 0805) is a femur of a Fuegian individual and is part of the skeletal collection of the "Anthropology Museum G. Sergi" at the Sapienza University of Rome, Italy

most cases, segmentation is still very time-consuming and poorly standardised, regardless of the experience of the operator.

Above we reported the application of a semi-automatic method for cavity extraction based on the use of meshes extracted from a 3D volume. The method requires limited contribution from an external operator, thus reducing manual operations and, therefore, human-linked errors. In addition, by working on 3D meshes, the method provides a result that is more evenly curved and less faceted than with procedures working through voxel density (Veneziano et al. 2018). Furthermore, the technique presented above is usually faster than manual segmentation, in particular for very complex structures such as networks of blood vessels. All these aspects contribute to the reproducibility of the isolation of virtual cavities. It has to be pointed out that the HPR operator is not the only method allowing a semi-automatic extraction of skeletal cavities. In fact, the brain endocast has received large attention and other techniques have been developed to provide a segmented braincase (Michikawa et al. 2017). Nevertheless, the method presented here is more generalised and applicable to a large range of skeletal cavities and other types of objects.

The method can be used to study all those pathologies affecting cavities directly or indirectly. For example, bone loss and increased porosity characterise long bones of osteoporotic individuals (Keshawarz and Recker 1984) while scurvy reduces the thickness of the cortical region of long bones in infants (Kwon et al. 2002). The method presented above can be useful to isolate the cortical canal and trabecular spaces within long bones, whose volume can be then quantified. Such an approach to the 3D rendering of skeletal cavities has applications beyond biomedics, encompassing forensic anthropology, biological anthropology and bioarchaeology. Pathologies characterised by cortical thinning or increased porosity can be informative of population health, life conditions and demography in past populations (Brickley 2002; Turner-Walker et al. 2001; Larsen 1995) and also in human evolutionary contexts (Domínguez-Rodrigo et al. 2012; Odes et al. 2016). Besides pathologies, the method of mesh-based isolation of cavities can be useful to clarify the 3D orientation of complex structures, such as blood vessels. In the future, our approach could be applied on MRI-generated meshes to focus on cavities of soft tissues or even to isolate entire organs.

Standardising the visualisation and analysis of 3D data is necessary if the future automatisation of medical imaging procedures has to be trusted for diagnostic purposes or extended to comparative studies based on large databases. The method we presented above represents a far-reaching contribution to the process of standardising segmentation. Nevertheless, much has still to be done to generalise such reproducibility.

Acknowledgments The authors thank Dr. M. Zavattaro, curator of the Natural History Museum (Anthropology and Ethnology section) and Prof. Giorgio Manzi, director of the Museum of Anthropology “G. Sergi”, for kindly providing the virtual osteological material used in this study. We also thank the two R developers of the package Arothron Prof. Pasquale Raia and Dr. Marina Melchionna.

References

Ahlborg HG et al (2003) Bone loss and bone size after menopause. N Engl J Med 349(4):327–334

Amaral L et al (2003) MR imaging for evaluation of lesions of the cranial vault: a pictorial essay. Arq Neuropsiquiat 61(3A):521–532

Bartrolí AV et al (2001) Nonlinear virtual colon unfolding. In: Proceedings of the conference on visualization’01. IEEE Computer Society. pp 411–420

Beutel J, Kundel HL, Van Metter RL (2000) Handbook of medical imaging. Volume 1. Physics and Psychophysics. Spie Press, Bellingham

Brickley M (2002) An investigation of historical and archaeological evidence for age-related bone loss and osteoporosis. Int J Osteoarchaeol 12(5):364–371

Bruner E, Sherkat S (2008) The middle meningeal artery: from clinics to fossils. Childs Nerv Syst 24(11):1289

Bruner E et al (2011) The evolution of the meningeal vascular system in the human genus: from brain shape to thermoregulation. Am J Hum Biol 23(1):35–43

Chen L-S, Sontag MR (1989) Representation, display, and manipulation of 3D digital scenes and their medical applications. Comput Vis, Graphics, Image Process 48(2):190–216

Chien W et al (2009) Anatomy of the distal incus in humans. J Assoc Res Otolaryngol 10(4):485

Chiu SJ et al (2010) Automatic segmentation of seven retinal layers in SDOCT images congruent with expert manual segmentation. Opt Exp 18(18):19413–19428

Currey JD, Alexander RM (1985) The thickness of the walls of tubular bones. J Zool 206(4):453–468

D’antonio J et al (1993) Classification of femoral abnormalities in total hip arthroplasty. Clin Orthop Relat Res 296:133–139

Daniel SJ et al (2001) Clinical application of a finite-element model of the human middle ear. J Otolaryngol-Head Neck Surg 30(6):340

Dean O’Loughlin V (1996) Comparative endocranial vascular changes due to craniosynostosis and artificial cranial deformation. Am J Phys Anthropol Off Publ Am Assoc Phys Anthropol 101(3):369–385

Decraemer WF, Dirckx JJJ, Funnell WRJ (2003) Three-dimensional modelling of the middle-ear ossicular chain using a commercial high-resolution X-ray CT scanner. J Assoc Res Otolaryngol 4(2):250–263

Doi K (2007) Computer-aided diagnosis in medical imaging: historical review, current status and future potential. Comput Med Imaging Graph 31(4–5):198–211

Domínguez-Rodrigo M et al (2012) Earliest porotic hyperostosis on a 1.5-million-year-old hominin, Olduvai Gorge, Tanzania. PloS one 7(10):e46414

Farahani RM, Nooranipour M (2008) Anatomy and anthropometry of human stapes. Am J Otolaryngol 29(1):42–47

Feldman A (1989) A sketch of the technical history of radiology from 1896 to 1920. Radiographics 9(6):1113–1128

Hamberger CA, Marcuson G, Wersäll J (1963) Blood vessels of the ossicular chain. Acta Otolaryngol 56(sup183):66–70

Holloway RL et al (2009) Evolution of the brain in humans–Paleoneurology. In: Encyclopedia of neuroscience. Springer, New York, pp 1326–1334

Jaffe HL, Lichtenstein L (1942) Solitary unicameral bone cyst: with emphasis on the roentgen picture, the pathologic appearance and the pathogenesis. Arch Surg 44(6):1004–1025

Jones TR, Carpenter A, Golland P (2005) Voronoi-based segmentation of cells on image manifolds. In: International workshop on computer vision for biomedical image applications. Springer. pp 535–543

Kanzaki S et al (2011) Impaired vibration of auditory ossicles in osteopetrotic mice. Am J Pathol 178(3):1270–1278

Katz S, Leifman G, Tal A (2005) Mesh segmentation using feature point and core extraction. Vis Comput 21(8–10):649–658

Katz S, Tal A, Basri R (2007) Direct visibility of point sets. In: ACM Transactions on Graphics (TOG). 26. 2007. ACM. p 24

Kaus MR et al (2001) Automated segmentation of MR images of brain tumors. Radiology 218(2):586–591

Keshawarz NM, Recker RR (1984) Expansion of the medullary cavity at the expense of cortex in postmenopausal osteoporosis. Metab Bone Dis Relat Res 5(5):223–228

Kwon DS et al (2002) Physiologic subperiosteal new bone formation: prevalence, distribution, and thickness in neonates and infants. Am J Roentgenol 179(4):985–988

Larsen CS (1995) Biological changes in human populations with agriculture. Annu Rev Anthropol 24(1):185–213

Ma Z et al (2010) A review of algorithms for medical image segmentation and their applications to the female pelvic cavity. Comput Methods Biomech Biomed Engin 13(2):235–246

Mankin HJ et al (2005) Aneurysmal bone cyst: a review of 150 patients. J Clin Oncol 23(27):6756–6762

McKibbin B (1978) The biology of fracture healing in long bones. J Bone Joint Surg 60(2):150–162

Medeiros DM et al (2002) Bone morphology, strength and density are compromised in iron-deficient rats and exacerbated by calcium restriction. J Nutr 132(10):3135–3141

Michikawa T et al (2017) Automatic extraction of endocranial surfaces from CT images of crania. PLoS One 12(4):e0168516

Miller TT (2008) Bone tumors and tumorlike conditions: analysis with conventional radiography. Radiology 246(3):662–674

Morgan EF et al (2009) Micro-computed tomography assessment of fracture healing: relationships among callus structure, composition, and mechanical function. Bone 44(2):335–344

Nadol JB Jr (1993) Hearing loss. N Engl J Med 329(15):1092–1102

Nager GT, Nager M (1953) LXXXIII the arteries of the human middle ear, with particular regard to the blood supply of the auditory ossicles. Ann Otol Rhinol Laryngol 62(4):923–949

Newman TS, Yi H (2006) A survey of the marching cubes algorithm. Comput Graph 30(5):854–879

Odes EJ et al (2016) Earliest hominin cancer: 1.7-million-year-old osteosarcoma from Swartkrans Cave, South Africa. S Afr J Sci 112(7–8):1–5

Parfitt AM (1984) Age-related structural changes in trabecular and cortical bone: cellular mechanisms and biomechanical consequences. Calcif Tissue Int 36(1):S123–S128

Pham DL, Xu C, Prince JL (2000) Current methods in medical image segmentation. Annu Rev Biomed Eng 2(1):315–337

Powlan RY (1989) Prosthetic device and method of fixation within the medullary cavity of bones. Google Patents

Profico A et al (2018a) Reproducing the internal and external anatomy of fossil bones: two new automatic digital tools. Am J Phys Anthropol [Online] Available at: https://doi.org/10.1002/ajpa.23493

Profico A et al (2018b) Arothron: R functions for geometric morphometrics analyses. [Online]. Available at: https://doi.org/10.5281/zenodo.28194

Radinsky L (2017) Endocasts and studies of primate brain evolution. In: The functional and evolutionary biology of primates. Routledge, Chicago, pp 175–184

Raveh E et al (2002) Congenital conductive hearing loss. J Laryngol Otol 116(2):92–96

Ruff CB, Hayes WC (1982) Subperiosteal expansion and cortical remodeling of the human femur and tibia with aging. Science 217(4563):945–948

Saini A, Saifuddin A (2004) MRI of osteonecrosis. Clin Radiol 59(12):1079–1093

Schoenemann PT (2006) Evolution of the size and functional areas of the human brain. Annu Rev Anthropol 35:379–406

Seeger LL et al (1996) Ribbing disease (multiple diaphyseal sclerosis): imaging and differential diagnosis. Am J Roentgenol 167(3):689–694

Shapiro F (2008) Bone development and its relation to fracture repair. The role of mesenchymal osteoblasts and surface osteoblasts. Eur Cell Mater 15(53):e76

Sim JH, Puria S (2008) Soft tissue morphometry of the malleus–incus complex from micro-CT imaging. J Assoc Res Otolaryngol 9(1):5

Sutton PM et al (2000) A case study of isosurface extraction algorithm performance. In: Data visualization 2000. Springer. pp 259–268

Team RC (2015) R: a language and environment for statistical computing [Internet]. Vienna, Austria: R Foundation for Statistical Computing; 2013. Document freely available on the internet at: http://www.r-project.org

Turner-Walker G, Syversen U, Mays S (2001) The archaeology of osteoporosis. Eur J Archaeol 4(2):263–269

Udupa JK, Herman GT (1999) 3D imaging in medicine. CRC press, Boca Raton

Veneziano A, Landi F, Profico A (2018) Surface smoothing, decimation, and their effects on 3D biological specimens. Am J Phys Anthropol. [Online]. Available at: https://doi.org/10.1002/ajpa.23431. Accessed 15 Feb 2018

Zdero R et al (2010) The effect of cortex thickness on intact femur biomechanics: a comparison of finite element analysis with synthetic femurs. Proc Inst Mech Eng H J Eng Med 224(7):831–840

8

Recommended Workflow Methodology in the Creation of an Interactive Application for Patient's Diagnosed with Pancreatic Cancer

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Abstract

Pancreatic cancer is a leading cause of cancer related deaths in the UK. However, public knowledge and understanding of the pancreas is generally poor, therefore pancreatic cancer patients often have to contend with understanding large quantities of new information at a pivotal time in their lives.

Despite utilisation of digital visualisation techniques in medical education, very rarely are they being used to help clinicians communicate information to their patients. Specifically, there is no literature describing use of an interactive digital application for use by healthcare professionals to aid discussions specific to pancreatic cancer.

Therefore, we developed a workflow methodology, and created an interactive application, thus creating a tool that could help clinicians explain pancreatic cancer anatomy, and staging, to their patients. Three-dimensional (3D) digital models were created using ZBrush and Autodesk 3DS Max, and exported into the Unity game engine. Within Unity, the interactivity of models was maximally utilised, and a simple user interface created.

The application centres on anatomically accurate, visually simple, 3D digital models, demonstrating a variety of common scenarios that arise in pancreatic cancer. The design of the application is such that the clinician can select which model is relevant to the patient, and can give an explanation of the anatomy and disease process at a speed and level appropriate to that person. This simple, robust and effective workflow methodology for the development of an application could be useful in any clinical setting that needs visual and interactive tools to enhance patient understanding of a clinical condition.

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P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7_8

Keywords

Blended learning · Patients · Digital model · Cancer · Pancreas

8.1 Introduction

Pancreatic cancer is the fifth commonest cause of cancer related deaths in the UK, with a 5-year survival rate of around 4%. Patients are often diagnosed with advanced disease and consequently less than 20% are suitable for curative surgical management.

Unlike more prevalent cancers, public knowledge and understanding of pancreatic cancer is poor. The anatomical location of the pancreas and its complex functions mean it can be a difficult organ for patients to understand. A 2014 Pancreatic Cancer UK poll showed only 37% of Scottish respondents reported that they knew 'something' about pancreatic cancer, compared to 73% for breast cancer (Pancreatic Cancer UK 2015).

This lack of baseline knowledge often means health care professionals are tasked with having to explain the basic anatomy of the pancreas and its proximity to other structures to patients. This context is required to explain disease staging and to justify the next set of investigations or why certain treatment options are being suggested. Conveying such information with the confines of a short outpatient appointment can be difficult.

There is research showing that global satisfaction of cancer patients is predicted by how well information is given to them by their doctor (Ong et al. 2000). Studies on a variety of medical conditions have demonstrated that effective communication has a positive effect on patient satisfaction, adherence to treatments and also recall of facts (Roter 1989; Hanratty et al. 2012). Poor communication, particularly with cancer patients, can cause confusion over prognosis and dissatisfaction at not being involved in the decision making process (Hanratty et al. 2012). However, general recall of information given to patients during a medical consultation has been shown to be poor with somewhere between 40–80% forgotten immediately (Kessels 2003). Delivery of stressful information has also been shown to be associated with something called "attentional narrowing." This means that information following the news a cancer diagnosis, such as treatment options will not be processed and stored in the same way that the initial message is.

For the healthcare professional, communication difficulties lead to lower job satisfaction and higher stress levels, as well as being behind a high proportion of errors and complaints (Payne 2014). Therefore, the medical profession needs to ensure the best is being done to ensure this information is being delivered in the most effective way. Education, literacy levels and linguistic fluency clearly have an impact on any spoken or written information, and visual adjuncts are a way of overcoming these barriers to effective information delivery.

Currently most hepatopancreatobiliary (HPB) clinicians will use verbal explanation and often resort to hand drawn diagrams to illustrate certain points, for example how pancreatic cancer is staged based on where the disease may have spread. There is little literature looking at use of a blended learning model with digital adjuncts in these scenarios, but they could reduce the information that the clinician has to verbally convey during an outpatient appointment, thus saving time and reducing anxiety (Murgitroyd et al. 2015).

There are several studies looking at the effectiveness of 3D models as a teaching tool within anatomical and medical education (Welsh et al. 2014; Clunie et al. 2015; Fredieu et al. 2015; Manson et al. 2015). Most studies appear to show little evidence of their superiority over traditional teaching methods. However, many advocate their use in a blended learning method, as there does seem to be some evidence that it can at least enhance student's understanding and performance when used as an adjunct to traditional teaching. McNulty et al. (2009) examined the use of a computer based learning (CBL) program provided to their students for use in their own time for anatomy. They found that the students that utilized this resource tended to perform better in their assessments, and retention of knowledge about anatomical structures McNulty et al. (2009). Tam et al. (2010) had similar findings when they looked at the use of a CBL program that demonstrated gastrointestinal anatomy using CT 3D reconstructions.

Therefore, with a growing body of evidence in the education setting showing that digital products and 3D models for anatomy can enhance knowledge, understanding and retention of information, it could be translated into the use for patient's to explain complex anatomy more simply.

In a clinical setting an advantage of digital 3D models over a physical model is that they can be manipulated to depict changes in a structure depending on site or progress of disease. A series of physical models is required to do this and would be limited by storage space and number of models available.

Multiple studies have shown that patients often state their preferred primary source of information with regards to their disease is from a clinician (Kessels 2003; D'Angelica et al. 1998; Jenkins et al. 2001). Our hope is that by combining spoken information from the clinician with a 3D digital model it will augment the verbal information given regardless of a persons' educational background, by removing any ambiguity or misinterpretation of anatomical information given.

Therefore, our aim was to develop a workflow methodology using industry standard software, in the creation of a tool to assist clinicians in communicating information effectively about pancreatic cancer, to their patients. A face-to-face driver model of blended learning was used as a basis for the design of a tool to help clinicians explain pancreatic cancer staging to their patients. This model was chosen to enable the clinician to tailor the delivery speed and type of information to each patient, whilst augmenting their explanations with digital models.

8.2 Materials and Methods

8.2.1 Materials

8.2.1.1 Hardware

The following hardware was used:

(a) Computer

64-bit Intel® or AMD® multi-core processor with dedicated NVIDIA or AMD graphics card to meet Autodesk 3DS Max recommendations was used.

(b) Apple iPad Air 2 (WiFi)

9.7inch display. 2048 x 1536 resolution. A8X chip with 64-bit architecture.

8.2.1.2 Software

The software adopted for this study are industry standard, easily accessible, and require simple training. They are detailed below in Table 8.1, with explanations of the uses of each package.

8.2.2 CT Dataset

The CT dataset of a 69-year-old male patient with a head of pancreas tumour was used to create the tumour model. Patient consent for use of images gained by lead clinician (RC) in accordance with NHS guidelines, where the DICOM (Digital Imaging and Communication in Medicine) files were anonymised in accordance with National Imaging Clinical Advisory Group Guidelines. This was approved as a service improvement investigation and as such, ethical approval was not required.

Table 8.1 This lists, in alphabetical order, the software packages used, and a brief description of what each was used for in this study, as its general features. BodyParts 3D Library licensed under CC Attribution-Share Alike 2.1 Japan. All remaining software was obtained on educational licenses through Glasgow School of Art

Name	Description
Autodesk 3DS Max 2016 2016 Autodesk Inc.	Design software used for 3D modelling and adaptation/finishing of imported meshes to export for use in Unity.
Adobe Photoshop CS6 2012 Adobe Systems Incorporated	Image editing, using layers and masking to create images suitable to exported as PNG files for use in Unity.
BodyParts 3D library 4.3 © The Database Center for Life Science	Pre-made 3D body part models. Meshes exported to be used as templates to build new meshes.
Slicer 4.5 BWH and 3D Slicer Contributors www.slicer.org	Open source software package for visualisation and medical image computing. Used for creation of 3D model meshes from CT data.
Unity 5.2.1f1 (64-bit) 2015 Unity Technologies	Unity is a game development engine that was used to create the interactive platform to build into an iPad app.
Unity Remote 4 App 2015 Unity Technologies	Enables testing of app live inside the Unity Editor by creating a remote control out of your iOS device.
Xcode 8 2016 Apple Inc.	Xcode is a suite of software development tools developed by Apple to build apps for use on Apple hardware. An Xcode project is generated when the app is built for iOS in Unity.
ZBrush 4R6 FL 2016 Pixologic Inc.	Digital sculpting tool. Primarily used to simplify and sculpt new meshes using 3D body parts library models as templates.
7-Zip 9.20 1999-2010 Igor Pavlov	Open source file archiver. Used to compress files for ease of transport and storage.

8.3 Methods

Figure 8.1 highlights the methods used to create the digital 3D models and how to incorporate these into an interactive application (app) for use in clinical discussions with patients.

8.3.1 App Design

The number of 3D models to be included in the app was determined by attending the West of Scotland Pancreatic Unit outpatient clinic. Senior registrars, clinical nurse specialists (CNS) and a consultant surgeon were observed explaining pancreatic cancer to patients. The purpose of this was to gain insight into how the department ran their clinics to ensure the app would meet the user and organisational requirements.

Further unstructured interviews with a consultant pancreatic surgeon and an HPB CNS were undertaken. As a result of these observations in clinic, and the discussions with clinicians, the commonest scenarios, which they had to explain to patients with the help of a diagram, are listed below no particular order:

- Where the pancreas is located
- Location of tumour
- Invasion of tumour into adjacent structures (e.g. bile ducts, blood vessels)
- Spread of disease (lymph nodes and distant metastases)

On the basis of these discussions a set of scenarios to create digital models for, was decided with the potential health professional users. Approximate app layout, number of scenes and their navigation order and flow was decided using a paper prototyping session with the lead clinician (RC). This involved printing blank templates for the iPad and blank buttons. The session was used to determine the most intuitive positioning of buttons and layout of the app screen.

8.3.2 Model Production

The 3D models required for the app were produced using a variety of techniques. A head of pancreas tumour was modelled from CT data using Slicer. The remaining anatomical models (Table 8.2) were modelled using a combination of Zbrush and Autodesk 3DS Max. The models required clean geometry to allow clear rendering in Unity and with a target total polygon count of

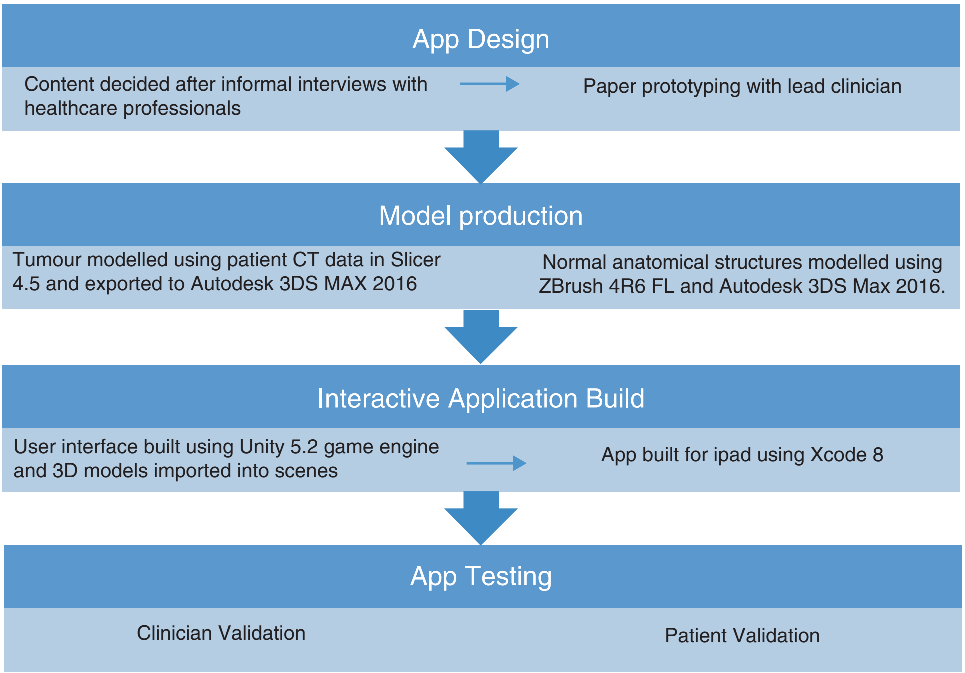


Fig. 8.1 Workflow to undertake the design and creation of an app, in this case for pancreatic cancer patients

<100,000 per frame to ensure optimal performance. All models were then exported as .OBJ files into Unity game engine.

8.4 Anatomy Modelling

BodyParts 3D library 4.3 was used to act as a template for most of the models. However, the meshes were complex, had a high polygon count and most organs were comprised of several segments. This division of the organs meant there was internal geometry and therefore, when material opacity applied to the organ was adjusted in Unity, the internal geometry became visible and became confusing to look at (Fig. 8.2). In addition to this the complex mesh made any modifications extremely difficult.

This meant creation of new, cleaner mesh topology was required. The original BodyParts 3D library component was imported as an .OBJ file into Zbrush. The 'Zsphere' subtool was then used to create a shape surrounding the original. This Zsphere shape could then be converted into a polygonal mesh using the 'adaptive skin tool'. Further adaptation could be performed to increase or decrease the polygon count as desired using the Zremesher tool. This new 'retopologised' mesh was then exported as an .OBJ file into Autodesk 3DS Max for final editing and sculpting. Here it was possible to use the freeform sculpting tools to shrink the Zbrush mesh to the surface of original BodyParts 3D model. This workflow is summarised in Fig. 8.3.

8.5 Tumour Modelling

To create realistic tumours, a CT dataset of a 69-year-old male with a pancreatic head tumour was used. Slicer 4.5 was used to transform the 2D CT images into a 3D surface using the visualisation pipeline shown in Fig. 8.4.This created a polygonal mesh that could be imported into 3D modelling software for post-processing and scaling to fit the other models in the scene. A lack of CT data from appropriately consented patients with representative tumours meant this tumour mesh was then edited in 3DS Max and adapted to suit different tumour locations, rather than modelling new tumours from different patients for each scenario.

Table 8.2 Components of 3D model required for app and their creation method

Modelling technique	3D Models	
Modelled from scratch	**Tumours**	Pancreatic lymph nodes
	Resectable head	
	Resectable tail	Gastroduodenal artery stump
	T4 head of pancreas involving portal vein and hepatic artery	Liver metastases
	T4 head of pancreas involving SMA & SMV	Lung metastases
	T4 tail of pancreas	
BodyParts 3D library mesh	Aorta (thoracic and abdominal)	Key abdominal veins
		Portal vein
		SMV
		Splenic vein
Retoplogy +/− remodelling	Biliary tree	
	Colon and rectum	
	Duodenum	
	Gallbladder	
	Heart	
	Key abdominal arteries	
	Coeliac	Lungs
		Liver
		Oesophagus
	Splenic	
	Hepatic/ common hepatic	Pancreas
		Pancreatic ducts
	SMA	Skin
	Ileocolic	Stomach
	Right colic	Small bowel (jejunum & ileum)
	Middle colic	Urinary bladder

The anonymised raw CT data was imported as an unzipped DICOM folder into Slicer4.5. The dataset was of a CT abdomen and pelvis with IV contrast and comprised of 306 axial slices taken at 1 mm intervals. The data was then filtered using the gradient anisotropic diffusion filter. This is a ‘denoising’ filter that smooth’s the data yet preserves edges.

A manual segmentation method was used as the pancreas and tumour are of relatively similar radio density; therefore automated segmentation (mapping) techniques were not appropriate. The tumour in the head of the pancreas was best seen in the axial views. The tumour was segmented using paintbrush tool with threshold paint effect applied to 0-95 Hounsfield Units (HU), meaning the adjacent blood vessels with a higher HU value would not be unintentionally segmented. These tools were then used to paint the tumour in each axial slice (39 slices in total), as shown in Fig. 8.5.

Once segmentation was completed the 3D surface was then rendered. Indirect volume rendering was used to give the 3D polygonal mesh of the tumour surface. This was achieved by applying ‘Model Maker’ extraction algorithm to the area segmented in 2D slices.

The model was saved and exported as .STL file to allow further post-processing in Zbrush to smooth, make modifications and simplify the mesh by using the ZRemesher tool. This was then saved as OBJ file and placed in the 3DS Max scene.

8.6 Interactive Application

The app was designed using the Unity 5.2 game engine, and was developed to be a standalone application for an iPad tablet. This meant that throughout the design of the user interface (UI), it was kept in an iPad wide (1024 x 768) aspect. All scripting was done in C# language and a map of the app scene flow is shown in Fig. 8.6.

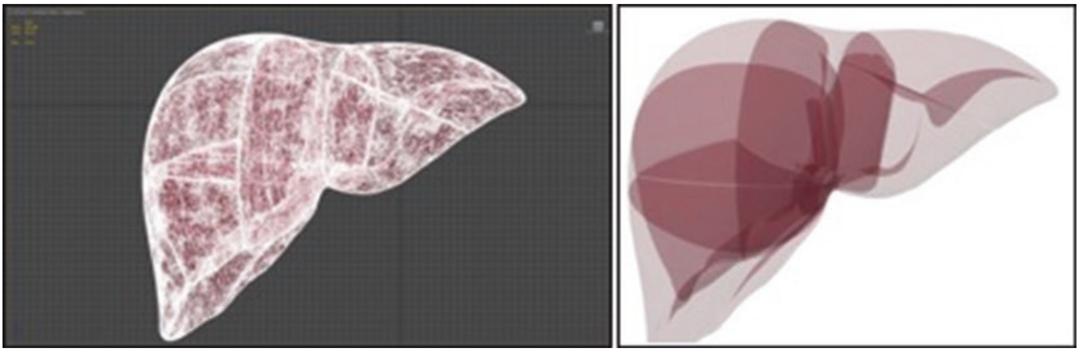


Fig. 8.2 Original BodyParts 3D liver. (Mesh on left. Rendered appearance with 50% opacity on right.)

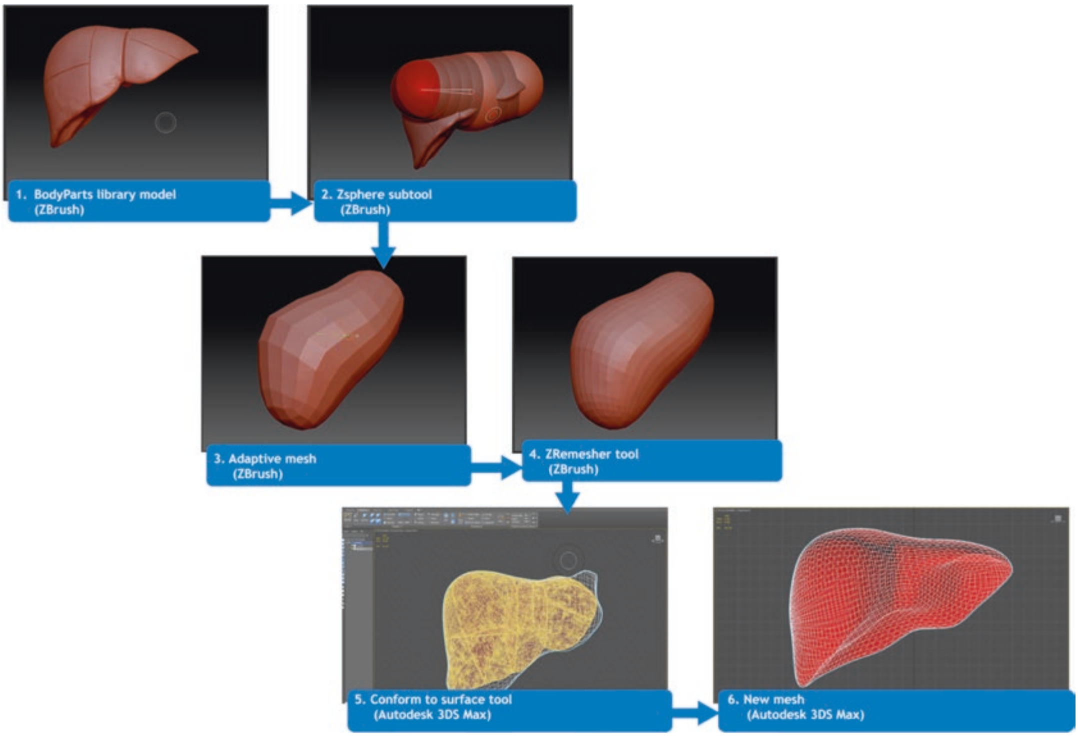


Fig. 8.3 Steps to create new simplified mesh topology

Fig. 8.4 Visualisation Pipeline used with Slicer to make tumour model

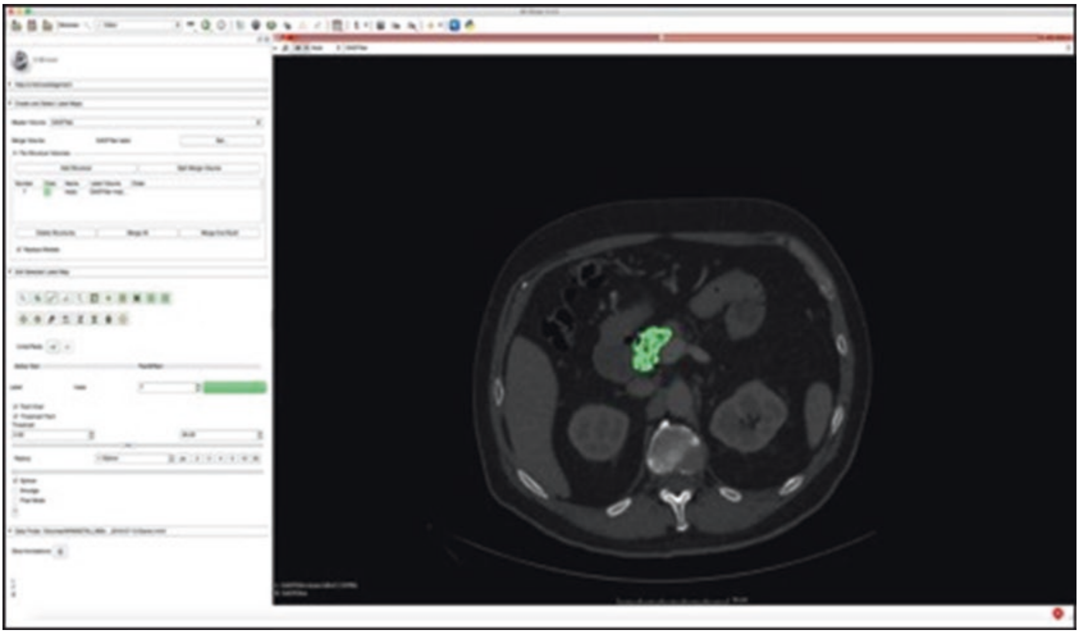


Fig. 8.5 Screenshot of manual segmentation of tumour

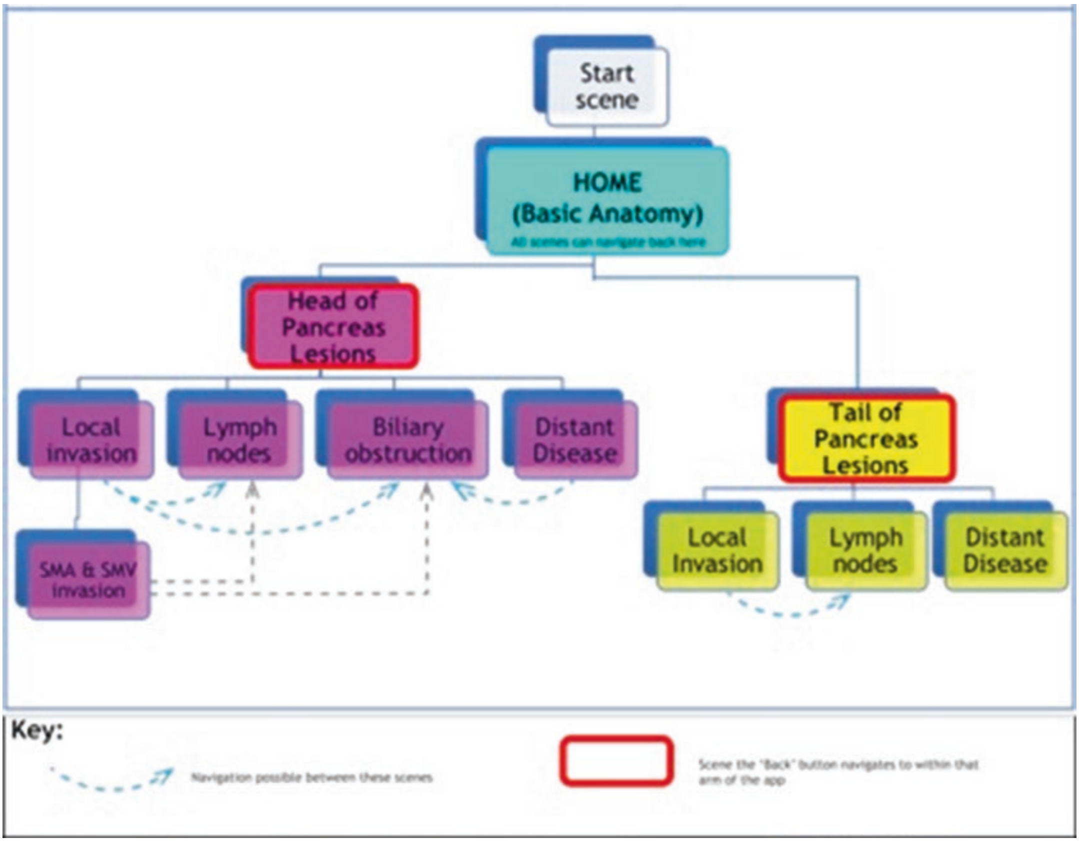


Fig. 8.6 Map of scenes and their links within the app

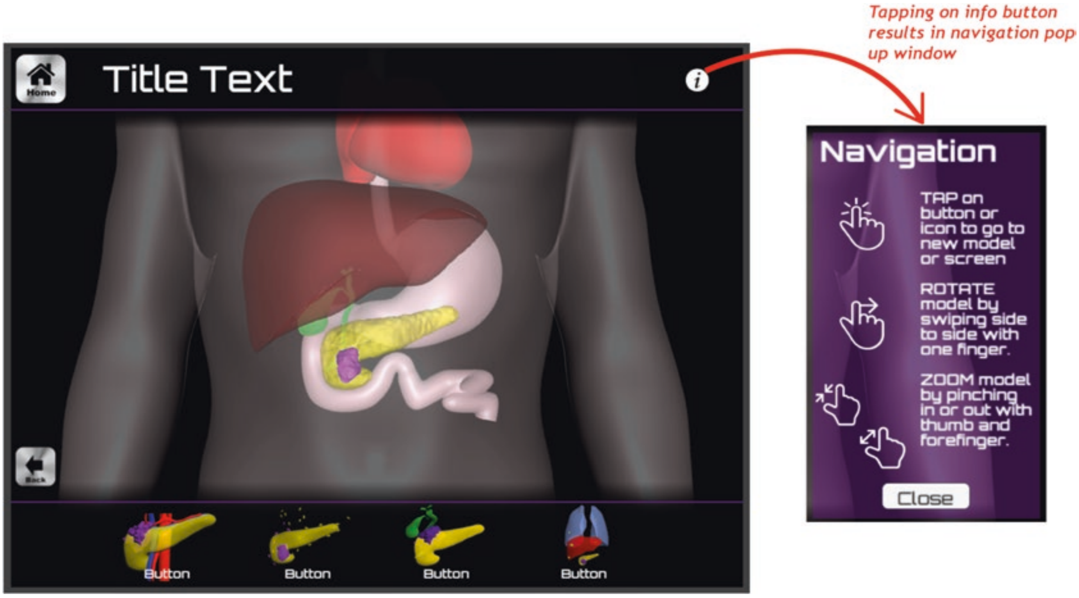
8.7 Scene Design

Each scene was laid out identically, with the same user interface as shown in Fig. 8.7. Purple was selected as the colour of choice as this is the colour of many of the pancreatic cancer charities. Each user interface has a back button to return to the "home scene of tumour type", home button and an "info" button to remind the user of the gestures needed to manipulate the model. Simple patient friendly language was adopted e.g. the use of "distant disease" rather than metastases.

The app was designed to have the models at the centre of each scene. The models were imported as .OBJ files with coordinates and pivot points as they were set in Autodesk 3DS Max. Standard shader materials were then applied to each component of the model for that scene. Simple flat colours were chosen to give the models a cartoon like quality. It was felt an overly realistic material might have been distracting for patients of a more delicate nature. In addition, realistic colours would also have given insufficient definition between different organs to give a clear visualisation, which is at the crux of the app. To see the pancreas underneath the overlying organs, the material needed to be made semi-transparent. This was achieved by adjusting the alpha channel until the desired level of opacity was achieved.

Identical directional lights, front and rear, were also added and focused on the anatomical model. A single main camera was placed in each scene. Adding scripts to the camera created the ability for the user to interact with the models by zooming in and rotating. On pinching the model, the camera then zooms in or out on predetermined centre point/area of interest. Swiping left or right will rotate the model along the x-axis only. For clarity, non-essential structures such as the skin were also made to fade on zooming in closer, leaving only essential structures behind.

A short, basic animation was created in Unity for biliary obstruction with the head of pancreas tumour expanding to obstruct the distal common bile duct, and then the biliary tree is seen to dilate with the skin colour turns yellow to represent the patient becoming jaundiced. The animation is controlled by play, pause and reset buttons to allow the clinician to explain the processes at a rate that they determine suitable for the patient they are talking to. The app was then built for iOS format in Unity 5.2 and Xcode 8 was used to convert and package it as an iPad app.



Tapping on info button results in navigation pop up window

TAP on button or icon to go to new model or screen

ROTATE model by swiping side to side with one finger.

ZOOM model by pinching in or out with thumb and forefinger.

Fig. 8.7 Example of standardised layout used throughout app

8.8 Validation of App

The main aim of this study was to demonstrate a clear workflow methodology in the creation of an app for healthcare practice in pancreatic cancer. However, we also undertook a small-scale analysis of questionnaire feedback from patient's attending a local outpatient department with a diagnosis of pancreatic cancer. The aim was to gather a snapshot of how well patients felt they understood information with current practice of verbal explanations combined with 2D sketches. The first six questions were designed to assess this. A further five questions looked at possible alternative information deliveries to establish if there was a pattern of people's preferences. The questionnaires were kept deliberately brief, with Likert scale responses to enable a score to be given to each question. A mix of positively and negatively worded statements was used to try to eliminate acquiescence bias (a tendency to agree with statements). The questions are detailed as follows:

Your Appointment

1. I did not know where the pancreas was located before my appointment
2. I did not know how the pancreas was connected to other organs
3. Information given to me was easy to understand
4. After the appointment I feel I have a good understanding of where the pancreas is in the body
5. I now understand how the pancreas links to other organs
6. Understanding where the pancreas and its relationship to other organs helps me understand my problem better.

Preferred Information Delivery

1. Verbal explanation alone is enough
2. I find 2D diagrams and pictures helpful
3. A 3D model would be more helpful than a 2D diagram
4. I would like a diagram to take away from the appointment
5. A website to see the same information would be helpful

In both sections, there was also a free comments box should the patient wish to write any additional comments. The patients were also asked their age group, sex, highest level of education and where they looked for medical information. These questionnaires were anonymised, and patient consent given for the use in this study.

The app was designed and trialled for a 1-week period within the West of Scotland Pancreatic Unit. Individuals then completed similar questionnaires after any interaction with a healthcare professional that had used the app. The same initial six questions looking at patient understanding and satisfaction with the delivery were used, as stated above under "Your Appointment". A further 6 questions specific to the app were asked in the trial group as follows:

1. The 3D models helped me understand where the pancreas was located
2. The digital models were easy to see
3. I found the app distracted me from the information being given to me by my doctor or nurse
4. I prefer 2D diagrams on paper
5. Putting these models onto a website to look at in my own time would be helpful
6. Overall I thought this app was useful

Again, a free text box for additional commentary was present.

Two specialist nurses who used the app also completed questionnaires giving feedback on the usability, with free text boxes too. The questions posed to them were as follows:

Current Practice

1. Most patients do not know where their pancreas is located
2. Explaining anatomy is important to help the patient understand their disease
3. Explaining anatomy relevant to pancreatic cancer to patients is difficult
4. I think patients have a clear understanding of pancreatic anatomy after consultations
5. What resources do you normally use to explain pancreatic anatomy to patients?

Using the App

1. The app was easy to navigate round
2. The digital models were easy to see
3. IO found the app distracted from the information I was trying to get across to the patient
4. I though the app slowed down the consultation
5. Putting these models onto a website with information for patients to refer to after their consultations would be helpful
6. Overall, I though the app was useful

This feedback was used to make final edits to the app. All questionnaires were distributed as paper copies to enable rapid, on the spot feedback. All respondents did so voluntarily and responses were anonymised. An online format was deemed inappropriate as patient’s attending the clinic are >60 years old, and computer access could not be assumed.

8.9 Results

8.9.1 Model Production

8.9.1.1 Tumour Modelling

A 3D polygonal mesh was created by manually segmenting the tumour from a CT dataset in Slicer. The resulting mesh was then exported as an .OBJ file and is shown in Fig. 8.8. It was complex, consisted of approximately 30, 000 polygons and the surface had multiple holes as a result of the indirect volume rendering algorithm interpreting spaces as holes when creating the isosurface.

Therefore, the mesh required some modifications to smooth, fill holes and give a surface that would be easy to manipulate for future model creation. The result reduced the polygon count to under 10,000 and is shown in Fig. 8.9.

8.9.2 Normal Anatomy Models

Models were created for each scene. The priority was to combine anatomical accuracy, with a clear visualisation that was easy for patients to understand. Photorealism was therefore not a priority and therefore a ‘cartoon-like’ appearance was decided upon, with colours that provided clear definition between each structure. Table 8.3 shows a screenshot from the resulting model central to each scene.

8.9.3 App Design

The content of the app was largely determined from discussions with the lead clinician (RC) and a specialist nurse who would be using the app. The content is shown in Table 8.3, which shows

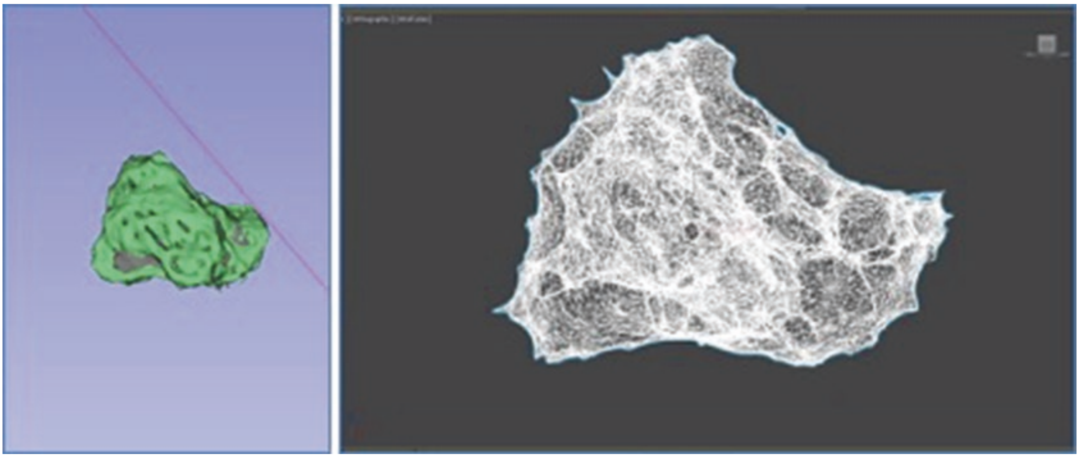


Fig. 8.8 Left: 3D model of tumour as seen in Slicer. Right: Polygonal mesh of same tumour in Autodesk 3DS Max

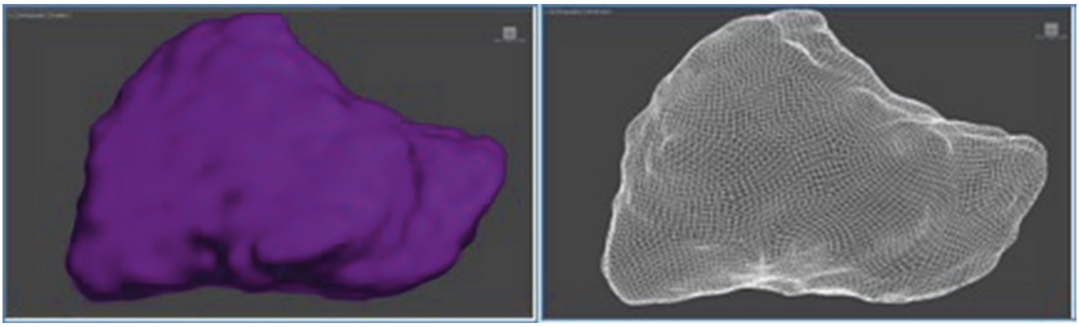
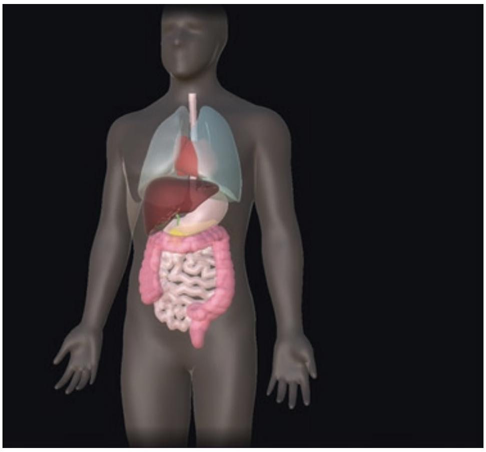
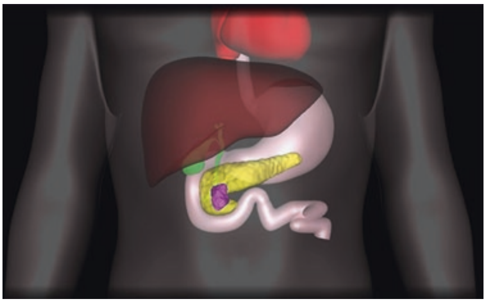
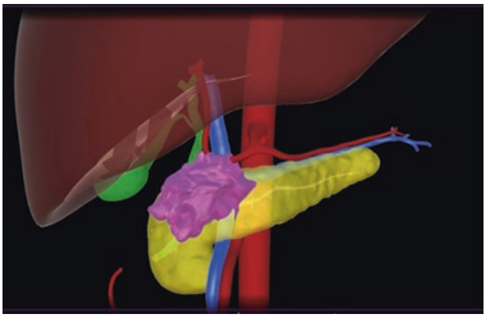


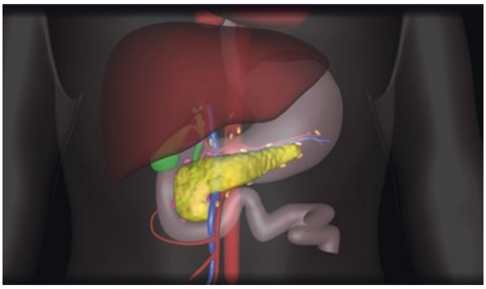
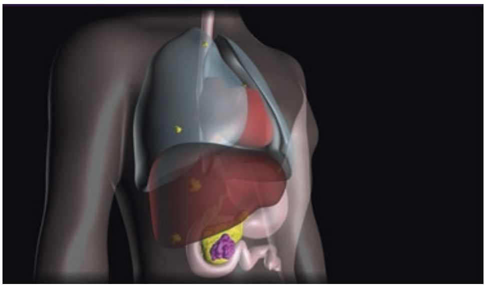
Fig. 8.9 Resulting tumour model after mesh modifications in Zbrush and Autodesk 3DS Max

Table 8.3 Scene title and model created to demonstrate the aims

Scene	Aims	Model screenshot
Basic anatomy (Home)	To show location of pancreas in the body and relations to other organs	
Head of pancreas lesion (Home)	To show location of a tumour described as a "head of pancreas lesions"	
Local involvement	To show head of pancreas lesion invading the hepatic artery, gastroduodenal artery and portal vein to facilitate discussions regarding difficulty resecting such tumours.	

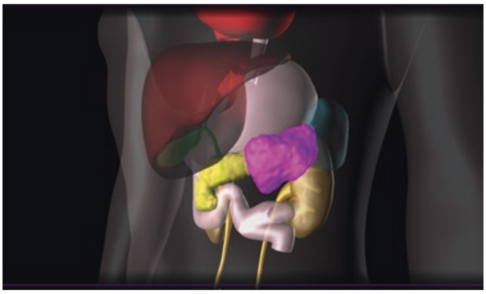
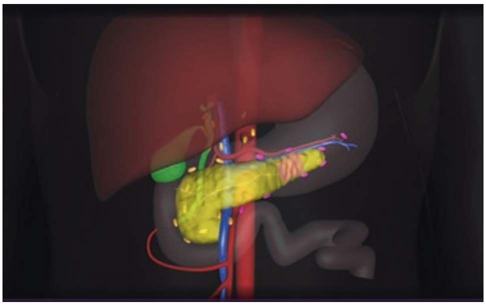
(continued)

Table 8.3 (continued)

Scene	Aims	Model screenshot
SMA and SMV involvement	To show head of pancreas lesion that has involved the SMA and SMV to facilitate discussions regarding difficulty resecting such tumours despite lack of metastases.	
Lymph nodes	To facilitate discussion regarding lymph node involvement and the difference between local and distant from tumour site.	
Biliary obstruction	To demonstrate that tumours can cause CBD obstruction. To be used in discussions regarding CBD stenting.	
Distant disease	To show common sites of metastases (liver and lung) and to enable discussions with regards to need for systemic treatments rather than resection.	
Tail of pancreas lesion (Home)	To show a tumour in the head (or uncinated process) of pancreas.	

(continued)

Table 8.3 (continued)

Scene	Aims	Model screenshot
Local involvement	To show tail lesions can invade adjacent organs (stomach, left kidney and spleen). Invasion of all 3 is shown to minimise the scene numbers. The user can then specific which is relevant to the patient.	
Lymph nodes	To facilitate discussion regarding lymph node involvement and the difference between local and distant from tumour site.	
Distant disease	To show common sites of metastases (liver and lung)and to enable discussions with regards to systemic treatment rather than resection.	

the aim of each scene complete with a screen shot of the model created to achieve this.

The layout was determined with a brief paper prototyping session. The app, being in landscape view, seemed to be the most intuitive to the users. This is likely to have been because the area of interest in the upper abdomen could then be displayed at its maximal dimensions.

The buttons that navigate the user to the next scene were placed along the bottom of the screen, rather than down one side. This meant whichever side the patient and clinician/user were sat relative to the iPad they could access without having to awkwardly reach across the screen. In determining the flow between scenes, it was found that in addition to a home button taking the user back to the initial 'Basic Anatomy' scene, a 'BACK' button to return to the previous scene or the 'home' scene for that particular tumour site would be helpful. The navigation links between scenes was also decided using the paper prototype. These buttons were placed on the left, this seemed to the natural position due to the layout of the clinic rooms meaning the majority of the time the user would be on the left of the iPad with the patient viewing and sitting on the right.

8.9.4 Interactive Application

The models for each scene were imported as . OBJ files from Autodesk Max into Unity 5.2.

They were then made to be interactive by adding scripts to the scene main camera, meaning that certain gestures would manipulate the camera to give the impression of the model moving closer or rotating. Pinching movements in or out result in the camera zooming in or out of the centre point on the model. A script was also added to make the non-essential objects within the scene gradually disappear as you zoomed in closer.

8.9.5 Validation of App

The main purpose of this study was to construct a workflow methodology in the creation of an app. In addition, as a pilot study, a basic evaluation of patient satisfaction both before and after use of the app was undertaken. This took the format of a simple questionnaire with responses given on a Likert scale. Simple demographic data was also collated with each questionnaire to assess if feedback was being received from a representative selection of patients.

Four males and three females completed the questionnaire, 2 were aged 40–49 years old, 1 each in the age ranges 50–59 and 60–69 years old and 3 aged 70–79 years old.

Prior to the trial of the app, a short survey was completed by the patient's and all stated they either agreed or strongly agreed that they:

1. Did not know where the pancreas was located before my appointment
2. Did not know how the pancreas was connected to other organs
3. Information given was easy to understand in the appointment
4. After the appointment they felt they had a good understanding of where the pancreas is in the body
5. After the appointment, they understood how the pancreas links to other organs
6. Understanding where the pancreas and its relationship to other organs would help them understand their problem better.

All patient's who completed the survey also felt that verbal explanation alone was not enough, would like a 3D model to understand a 2D diagram, would like to take away a diagram and would find websites useful points for information.

In terms of the opinion of the app, all patient's either agreed or strongly agreed that the 3D models helped them to understand where the pancreas was located, found the digital models easy to see, did not find the app distracting, preferred the app to 2D diagrams, would like the models on a website, and thought overall the app was useful.

Two clinical nurse specialists also inspected the app, and the viability of the 3D model in patient communication. They reported that all patient's responded positively to it, with some of the older patient's excited by the use of "modern technology". The clinical nurse specialists found the iPads to be a good platform to use, liked the portability, and did not experience any functionality and usage issues. Overall, they were highly supportive about the app, although, this also needs formal study to examine this in greater detail.

8.10 Discussion

Here we have presented a simple, easy to follow, workflow methodology to create an app for a serious disease process to be used in a healthcare setting. The design of this app has followed a human centred design process, with the users of the app including healthcare practitioners and patients.

We opted in this instance, to create an app, which would be used by clinicians, and specialist nurses communicating with patient's about their diagnosis of pancreatic cancer, and related issues. In the first instance, we have not created one for at home access at the moment, as the population served by the West of Scotland Pancreatic Unit is an area of low annual income and qualifications, and the age range of the patient's is such that typically those with pancreatic cancer have a median age of 70 years old, and not as likely to use the internet/computer (Green and Rossall 2013).

The key purpose was to introduce a clear methodology of visualisation at the time of diagnosis, and to facilitate patient understanding of their disease. It was felt that creating this app for the clinical setting by the nurse or doctor removed any issues related to computer access or literacy levels. By not including sound or written information allowed the user to tailor the information given to the patient depending on the individual's clinical details and understanding.

With pancreatic cancer being the fifth commonest cause of cancer related deaths in the UK, with a 5-year survival rate of around 4%, there is a need for tools that aid communication between healthcare practitioners and patient's. In addition, a 2014 Pancreatic Cancer UK poll showed only 37% of Scottish respondents reported that they knew 'something' or 'a lot' about pancreatic cancer, compared to 73% for breast cancer or 53% for prostate cancer (Pancreatic Cancer UK 2015).

For patients to fully understand subsequent investigations or management options, they need to have at least a basic grasp of anatomy relevant to their cancer. A lack of baseline knowledge often means health care professionals are tasked with having to explain the basic anatomy of the pancreas and its proximity to other structures to patients. This is necessary before discussions of specific details specific to a patient's disease. Conveying such information with the confines of a short outpatient appointment can be difficult.

Poor communication, particularly with cancer patients, has been shown to be associated with worse clinical and psychosocial outcomes, including non-adherence to treatment, confusion over prognosis and dissatisfaction at not being involved in decision-making (Hanratty et al. 2012). For the healthcare professional, communication difficulties lead to lower job satisfaction and higher stress levels, as well as being behind a high proportion of errors and complaints (Payne 2014). Pancreatic cancer has a globally dire prognosis, and therefore clear communication is both critical as well as challenging.

Currently the main methods of information transfer between health professionals and patients in the hepatopancreatobiliary (HPB) setting involve verbal communication with assistance of basic 2D diagrams, most commonly sketched by clinicians themselves. However, there is evidence that patients find 3D models easier to understand when explaining complex anatomy with respect other conditions (Biglino et al. 2015).

The use of pictures or visual aids has been explored as a method for improving patient understanding and retention of information (Kessels 2003; Houts et al. 1998). However, the digital revolution and widely available Internet connection has meant more novel methods of conveying information about pancreatic cancer are now being utilised. Johns Hopkins Medicine has developed an interactive iPad and iPhone applications for pancreatic cancer. Their iCareBook for Pancreatic Cancer is an educational guide for patients and their families to learn more about the disease. These essentially give detailed information in text form, along with embedded YouTube videos of clinicians explaining the disease. There are also 2D images built into an "interactive teaching module" which allow the user to navigate through information about location of tumours as they wish. However, other than selecting the information they want to view, there is minimal interactivity and there are no three dimensional (3D) models or animations used.

3D digital anatomical models are however becoming commonplace in medical education. As technology such as iPads, laptops and other similar devices have become widely available to most students; the number of web-based or computer-aided resources has also grown.

There are several studies looking at the effectiveness of 3D models within anatomical and medical education (Welsh et al. 2014; Clunie et al. 2015; Fredieu et al. 2015; Manson et al. 2015). Most studies appear to show little evidence of their superiority over traditional teaching methods, however many advocate their use in a 'blended' teaching method. There does, however, seem to be some evidence that it can at least enhance student's performance when used as an adjunct to traditional teaching. McNulty et al. (2009) examined the use of a computer based learning (CBL) programme provided to their students for use in their own time. They found that the students who utilised this resource tended to perform better in their assessments. Tam et al. (2010) had similar findings when they looked at the use of a CBL program that demonstrated gastrointestinal anatomy using CT 3D reconstructions.

3D models therefore are now widely available for teaching and surgical planning purposes, but perhaps not as much in a patient education setting. The few examples found of 3D digital animations and applications being used in relaying anatomical and surgical information were to patients before thyroid surgery, breast reconstructive surgery and iliotibial band syndrome diagnosis and treatment (Hermann et al. 2002; Heller et al. 2008; Ma et al. 2012). These studies looked at the effects of providing patients with computer animations or interactive digital aids to patients prior to surgery or physiotherapy. They found an increase in knowledge and understanding, and a reduction in pre-operative anxiety and engagement with treatment regimes.

A recent study at Great Ormond Street Hospital looked at the use of 3D printed patient specific models of congenital heart defects to aid communication (Biglino et al. 2015). Similar to pancreatic ductal adenocarcinoma, congenital heart disease is a subject matter where there is 'expert to non-expert' interaction and very little shared knowledge. Communicating such information verbally is difficult and carries a high chance of being unsuccessful. The authors looked at the used of 3D models as a solution. Overall, parents of the children found the 3D models 'very useful', some of the feedback included the fact that they found 3D models more immediate to understand than sketches. Other comments were that they thought such models would be most useful at the time of diagnosis. Therefore, the use of digital models in a patient education and communication setting, especially at the time of breaking bad news, could be the way our healthcare services should be going.

As a small-scale pilot study, we did attempt to undertake analysis of the app created both by patient and clinical staff users, although this was not the main focus of the study, in the first instance.

Evaluation of the app was carried out during a one-week period. It was used to explain a pancreatic cancer diagnosis with 7 patients. Understandably, we had a low response rate due to the fact these patients are being seen at one of the most difficult times in their lives, having just been given the devastating diagnosis of pancreatic cancer. Pursuing longer-term feedback in such a limited time period was not appropriate. Detailed analysis or patterns cannot therefore be established at the moment, but some anecdotal observations can be made.

Overall, patient's stated that they had a poor understanding of where the pancreas was located and how it linked to other organs, prior to use of the app. It was felt that the visual element of the app was clearer and easier to understand than 2D diagrams, and aided their understanding of the pancreas, pancreatic cancer and spread of the disease. This clearly needs further study in comparing patient's who do and do not have access to the app during the time of diagnosis. However, this will be a difficult area to study, due to the highly emotional time for these patient's, and follow up may be challenging.

We did also conduct a small-scale analysis of clinical nurse specialists who were highly supportive and positive about the app. This certainly does need further exploration, and a more formal study set up in the future to examine this in more detail. It does hint at the additional benefit of this app in the clinical setting.

8.11 Future Development

This study has shown the workflow methodology in the creation of an app using industry standard software for the use on an iPad. To maximize usability and access, this certainly needs to be developed for use across multiple platforms. Indeed, it could also be developed into a web based desktop version, which could be used on the outpatient clinic computer. There may also be the option of developing this further to be made available for patient use at home, and via the Internet.

Furthermore, the content of the app could be extended to include models of the anatomy pre- and post-surgery. Therefore, there is also the possibility that this workflow methodology can be used for developing communication apps for patients about other cancers/medical conditions. During consultations, patients tend to forget key aspects of the discussions (Selic et al. 2011), and it may be that digital models will enhance communication, retention of information and engagement with treatment regimes in the clinical setting.

8.12 Conclusion

The aim of this study was to present a clear workflow methodology in producing an interactive application to help healthcare professionals explain pancreatic cancer anatomy and staging to patients. The human centered design process meant that the models created and developed linked directly into the needs of the clinical team for effective patient communication about key anatomical and surgical points.

Jenkins et al. (2001) found that patients typically want to know as much as possible about their disease. We know factors such as educational background and age can affect the quantity and delivery of information patients are able to cope with. Our iPad application acts as a useful adjunct for clinicians to explain pancreatic cancer, its sequelae and treatment options. By creating a purely visual aid, without text or audio commentary, means the user can still explain things sensitively and in a way that was personalised to the patient. It could be that this app is rolled out further across healthcare authorities, but also presents an effective plan to develop other healthcare related apps for a wide variety of clinical settings, and educational environments.

References

Biglino G, Capelli C, Wray J, Schievano S, Leaver L-K, Khambadkone S, Giardini A, Derrick G, Jones A, Taylor AM (2015) 3D-manufactured patient-specific models of congenital heart defects for communication in clinical practice: feasibility and acceptability. BMJ Open 5(4):e007165. https://doi.org/10.1136/bmjopen-2014-007165

Clunie L, Livingstone D, Rea P (2015) Innovative taught MSc in medical visualisation and human anatomy. J Vis Commun Med Early Online Publication:1–6. https://doi.org/10.3109/17453054.2015.1038501

D'Angelica M, Hirsch K, Ross H, Passik S, Brennan MF (1998) Surgeon-patient communication in the treatment of pancreatic cancer. Arch Surg 133:962–966

Fredieu JR, Kerbo J, Herron M, Klatte R, Cooke M (2015) Anatomical Models: a Digital Revolution. Med Sci Educ 25(2):183–194

Green M, Rossall P (2013) Digital inclusion evidence review. Available at: http://www.ageuk.org.uk/Documents/EN-GB/For-professionals/Research/Age UK Digital Inclusion Evidence Review 2013.pdf?dtrk=true. Accessed 17 May 2017

Hanratty B, Lowson E, Holmes L, Grande G, Jacoby A, Payne S, Seymour J, Whitehead M (2012) Breaking bad news sensitively: what is important to patients in their last year of life? BMJ Support Palliat Care 2:24–28

Heller L, Parker P, Youssef A, Miller MJ (2008) Interactive digital education aid in breast reconstruction. Plast Reconstr Surg 122(3):717–724. https://doi.org/10.1097/PRS.0b013e318180ed06

Hermann M, Abteilung C, Spital KE (2002) 3 D computer animation – a new medium to optimize preoperative information for patients. Evaluation of acceptance and effectiveness in a prospective randomized study. Chirurg 73:500–507

Houts PS, Witmer JT, Egeth HE, Loscalzo MJ, Zabora JR (1998) Using pictographs to enhance recall of spoken medical instructions. Patient Educ Couns 35:83–88

Jenkins V, Fallowfield L, Saul J (2001) Information needs of patients with cancer: results from a large study in UK cancer centres. Br J Cancer 84(1):48–51

Kessels RPC (2003) Patients' memory for medical information. J R Soc Med 96(5):219–222

Ma M Bale K, Rea P (2012) Constructionist learning in anatomy education: what anatomy students can learn through serious games development. In Ma M et al (eds) Serious games development and applications, lecture notes in computer science, LNCS; 7528, 43–58. Springer-Verlag Berlin Heidelberg, ISBN 9783642336874

Manson A, Poyade M, Rea P (2015) A recommended workflow methodology in the creation of an educational and training application incorporating a digital reconstruction of the cerebral ventricular system and cerebrospinal fluid circulation to aid anatomical understanding. BMC Med Imaging 15:44. https://doi.org/10.1186/s12880-015-0088-6

McNulty JA, Sonntag B, Sinacore JM (2009) Evaluation of computer-aided instruction in a gross anatomy course: a six-year study. Anat Sci Educ 2(1):2–8

Murgitroyd E, Madurska M, Gonzalez J, Watson A (2015) 3D digital anatomy modelling – practical or pretty? Surgeon 13(3):177–180

Ong LM, Visser MR, Lammes FB, de Haes JC (2000) Doctor-patient communication and cancer patients' quality of life and satisfaction. Patient Educ Couns 41:145–156

Pancreatic Cancer UK (2015) Diagnosis Manifesto for Scotland

Payne J (2014) Breaking bad news, Patient.co.uk. [Online]. Available: http://m.patient.media/pdf/1884.pdf?v=635967785697445383. Accessed 17 May 2017

Roter D (1989) Which facets of communication have a strong effect on outcome- a meta analysis. In: Stewart M, Roter D (eds) Communicating with medical patients, 1st edn. SAGE Publications, London, pp 183–196

Selic P, Svab I, Repolusk M, Guce NK (2011) What factors affect patients' recall of general practitioners' advice. BMC Fam Pract 12:141. https://doi.org/10.1186/1471-2296-12-141

Tam MDBS, Hart R, Williams SM, Holland R, Heylings D, Leinster S (2010) Evaluation of a computer program ('dissect') to consolidate anatomy knowledge: a randomised-controlled trial. Med Teach 32(3):e138–e142

Welsh E, Anderson P, Rea P (2014) A novel method of anatomical data acquisition using the Perceptron ScanWorks V5 scanner. Int J Recent Innov Trends Comput Commun 2(8):2265–2276. ISSN:2321-8169

9

Evaluation of Child-Friendly Augmented Reality Tool for Patient-Centered Education in Radiology and Bone Reconstruction

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and Paul M. Rea

Abstract

The use of augmented reality (AR) has a rich history and is used in a number of fields. Its application in healthcare and anatomy education is developing considerable interest. However, although its popularity is on the rise, its use as an educational and practical tool has not been sufficiently evaluated, especially with children. Therefore, this study presents the design, development and evaluation of an educational tablet-based application with AR functionality for children. A distal radius fracture was chosen, as it is one of the more common fractures in the younger age group. Following a standardized software engineering methodology, we identified functional and non-functional requirements, creating a child-friendly tablet based AR application. This used industry standard software and incorporated three-dimensional models of a buckle fracture, object and image target marker recognition, interactivity and educational elements. In addition, we surveyed children at the Glasgow Science Centre on its usability, design and educational effectiveness. Seventy-one children completed a questionnaire (25 also underwent a short structured interview). Overall, the feedback was positive relating to entertainment value, graphic design, usability and educational scope of the application. Notably, it was shown to increase user understanding of radiology across all age groups following a trial of the application. This study shows the great potential of using digital technologies, and more particularly augmented information, in engaging future generations in science from a young age. Creation of educational materials using digital technologies, and evaluating its effectiveness, highlights the great scope novel technology could have in anatomical education and training.

Keywords

Anatomy teaching · Augmented reality · 3-D imaging techniques · Digital anatomy · Education · Paediatrics

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P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7_9

9.1 Introduction

There has been a surge in the popularity of both virtual and augmented reality (AR) recently. They have featured in a variety of fields with many high profile uses including cinema and entertainment, engineering, military, flight applications and space training (Yuen et al. 2011; Peddie 2017).

Within the education setting, AR has been thought to enhance learner's experience. AR books have been created with interactive three-dimensional (3D) visualization of two-dimensional (2D) images and concepts. One such version, advancing on traditional children's 'pop-up' books, is The Magic Book (Billinghurst et al. 2001; Yilmaz et al. 2017). It uses a handheld augmented reality display to show computer graphics on a physical book. In a recent study by Ferrer-Torregosa et al. the concept of an AR-enhanced book has been adopted for use in anatomy teaching, reporting positive findings for improved spatial understanding (Ferrer-Torregrosa et al. 2015). More recently, the literature has suggested AR can promote learning motivation, enhance achievement and improve cognitive load (Küçük et al. 2016; Akçayır and Akçayır 2017; Chen et al. 2017). The interactivity and improved visualization of 3D objects minimises the effort placed on the working memory to understand 3D anatomical relationships, thus affording the user the expanded mental capacity for consolidating complex concepts (Gopalan et al. 2017). Educational learning tools that use 3D virtual models have been found to better engage students in learning compared with traditional methods (Liarokapis and Anderson 2010) and have been said to help a students' learning process turn from a passive process to an active one (Wojciechowski and Cellary 2013). The use of AR in education has been said to follow the learning theory of constructivism (Dunleavy and Dede 2014). In this learning theory, the learner builds their own perspective of the topic through many individual experiences. AR-enhanced learning aids can deliver information in multiple formats and therefore give the learner different perspectives on key learning objectives. The mobile nature of AR encourages independent use and self-directed learning, but also favors a social co-operative environment for learning (Bruner 1977; Dunleavy and Dede 2014).

Research into the efficacy and feasibility of AR as an educational tool is still unfolding. Kerawalla et al. (2006) showed that AR in the classroom can distract children from learning the prescribed content when compared with traditional teaching methods, and gave suggestions that for AR to be implemented as a learning aid it must be adaptable to provide individualized experiences, and must be able transfer information as quickly as the current standard teaching methods. Furthermore, in order to gain reliable insights into the learning benefits of AR, there must be more effective means of educational assessment than that which previous studies have failed to consistently show (Zhu et al. 2014).

In recent years, AR has been used to develop new teaching tools in medicine, new surgical guidance tools and even innovative therapies for patients. Simulators with AR functionality have been developed for training exercises and skill assessment for a range of medical procedures (Barsom et al. 2016) with the overall aims of minimizing error and invasiveness (Fraunhofer MEVIS 2018). Further to this, AR has also been successfully used in behavioral therapy for phobia desensitization (Baus and Bouchard 2014), for the distraction of child burn victims during painful dressing changes (Mott et al. 2008) and for improving social and emotional cues in children with Autism Spectrum Disorder (Chen et al. 2016). AR has been shown to afford a greater success rate over similar Virtual Reality (VR) based programs in therapy for psychological and mood disorders. VR creates a more immersive experience, yet it lacks the 'reality' that AR can afford the patient (Baus and Bouchard 2014), and furthermore can lack the ease-of-use that tablet-based AR systems carry. 'eHealth' is a growing trend seen within the literature and describes the use of information and communication technology in healthcare (Svensson 2002). This over-arching term can apply to the education of the public, patients, and medical students;

yet can also apply to the use of mobile technology for clinical informatics by healthcare professionals.

Mobile eHealth apps for the ‘layperson’ are becoming increasingly accessible to the public, with broad reaches that extend from inspiring a healthy lifestyle, facilitating self-management of care from home, monitoring wellbeing to educating on illnesses (Anderson and Emmerton 2016). Apart from few accredited examples, most ‘wellness’ apps have little scientific backing, yet they do hold the benefit of increasing interest in self-help and health awareness amongst the digital public.

With the focus of AR development for anatomy education primarily geared towards training in the medical profession, little attention is paid to the many other fields which have to gain anatomical knowledge and understanding. Indeed, the empirical research in this arena tends to focus on the creation and initial implementation of AR and overlooks the potential benefit to younger users. It is our younger members of society that we need to capture their imaginations, to encourage them to be the next generation of future scientists, doctors, dentists, allied health professionals and beyond (Kamphuis et al. 2014). There is a need to engage children in the sciences from an early age, especially with the increasing availability of digital technology to younger generations (Bennett et al. 2008). Educating our children from an early age in the sciences will enhance skills, attitudes and concepts to enhance understanding of more complex science in later life (Trundle 2015). Indeed, recently Taylor et al. (2018) had shown that anatomical literacy is neglected in the general public, with many unclear on where major structures within the body are actually found. It is clear that there is not a defined way to educate our younger generations about the human body. With widely available and popular digital technologies and interfaces like AR, this provides a unique opportunity to enhance public engagement and understanding about the human body using familiar and exciting technologies.

Successful digital interfaces are intuitive to the user which means that to navigate the functionalities of the app the user needs only to apply ‘unconscious’ cognitive processing and previously learned knowledge (Blackler et al. 2003). Three-dimensional virtual objects that can be touched and manipulated, as they would in real life, appear familiar to the user. Familiarity with object manipulation is a learned skill through prior life experience with real objects. Think of a child exploring the world through touch. This intuitive cognition is utilized in AR to provide an easy to use interface, and as such can transmit the subject material to the user in ways that are very easily gathered (Hornecker and Dünser 2009). It can be suggested therefore, that children may easily adapt to AR learning as it is an extension of their own learning through intuitive exploration of objects.

Research in to child-friendly AR technology for science education could afford significant benefits not solely focused towards taught curriculum in schools, but for the education of the general public in a healthcare setting. For instance, further development in this space could see improved tools for patient education employed in hospitals and for use at home, utilizing AR to educate children and family members of their anatomy and medical afflictions in an age-appropriate, sympathetic and engaging manner.

With this in mind, the aim of this study was to design, develop and evaluate an AR app based on the most common fracture site experienced by school-age children – the “buckle” fracture involving the distal radius/ulna (Valerio et al. 2010). Fractures to the distal forearm are the most common cause for hospitalization and account for over 30% of pediatric fractures treated at children’s hospitals (Valerio et al. 2010). Patient education in hospitals often relies on rushed explanations from the busy healthcare professional aided by text-heavy and diagrammatic learning materials (Kreps and Neuhauser 2010). Despite the rise in mobile technology in healthcare (Svensson 2002), there is a gap in the research into the use of tablet-based AR technology for anatomical and healthcare education of children. It was important to assess attitudes and engagement towards the AR app produced and anatomy in general, to inform future development and implementation of technologies in education. The three key concepts addressed were child-friendly app design, usability and educational value.

9.2 Materials and Methods

First, the AR app had to be created and will be referred to as the ‘i X-RAY’. Table 9.1 lists the software programs and hardware that were used to create the app.

9.2.1 Functional and Non-Functional Requirement Analysis

When designing educational apps for children, the target age needs careful consideration as small differences in age require vast differences in design, layout and user interaction (Gelman 2014). Most children are not familiar with the pinch-to-zoom-out function and inverse scrolling on mobile devices. Furthermore, the user interface (UI) needs to reflect realistic responses when

Table 9.1 List of software and hardware used in this study, the applications and the publisher

Software	Use	Publisher
3D Slicer V.4.6	3D visualisation and manual segmentation of medical imaging data	Open source platform from BWH and 3D Slicer contributors (BWH, 2017) Available at: www.slicer.org
Unity V.5.5.0f3	Games and app development engine	Unity Technologies, California, USA (UnityTechnologies, 2017) Available at: unity3d.com
Unity Remote 5	Application for Android, used to trial test application builds during development via USB connection to the desktop computer running Unity	Unity Technologies SF, CA, USA (UnityTechnologies, 2017) Available from the Android Play store
MonoDevelop	Interactive Development Environment for scripting in C# used in conjunction with Unity games engine	MonoDevelop Project, 2017.
Android SDK	Android Studio Software Development Kit (SDK) used to build an executable application to android device	Google, Inc., California, USA (Google, 2017) Available at: developer.android.com/studio/index.html
Java JDK	Java SE Development Kit (JDK) to allow Unity to interpret Java development language for the application build	Oracle, California, USA (Oracle, 2017) Available at: oracle.com/technetwork/java/javase/downloads/jdk8-downloads-2133151.html
Vuforia	Software development kit. The Vuforia plugin for Unity affords AR capabilities through target marker recognition	PTC Inc., Massachusetts, USA (PTC, 2017) Available at: www.vuforia.com
Vuforia Object Scanner	Android application used to scan a physical 3D object for AR recognition	PTC Inc., Massachusetts, USA (PTC, 2017) Available at: www.vuforia.com
Autodesk 3DS Max	3D modelling software used to separate the bone models and cap holes in mesh	Autodesk, Inc., New York, USA (Autodesk, 2017)
Autodesk Mudbox	Organic 3D sculpting software used for model refinement	Autodesk, Inc., New York, USA (Autodesk, 2017)
Adobe Photoshop	Digitisation of illustrations and graphic design of the user interface components	Adobe Systems, Inc., California, USA (Adobe, 2017)
Hardware	**Use**	**Publisher**
Samsung Galaxy Tab S2	Tablet device to test the application during development and evaluation stages. Running Android OS, v6.0.1 (Marshmallow) operating system with an aspect ratio and screen resolution of 2048x1536	Samsung Group, Seoul, South Korea (Samsung, 2017)
Wacom Intuos Graphics Tablet	7″ graphics tablet with stylus pen that connects to desktop computer by USB. Allows for illustration and graphic design within Adobe Photoshop	Wacom Co., Ltd., Kazo, Japan (Wacom, 2017)

a button is pressed so that the child acknowledges their action has administered a correct response to the system and is encouraged to continue. The UI layout must be large and not cluttered so the user can follow a clear navigated path through the application (White 2016). Furthermore, it has been found that children tend to skip over large bodies of text presented in mobile apps without reading (Nielsen 2010). Concise information presented at an appropriate reading level is imperative. These are just a handful of the many considerations to be taken into account when designing digital interfaces for children. The target age range for the app was set as 8–10 years, due in part to being a common age for treatment of childhood fractures to the distal radius in both sexes and to coincide with recommended design attributes for interactive technology for educating children (Gelman 2014). The design was centered around previously suggested UI elements for this age group. The components that constitute the 'child-friendly' interface design described in this paper are summarized as visual design, navigation & system layout, responsive feedback, and presentation and reading level of text. A list of functional and non-functional requirements for the AR system to hold was produced based on these known child-friendly design components, from which a System Modelling Language (SysML) diagram can be mapped to better visualize the requirements and how they relate to each other in the system's architecture.

In software engineering, a functional requirement describes a behavior or asset that the system must or should house. A non-functional requirement relates to the constraints on how well the system operates and therefore, the user's experience when using said system. Appendix 1 displays the SysML of the app, which was produced using Microsoft Visio, v16, (Microsoft Corp., Redmond WA).

9.2.2 Concept, Design and Development

Using the SysML diagram (Appendix 1) as a reference point, a workflow for app design and evaluation was structured. The narrative was created in which the target user is a child 8–10 years old and suffering from a buckle fracture of the distal radius. The user is told that they have access to an Android tablet with AR capabilities which will show the app entitled i X-RAY. A 2D avatar called Dr Ray introduces the story and guides the user through the application. The user is encouraged to interact with a plastic toy object-based marker and place adhesive target marker stickers over their forearm to visualize a 3D model of their own anatomy in AR.

9.2.3 Target Marker Design

Both image target recognition and 3D object recognition for AR are supported in i X-RAY. Circular images of the mascot were designed and printed as adhesive stickers for the image target AR recognition by Vuforia, v7 (Massachusetts, USA). There had to be sharp grey-scale contrast and sufficient points of interest to improve target recognition by Vuforia. To implement object based marker recognition, the chosen toy object was scanned to build a virtual map of features. To successfully trigger AR content, the object had to be rigid, have an opaque material and have few moveable parts, while the environment had to be well-lit by diffuse lighting, and clear of other objects or patterns that could affect the scan validity (Vuforia 2017).

9.2.4 Three-Dimensional Model

There are clearly significant differences between X-rays of adults and children, especially at the wrist joint. Open source DICOM data was used from OsiriX (Rosset et al. 2004). This was cropped to the left forearm and manually segmented using Slicer (v4.6, Massachusetts, USA). The 3D model was then refined and orientated into the anatomical position (due to being cupped in the original CT dataset; Fig. 9.1) in modelling software 3DS Max (v2017, New York, USA) before implementation into the Unity games

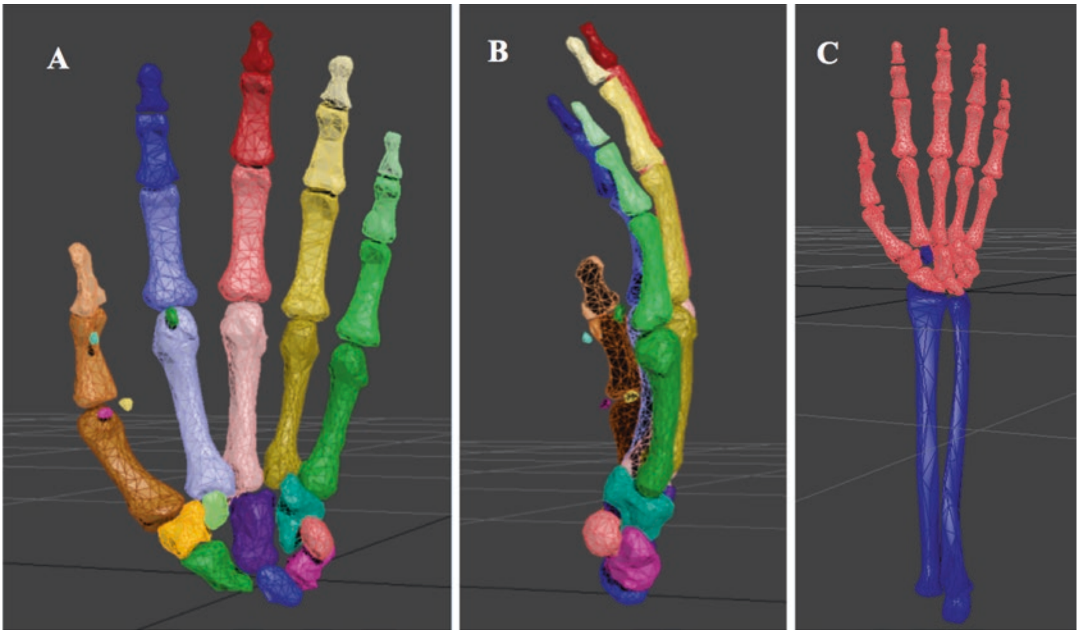


Fig. 9.1 Straightened hand model. (**a**) Palmar view. (**b**). Lateral view (**c**). Palmar view with downloaded ulna and radius models from BodyParts3D

engine (v5.5, California, USA). To ensure anatomical accuracy, a direct reference for 3D modelling was downloaded for free and imported into the 3DS Max (Autodesk Inc., New York, USA) scene from BodyParts3D (Mitsuhashi et al. 2009), an online database of anatomical structures accurately produced from human male DICOM data. The application includes models from the BodyParts3D Library, under a Creative Commons license: CC-BY-SA 2.1jp – https://creativecommons.org/licenses/by-sa/2.1/jp/deed.en_US. The result of the separation process gave 31 separate bone models: 8 carpal bones, 5 metacarpal bones, 14 phalanges and 4 sesamoid bones.

Anatomical surface landmarks on the skin model were defined such as the palmar creases, the anatomical snuffbox and palmar eminences.

To remodel the radius to represent the fracture, vertices were moved using Soft Selection, and a Spline object was modelled in order to exaggerate the fracture as a red jagged line to appear more visible to a child user within the AR scene. These edits were produced with anatomical reference to patient scan data.

9.2.5 Application Development

A unique interface was designed using both hand drawn elements and graphics from “The Free Platform Game Assets” Unity package from Bayat Games (Bayat Games 2017) as starting points. Additional components for the interface were illustrated and edited in Adobe Photoshop including speech bubbles, X-ray viewer light box and interactive UI buttons (Fig. 9.2).

In total, the application holds eight interactive scenes with a clear, chronological story for the user to follow. The educational path consists of a Welcome scene, an AR scene, five educational scenes that present the user with interactive 3D models and information behind the X-ray process, the skeletal hand anatomy, a distal radius fracture, and the recovery process, followed by an end scene.

The AR scene prompts the user to point the camera device towards either of the two AR target markers, an adhesive sticker or toy object, to trigger 3D models on screen. The models can be rotated in all planes by one finger touch input and scaled in response to two finger touch input.

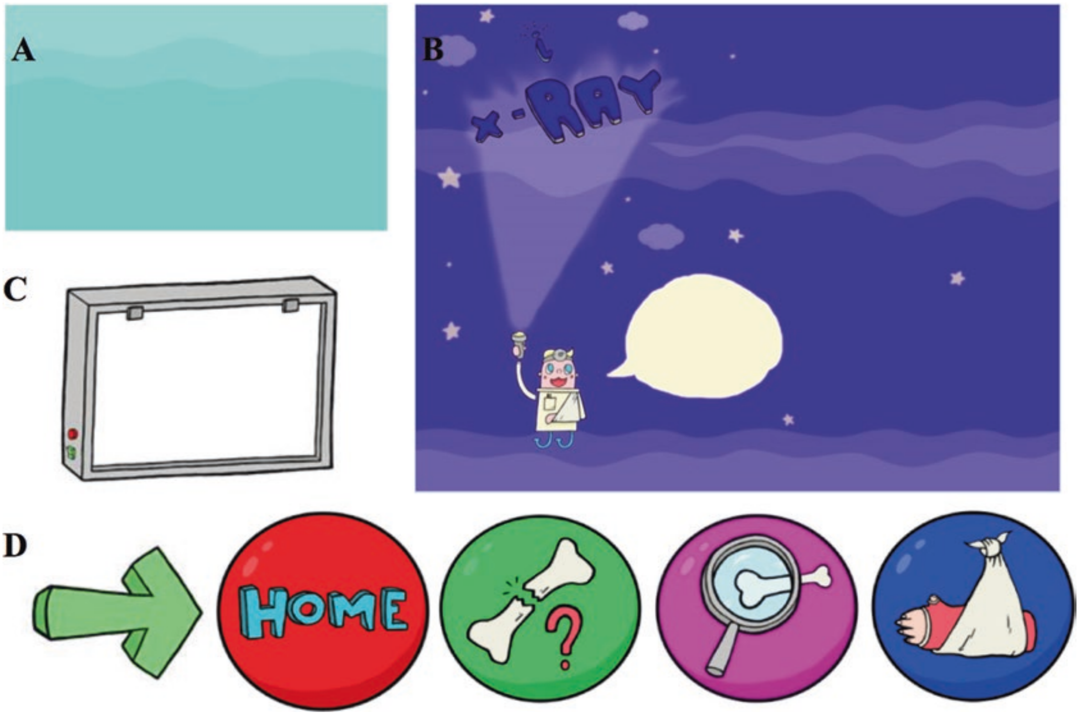


Fig. 9.2 UI Design (**a**). Original 'sky' sprite asset (Bayat Games 2017) (**b**). Completed welcome scene background with title, mascot, speech bubble and torch ray elements. (**c**). x-Ray viewer light box sprite (**d**). UI button designs

Animations show a representation of a recommended physiotherapeutic exercise for muscle strengthening following removal of a plaster cast, according to patient information guidelines given by the Physiotherapy Department at the Oxford University Hospitals NHS Trust (Vines 2012).

The Exercise and End scenes were not included within the user evaluation, but were produced in response to user feedback gained in the evaluation stage (detailed later). Throughout the development process, pilot usability tests were conducted on individuals who had no prior experience with the concept or development of i X-RAY, in order to continually improve the user interface. These were based on the recommended 'Concurrent Think Aloud' strategy for usability testing (Cooke 2010; Andersen et al. 2017) which served to identify system bugs and improve UI layout.

9.2.6 User Evaluation Methods

To validate the design and development process, and to assess the need and educational value of the resulting application, user evaluation on the target age group was conducted. The evaluation focused on user perception of the UI design, educational value, and established usability concepts for children such as comfort of use, reading-level, and satisfaction (Andersen et al. 2017). Furthermore, qualitative interview questions centered on prior experience with AR and knowledge of anatomy were used to probe knowledge gained following a trial of the app. This approach to user evaluation is based on usability testing methods for e-learning described by Koohang (2004), which gravitate around two main concepts: the users prior experience and perceptions towards the learning tool.

Access to the participant groups was achieved through the Glasgow Science Centre event 'Meet the Expert: Researchers in Residence'. Over two experimental days, a total of 71 participants consisting of children aged 5–15 were recruited. All participants and their parent/guardian were asked to sign a consent form and read a participant information sheet, prior to voluntary inclusion in the study. The study received approval from the

Table 9.2 Results of the screener questions posed to the 25 of the 71 participants

Age group	No. of participants (%) (n = 25)	Previously broken bone (%)	Home access to technology (%)
5–6	24	16.7	33.3
7–8	28	57.1	57.1
9–10	28	57.1	71.4
11–15	20	80	100

Ethics Committee at The Glasgow School of Art. All participants were asked their age following consent. The Samsung Galaxy Table 9.2 (Samsung Electronics Co. Ltd., South Korea) was used as the platform to showcase the i X-RAY application. Adhesive image target stickers, a rubber duck toy object target, a clipboard with the printed target marker, and a fake arm cast made from cardboard and bandages were also used.

Following a trial of the application, 71 participants were then asked to complete a questionnaire with 14 statements (Appendix 2) to help answer the broad research questions of:

- Can a child successfully use a specifically designed tablet-based AR application to learn about radiology and the bones of their hand?
- Does the AR application present an entertaining and child-friendly user interface?
- Can AR aid in educating a child about their anatomy and radiology?

The questionnaire was designed using Smileys as a Likert scale, recommended for use with children (Wan Yahaya and Salam 2008) and the questions were based on those for usability testing from the System Usability Scale developed by Brooke (1996), with simplified text to be read by children. The picture scale was produced by Wrench et al. (2015) and has been adopted from their open source book for the purposes of the research study.

In addition, 25 of the 71 participants were interviewed with three screener questions and two pre-test/post-test questions to assess demographics and knowledge before and after use of the application, respectively. The 25 users were asked their age, whether they had previously broken bones and whether they had access to tablet device technology at home. They were then asked questions before and after the trial of the application on whether they knew what an X-ray entailed and whether they were familiar with AR. The question list is given in Appendix 3.

9.3 Results

9.3.1 Evaluation

Of the 71 completed questionnaires, 5 had to be discarded due to incomplete responses, therefore a total of 66 were included in this analysis. Participants were divided by age into four age groups between 5 and 15 years of age.

9.3.2 Observational Analysis

From observing the user's interaction during their trial of the application, it was clear that many children preferred the researcher or their parent/guardian to speak the on-screen text aloud as they navigated through the application. For the younger participants, time to complete the application trial was greater than that of older participants (not formally assessed), due to reading ability, yet needed minimal help with scene navigation. Almost all participants progressed through the scene flow from start to finish uninterrupted, despite the experiment taking place in the open-plan science mall of the Glasgow Science Centre; which was busy and loud. In general, all child participants were visibly surprised and entertained by the appearance of virtual content in 'real-life' via the AR Scene. Several participants believed the virtual content shown through AR to be of their own anatomy. When participants were asked to locate the site of the buckle fracture on the 3D model within the Buckle Fracture Scene, most participants successfully pointed to the distal radius.

9.3.3 Short Interviews

Table 9.2 demonstrates the results to the screener questions that 25 of the 71 participants were invited to also complete randomly.

A sample of participants ($N = 25$) were required to provide an explanation of the terminology “X-Ray” before and after using the application, by answering to the simple question “What is an X-ray?”. Their answers would helped determining if the application was effective to support medical terminology learning. Participants’ answers were either right or wrong, so that they could be quantified accordingly using binary indicators: 0 for wrong and 1 for right.

A Paired Sample T-test was performed to compare participants answers before and after using the application. Statistical analysis showed a significant difference ($t(2) = 3.36$, $p < 0.005$) between tests, indicating there was a learning effect when using the application to inform about X-rays. In addition, a One-Tail Pearson Correlation between the occurrence of bone fracture among participants and their knowledge of X-ray before using the application showed that there was a positive correlation (r = 0.69, n = 25, p = 0.000), indicating that most participants who knew about X-ray did because of their personal experience with bone injuries.

Figure 9.3 shows the percentage of correct answers to the pre-test/post-test question ‘What is Augmented Reality’. Overall, 64% of participants had access to tablet-devices from home and 52% of participants had previously broken a bone. The percentage of participants with access to technology is shown to increase with age from 33.33% of 5–6 year olds, to 100% of participant’s aged 11 and over. The occurrence of bone fractures in children increases with age, with the greatest increase occurring between the ages of 5 and 8.

Overall, participant’s knowledge of X-ray increases with age, from 16.67% of 5–6 year olds to 100% of participant’s aged 11 and over. Only 1 participant out of 25 answered correctly to ‘What is AR?’ prior to using the application. Overall, correct answers to ‘What is AR?’ rose from 4% to 56% following a trial of the application.

9.3.4 Questionnaire Results

Analysis of user attitudes gained from the questionnaire can be divided into three categories based on the research questions: usability, child-friendly design and educational aspect of i X-RAY. The following charts show the mean responses related to each statement in the three categories and are based on the five-point Likert scale where 1 corresponds to ‘strongly disagree’; 2 to ‘disagree’; 3 as ‘neutral’; 4 to ‘agree’ and 5 corresponding to ‘strongly agree’. Any descriptive results within text are given as the mean ± standard deviation (±SD) unless otherwise stated as percentages.

9.3.5 Usability

In general, participants agreed that the application was easy to use (Fig. 9.4). For the statements that were posed in the negative, *‘I thought the app was heavy to hold’* and *‘I think that I would need help from a technical person to be able to use this app’*, participant responses were more varied. Yet, on average, attitude towards usability of i X-RAY was positive, with over 66% of participants reporting that the tablet was easy to hold and 53% agreeing that they could use the application without additional help.

9.3.6 Child-Friendly Design

Participants either agreed or strongly agreed with statements related to the design and entertainment value of the AR application. Over 92% of participants agreed that the color scheme and illustrations were to their liking. With respect to the entertainment value, participants thought that the use of AR and the toy and sticker target markers was ‘fun’, with only 3% of participants disagreeing with either statement. Only 1.5% of

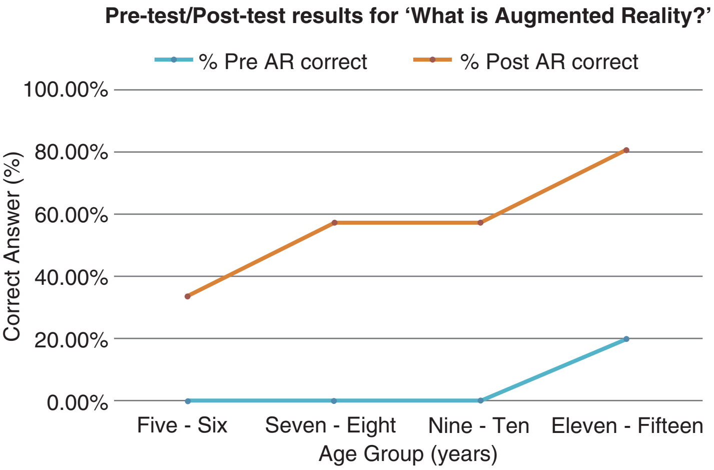


Fig. 9.3 Line graph of AR pre-test/post-test responses against age

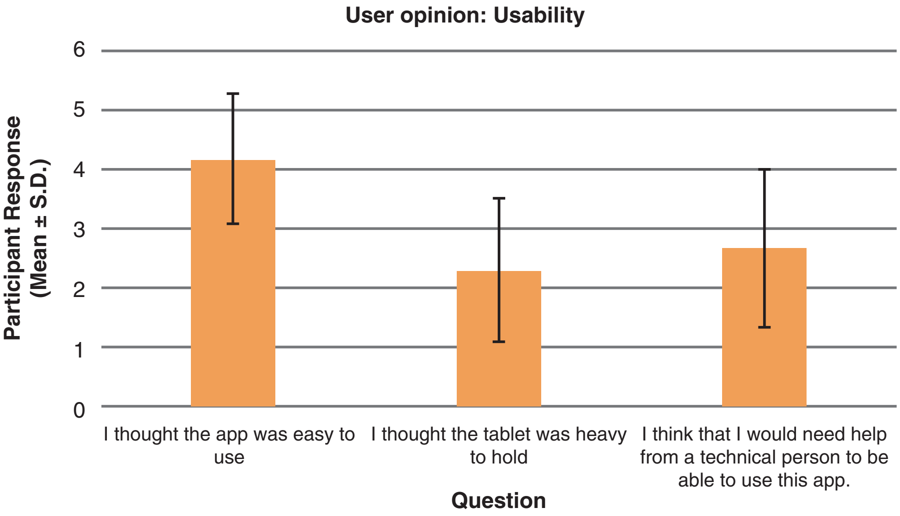


Fig. 9.4 Bar chart of mean responses to statements grouped by Usability

participants answered 'disagree' to '*I would like to use this app again in the future.*'

9.3.7 Education

Most participants thought that i X-RAY helped them learn about anatomy and recovery following a broken wrist (Fig. 9.5). No participants disagreed with the statement, '*The app helped me learn new things about the human body*'. Most participants responded positively to the educational value of the mascot, with 56% responding 'strongly agree' and only 1.52% responding 'disagree'. With respect to the reading level that the anatomical and medical information in i X-RAY had within it, participants agreed that they could understand the anatomical and medical terminology presented (4.03 ± 1.03). 15.15% of participants, however, were neutral to this statement. When asked whether AR helped them to better understand anatomy and the recovery process, over 74% of participants agreed or strongly agreed that it had, with almost half (48.5)% responding 'strongly agree'.

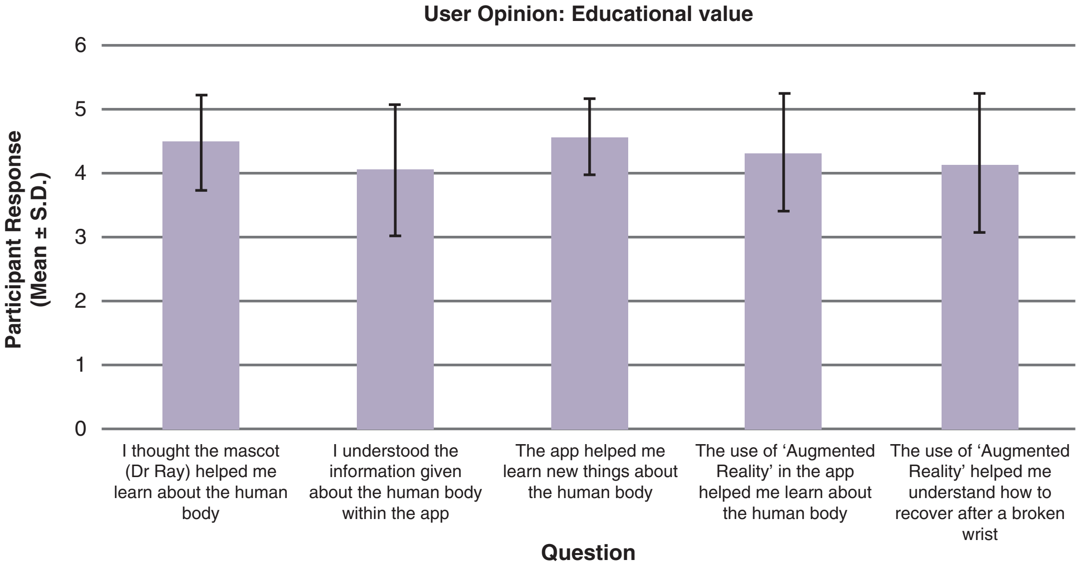


Fig. 9.5 Bar chart of mean responses to statements grouped by educational value

When asked if the participants felt that i X-RAY could be implemented in schools as a classroom learning aid, and in hospitals to aid in patient education to children, over 89% of participants agreed, with only 2 participants out of 66 disagreeing with these statements. With respect to using i X-RAY as a tool for patient education, 71.21% of participants strongly agreed.

9.3.7.1 Additional Comments

Of the comments that were legible, most were resoundingly positive, with phrases such as '*fun*' and *'cool'* occurring with higher frequency than other phrases. The only negative comment was '*Not all my friends would understand it'*. Several of the parents/guardians of the participants had backgrounds in teaching primary or secondary education and gave helpful suggestions for edits to the application, given below:

Parent 1: *'I think that the* [use of] *pictures are better for kids who find reading hard. I think it would be great to have a speaking voice on the app'*.

Parent 2: '*Would be really useful for classroom-based learning! Really enjoyed it!'* And when talking about technology access and children: *'For most kids these days, technology is their second language.'*

Parent 3: '*Would it work on an interactive whiteboard to teach the whole class? If you expanded it to include other body parts, it could work well with how we split classes into groups for biology teaching. We tend to assign each group a different area*', which coincides with one participants comment: '*more body parts would be cool'* and another's: '*more gore*!'. This parent, who had been teaching primary 5 for the past 3 years, was asked what age she thought i X-RAY would best be targeted towards, to which she suggested ages 7–9, as the 'younger kids' cannot yet read without supervision.

9.4 Discussion

This study illustrates how to create a clear workflow methodology, using standardized widely available software, to create an individualized AR application, in this instance, for educating children about the anatomy of the forearm and wrist, and fractures. In addition, the short interview and questionnaire based feedback has shown the many benefits of this type of technology in public engagement, anatomical education and informing people about common fractures.

From the participant sample tested, i x-RAY has been shown to effectively educate school-aged children about radiology in an age-appropriate manner. Prior knowledge of radiology and hand anatomy follows the incidence of previously broken bones in children. This suggests that until a certain age, most likely coinciding with the introduction of related content into the school curriculum, a child's knowledge about radiology is primarily gained through experience of having suffered from a broken bone. Yet, after having explored the i x-RAY application, over 90% of participants could quote correct information about radiology when asked. This increase in obtained knowledge is represented across all age groups, yet most notably in the younger participant age groups. Therefore, this suggests that the application is an effective approach to explain – especially to younger children who generally have less direct experience of bone fractures – the medical terminology, anatomy and technology used in radiology.

The conclusions drawn on educational value in this study were largely based on user perceptions from the questionnaire, and from the broad questions asked in the pre-test/post-test construct. In future iterations, larger cohorts with improved educational assessment methods, such as short answer testing, should be employed. A study on the use of AR in anatomical education of university students has shown that test scores on multiple choice and short answer questions were significantly improved with the use of an AR learning tool above traditional anatomical teaching methods (Ferrer-Torregrosa et al. 2015). Adopting the more extensive assessment methods used towards use with children in future evaluations of i x-RAY will provide a clear conclusion on the educational benefit of AR in teaching anatomical sciences at all levels. Further in-depth investigation into the educational benefits of AR, to expand upon the precedent set through the user evaluation conducted in this research project, could afford validity and the significance needed for *in situ* application of i x-RAY in hospitals.

As previously mentioned, AR is thought to be an effective tool for anatomical education as the learner's cognitive load is lightened, allowing greater mental capacity to infer and better understand complex spatial concepts (Küçük et al. 2016). Not only does it ease the consolidation of new information, the findings discussed in this study have shown AR to increase motivation and engagement in learning. Therefore, AR could be an effective tool to educate the public and young people in the complicated anatomy, physiology and pathology of the human body; concepts which are too often dumbed down and misrepresented in public resources. To truly assess the educational value and practicality of an AR app such as i x-RAY, further user testing should be carried out, both in a clinical setting with patients, family members and healthcare professionals, but also in an academic setting with school students and teachers. From the additional comments made from parents and existing literature on AR in education, it is clear that there is a space for AR in classrooms. This study focused on investigating an under-researched potential use of AR, for public health education of children. There is no reason why the app developed could not be adapted to align with a taught curriculum for use in schools. Further iterations could branch to cover visualization of subject areas such as chemistry, geography, history and more. Further research is needed with educational professionals in order to validate their positive comments towards AR in education. Qualitative investigation with the target users, hospital patients with distal radius fractures, and healthcare professionals would gain a direct insight into the 'need' and 'want' for an AR educational tool in patient consultation sessions.

Technology is becoming increasingly accessible to young children. By the age of 11, all participants asked had access to tablet-devices from home and most participants reported ease of use when trialing the tablet application. From observing a child's excitement and obvious surprise over the appearance of virtual content in their field of view; and from the subjective short interview data that showed only 1 out of 25 were already familiar with AR, we can propose that for many school-aged children this trial would have been their first direct interaction with AR. With this in mind, the answers given in agreement with statements concerning AR have to be more carefully considered. It can be said that the features of the AR system lend themselves for use by children, as the majority of participants reported positive opinions towards all three aspects assessed, in what could have been their first glimpse of AR.

Despite the fact that children are becoming increasingly literate in digital technology (Billington 2016), the use of mobile 'gadgets' in teaching may lack a correct pedagogical construct and fall as a passing fad (Falloon 2013a, b). Nonetheless, learning through play is instinctive to children. The entertainment value of object targets and sticker targets for AR could engage school-aged children in their taught curriculum both at school and from home, which would clearly benefit from further research. It is clear that children respond well to the 'wow factor' introduced from stickers placed on their own anatomy and plastic toys that trigger realistic 3D models. The majority positive perceptions towards UI graphic design, narrative, mascot and the use of stickers and toys as target markers for AR, validated the 'child-friendly' design aspect. It can therefore be suggested that the appeal to children that both AR and child-friendly UI design bring can be a motivating factor in education.

With respect to the two statements posed in the negative in this questionnaire (Appendix 2), which relate to hardware and software usability, the large standard deviations from the mean could have been due to a misrepresentation of the user's attitude in the pictorial Likert scale used. Questions phrased in a confusing manner could give skewed answers and lead the researcher to false findings. A revision to the scale to show an unhappy face when agreeing to 'I thought the tablet was heavy to hold' could have more effectively represented user opinion for these statements. Despite this, the results present mixed views on ease-of-use. Therefore, future applications of AR should attempt to minimise technical faults introduced with AR, particularly delay in target recognition and object jitter, to maximise usability.

It was clear younger children struggled with reading the informative text panels and would benefit from a voice-over. Sound effects were integrated into the system's architecture following user evaluation to improve the child-friendly aspect and overall user experience. UI button click noises were added to reinforce the positive feedback given to the user; camera shutter effects were added to convey how an x-ray works; an exaggerated x-ray machine sound for the AR scene; air 'whooshes' for the animations; and a voice in the Welcome scene to demonstrate how Dr. Ray would have read text on screen aloud. Further post-evaluation modifications were the addition of an animated physiotherapy exercise to better visualize textual information, and an end scene to improve user experience by bringing the narrative to a close, and to allow navigation back to the start scene.

Further observational research into a child's interactions with AR technology is recommended in order to further assess usability and scope for implementation in practice. The technical issues that inherently come with tablet-based AR, namely the unpredictable nature of virtual content activation and the patience that is required for target recognition by a camera device, may not marry well with a child's impulsive nature. This study primarily centred on design and user experience as opposed to usability, and did not follow a classic usability test construct. Performing a more robust round of usability testing would allow clear inferences in to whether a child can easily use the app, whether they are satisfied by the app and whether they are motivated to use it in the future; which are three main concepts identified and validated for successful usability for e-learning tools (Koohang 2004; Koohang and Paliszkiewicz 2014; Gould et al. 2008). Furthermore, most research into usability testing for educational apps have been developed with adults in mind, with little focus on children

(Andersen et al. 2017). As mentioned previously, there are narrow windows of age that dictate the design of child-friendly UI (Gelman 2014). Methods employed for user evaluation should also be selected with the unique requirements for the target user's age range in mind (Markopoulos and Bekker 2003). The Concurrent Think Aloud method used in this study for initial usability testing on adults during the app development phase could be an acceptable means for usability testing of older children, if they are in a comfortable environment and well-informed (Andersen et al. 2017). Other techniques such as observing 'first-tap' responses and task-based success rate are also proven methods for assessing user experience (Rohrer 2014). The positive user perceptions towards the child-friendly design aspects provide a promising basis for future iterations. It is important to involve the target users in the development of an educational app from an early stage, so that both the content and UI are tailored to the correct age and reading level (Koohang 2004; Doubleday et al. 2011). This is imperative so that educational value and satisfaction are maximized and so that the user is motivated to use it again in future.

In recent years, excitement over the potential for AR technology to transform our daily lives has overtaken the rate of its development. With our minds set on virtual interfaces integrated with our vision, we have overlooked the potential for mobile device-based AR to improve vital fields such as education and healthcare. Although there is mounting research into the use of AR in these fields, research is currently lacking into the interaction between AR and children for patient education. The intuitive ease-of-use and entertainment value of AR could provide children with an invaluable educational tool. Furthermore, AR could be a useful tool to minimize hospital-related stress by distracting patients with entertaining design and interactive content (McQueen et al. 2012).

The wide accessibility of mobile technology has revolutionized healthcare and education.

9.4.1 Limitations of the Study

This study has significant benefits and has demonstrated considerable enthusiasm for AR technology in educating our younger audiences in anatomy. However, the data obtained through the short interview is merely anecdotal. It is questionable whether the data obtained through the screener and pre-test/post-test questions can be used as a generalized representation of the whole participant sample, as only a third of the participants were included. Therefore, this data can only *suggest* a trend over the whole participant sample. All comparisons made between the short interview and the questionnaire analyses were constructed with this fact in mind.

Questionnaires are often the most efficient method for extracting user perceptions, however, they often come with a level of bias. If the participant is aware of the research goal, then this could lead to false results. As with any study of this nature, a higher number of participants is always ideal. However, we performed this study over a busy weekend at the Glasgow Science Centre and there was a high footfall. This could be repeated over a number of weekends to provide a wider cohort of people and this will be considered for future investigation. Future research would benefit from focus groups with a smaller sample size to further assess the usability of i X-RAY with children.

Data obtained on participant demographics in this study was limited to age, access to tablet device technology from home, incidence of previously broken bones and knowledge of radiology. From age asked, level of schooling can be inferred and the target age range can be narrowed. This study has shown that the AR app can educate younger ages (from the ages of 5–10, coinciding with primary levels 1–6) on anatomy and radiology concepts. The ages of 11–15 (primary 7- secondary level 4) already had a grasp of these concepts, most likely due to induction of related components in the school curriculum. This supports the initial target age range for the designed app, ages 8–10, as the informative content was appropriately and effectively presented to the user allowing for an increase in obtained knowledge, short term. By evaluating access to technology one can infer whether the AR app would be likely to be used in practice. Since access to mobile technology becomes commonplace in households with children aged 7 and up; and seeing as most classrooms are now equipped with tablet device technology, it can therefore be suggested that the AR app is an accessible means for educating school-aged children on health-related concepts. For children in the younger age bracket, found to have less access to mobile technology and with the primary means of learning about anatomy and radiology found to be correlated to direct prior experience with broken bones, implementation of the AR app on the devices of healthcare professionals could aid in patient consultation sessions and ease the education of anatomy, illness and at-home therapy regimes to this young audience. Future studies should further assess factors such as socio-economic background, age, gender and familial disabilities on user perceptions to an AR learning tool to further gauge those most in need of an engaging and interactive educational tool. Tablet technology in public settings such as healthcare practice waiting rooms or classrooms, can allow children from low-income backgrounds to experience this technology first hand.

In relation to future educational AR app development, it is recommended that researchers conduct target user research prior to development, in order to produce a specified list of development requirements and a SysML 'blueprint' for the app. This workflow methodology proved beneficial as the design process was clearly mapped resulting in a streamlined process with little deviation from the brief. Furthermore, it is recommended that for future app design with object based AR, the researchers select an object with more interest points and a specular surface material to minimize difficulty in triggering the 3D model (for example a hard plastic and not matte rubber, which would therefore better pick up lighting changes).

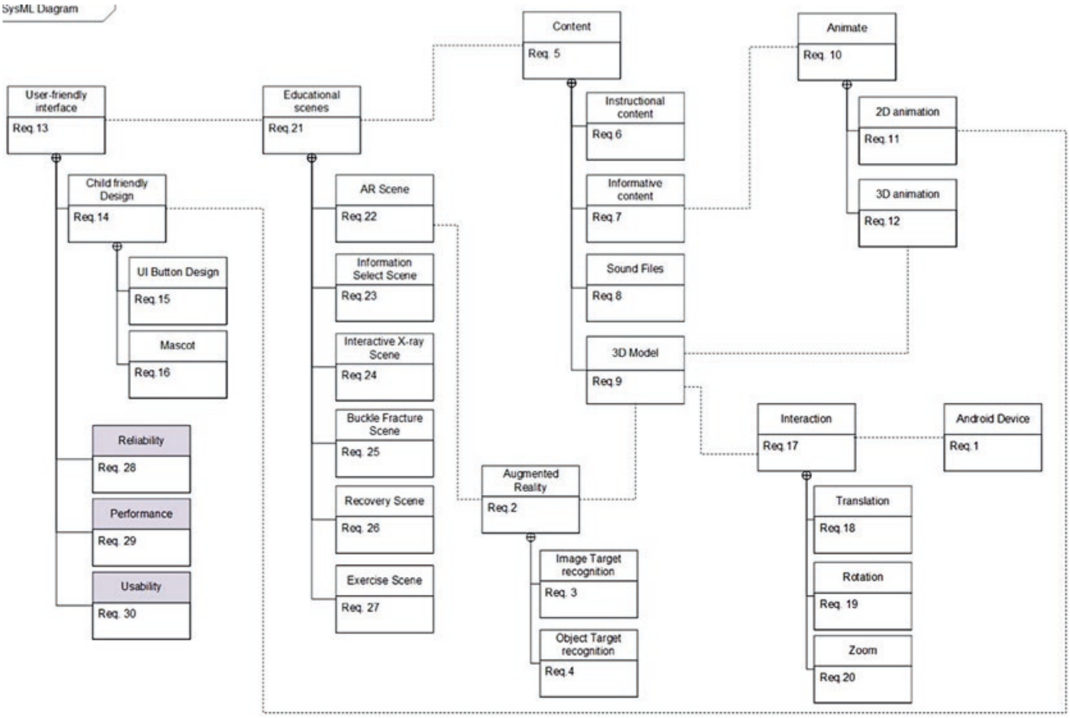
9.5 Conclusion

The successful evaluation of the application with the target age group shows the wider potential of AR in the education and motivation of children to learn, and beyond. Focusing the theme of the application on radiology, a hospital department visited by most individuals in their lifetime and whose concepts may be more easily grasped from a young age than other departments, allowed for a pilot study with a simple, straight-forward design to be conducted. i X-RAY was created with a clear concept, and easily-gathered educational content. By using simple questions in a short interview format with user perception questionnaires, educational value and engagement were assessed, and established. Children were able to understand the reading level presented in the informative text panels and were motivated by AR and appropriate design choice. They were therefore able to learn details about how an x-ray works, how best to recover following a broken wrist and the anatomical terminology for areas of the hand and wrist; and were likely to want to use the app again.

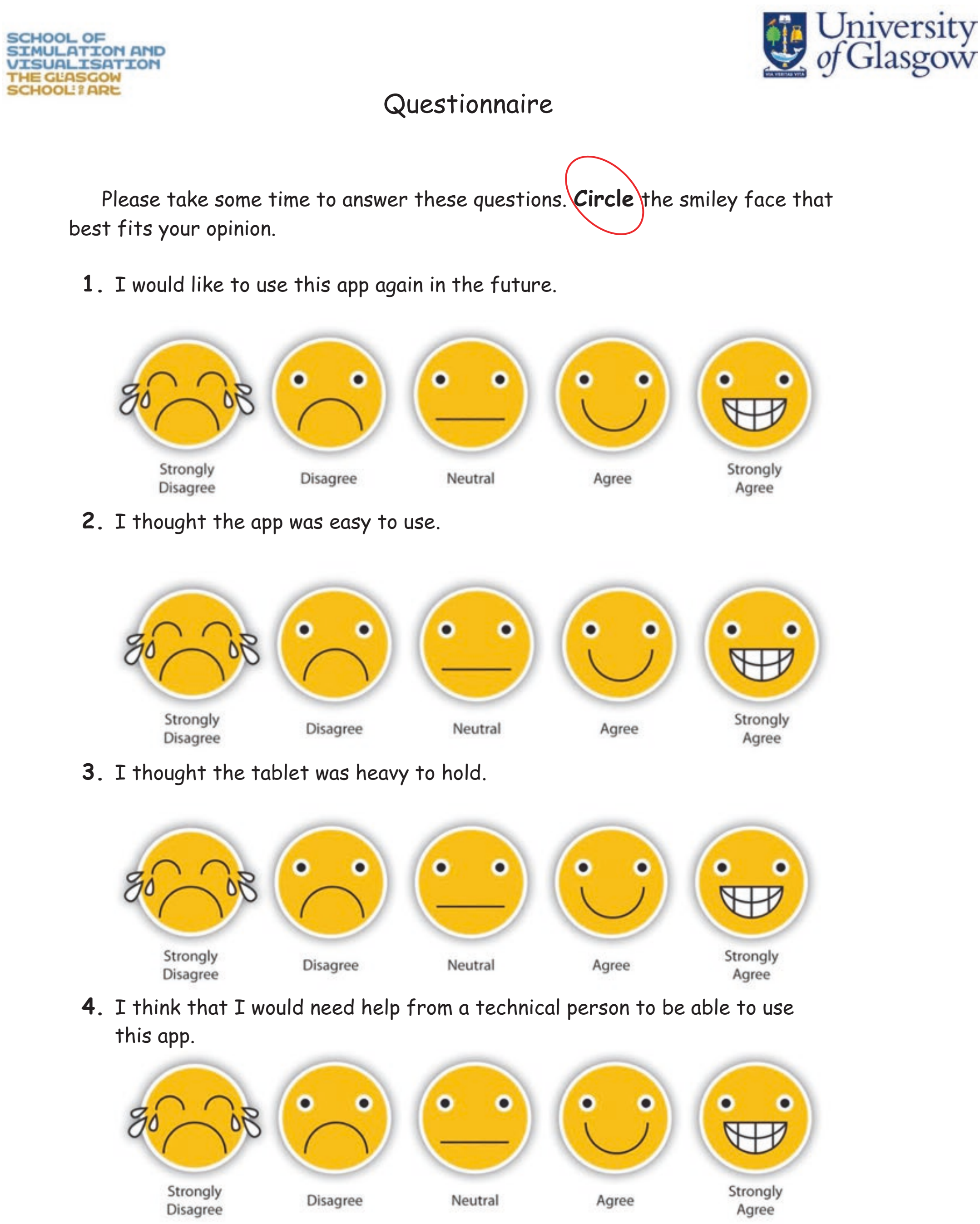
The positive results obtained in this preliminary study can therefore be indicative of the greater scope of AR in education. Effectively engaging a child patient in learning about their condition could encourage adherence to a treatment regimen and improve outcome for recovery. AR could benefit critical pediatric units such as oncology and intensive care by providing entertainment and informative content. Moreover, tablet based AR is an easily accessible and affordable technology, which could provide schools with an alternative channel to encourage a child to participate in learning through games and interactivity. In addition, following this easy to follow guide in creating an AR application, with feedback, shows how this could be extended further into many aspects of education, training and engagement in many medical conditions and structure and function of the human body.

Appendices

Appendix 1



Appendix 2



SCHOOL OF SIMULATION AND VISUALISATION
THE GLASGOW SCHOOL OF ART

University of Glasgow

Questionnaire

Please take some time to answer these questions. **Circle** the smiley face that best fits your opinion.

1. I would like to use this app again in the future.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

2. I thought the app was easy to use.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

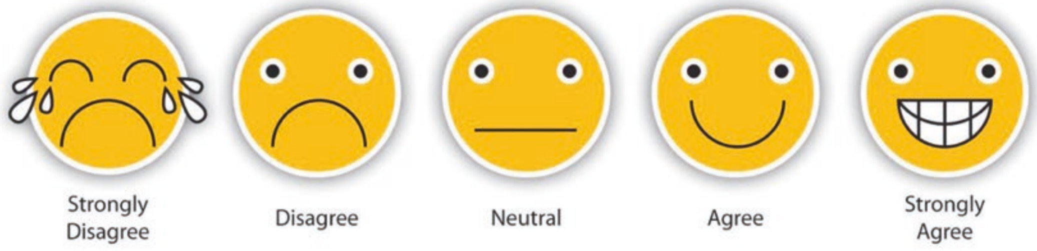
3. I thought the tablet was heavy to hold.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

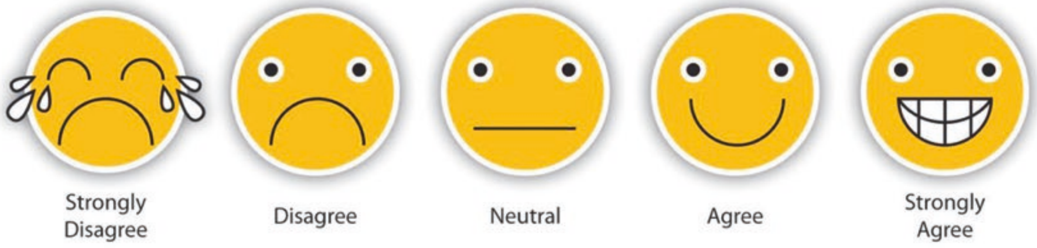
4. I think that I would need help from a technical person to be able to use this app.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

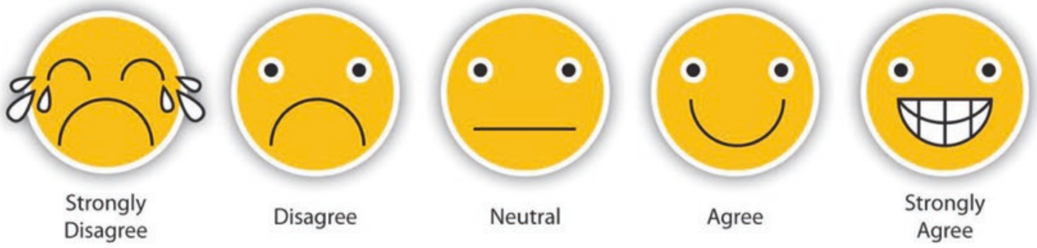
5. I liked the colours and the pictures used in the app



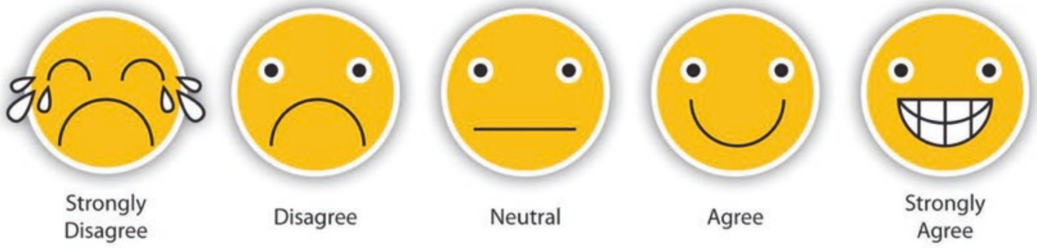
6. I thought the mascot (Dr Ray) helped me learn about the human body



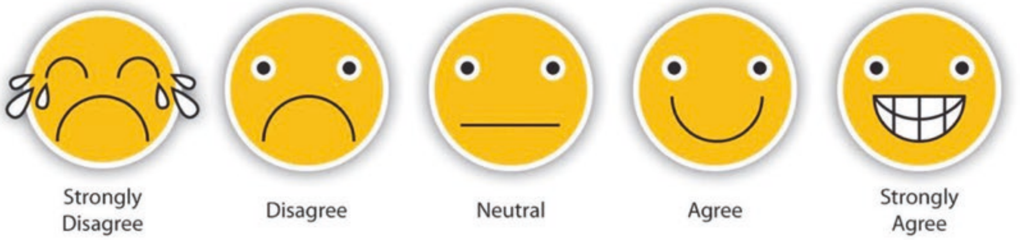
7. I understood the information given about the human body within the app



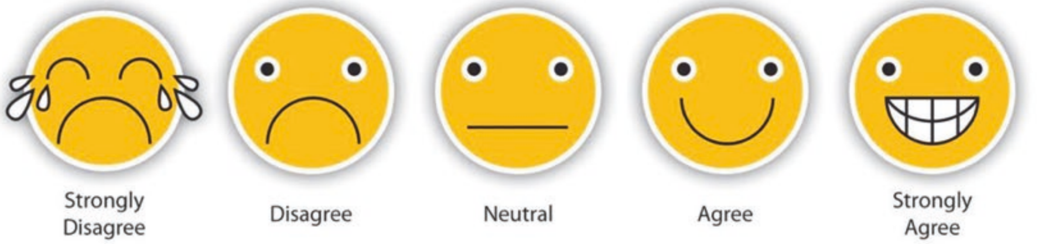
8. The app helped me learn new things about the human body



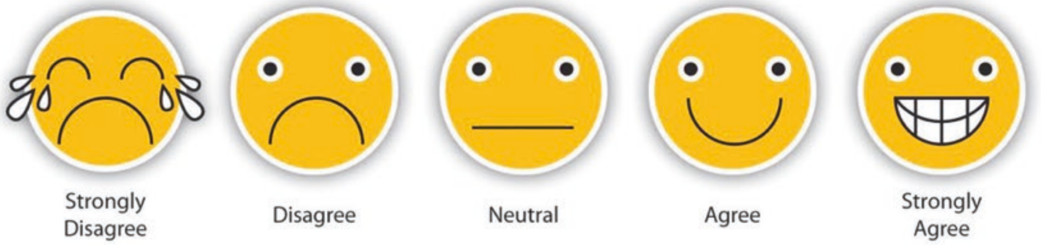
9. The use of 'Augmented Reality' in the app helped me learn about the human body



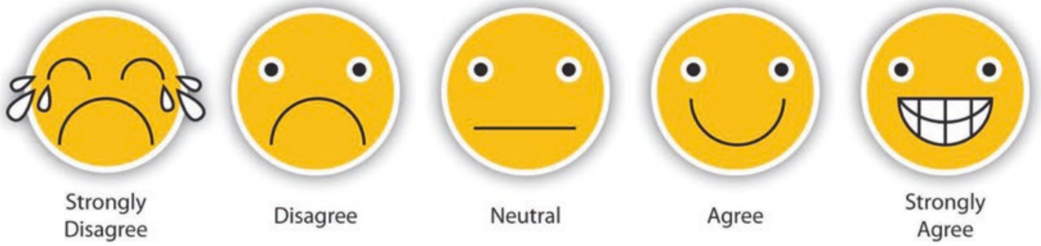
10. I thought the use of the camera was fun and made me want to use the app again



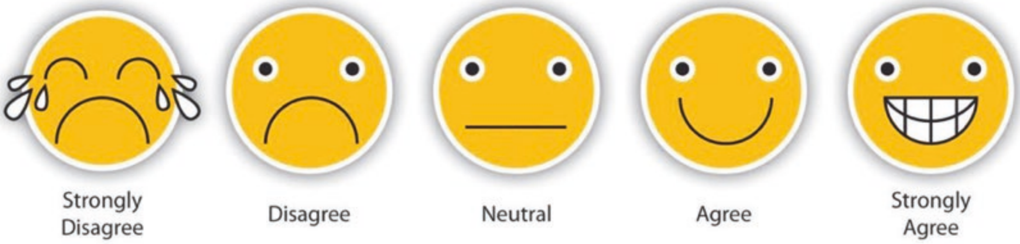
11. I thought using Dr Duck and the clipboard made learning about broken wrists fun



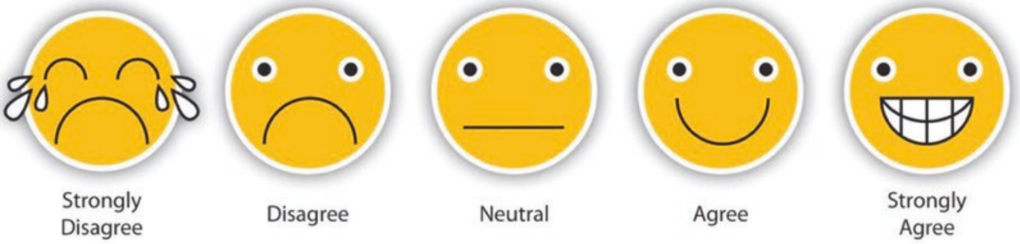
12. The use of the 'Augmented Reality' helped me understand how to recover after a broken wrist



13. I think this app could be used in school to help my class learn



14. I think this would help doctors explain the human body to sick children



15. Please write any extra comments in this box!

Before returning these sheets to the researcher please make sure you've answered all questions!

Appendix 3: Evaluation Interview and Pre-test/Post-test Questions

Demographic Screener Questions

1. How old are you?
2. Do you have access to a tablet device or other mobile device technology at home?
3. Have you ever broken a bone before?

Pre-test/Post-test Questions

1. What is an x-Ray?
2. What is Augmented Reality?

References

Akçayır M, Akçayır G (2017) Advantages and challenges associated with augmented reality for education: a systematic review of the literature. Educ Res Rev 20:1–11

Andersen MH, Khalid MS, Brooks EI (2017) Considerations and methods for usability testing with children. In: Brooks A, Brooks E (eds) Interactivity, game creation, design, learning, and innovation. ArtsIT 2016, DLI 2016. Lecture notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 196. Springer, Cham

Anderson K, Emmerton LM (2016) Contribution of mobile health applications to self-management by consumers: review of published evidence. Aust Health Rev 40:591–597

Barsom EZ, Graafland M, Schijven MP (2016) Systematic review on the effectiveness of augmented reality applications in medical training. Surg Endosc 30:4174–4183

Baus O, Bouchard S (2014) Moving from virtual reality exposure-based therapy to augmented reality exposure-based therapy: a review. Front Hum Neurosci 8:112

Bayat Games (2017) Free platform game assets. Version 1.0. GitHub, Inc., Abbasabad, Iran. 21.5 MB. https://assetstore.unity.com/packages/2d/environments/free-platform-game-assets-85838. Accessed 20 May 2019

Bennett S, Maton K, Kervin L (2008) The 'digital natives' debate: a critical review of the evidence. Br J Educ Tech 39:775–786

Billinghurst M, Kato H, Poupyrev I (2001) The MagicBook: a transitional AR interface. Comput Graph 25:745–753

Billington C (2016) How digital technology can support early language and literacy outcomes in early years settings: a review of the literature, 1st edn. National Literacy Trust, London. 17 p. https://literacytrust.org.uk/documents/194/2016_06_16_free_research_-_digital_technology_early_literacy_review_2016_oWCanmt.pdf. Accessed 20 May 2019

Blackler A, Popovic V, Mahar D (2003) The nature of intuitive use of products: an experimental approach. Des Stud 24:491–506

Brooke J (1996) SUS: a 'quick and dirty' usability scale. In: Jordan PW, Thomas B, Weerdmeester BA, McClelland IL (eds) Usability evaluation in industry, 1st edn. London, Taylor & Francis Ltd, pp 189–194

Bruner JS (1977) The process of education, 2nd edn. Harvard University Press, Cambridge, MA. 128 p

Chen CH, Lee IJ, Lin LY (2016) Augmented reality-based video-modeling storybook of nonverbal facial cues for children with autism spectrum disorder to improve their perceptions and judgments of facial expressions and emotions. Comput Hum Behav 55:477–485

Chen P, Liu X, Cheng W, Huang R (2017) A review of using augmented reality in education from 2011 to 2016. In: Popescu E, Kinshuk KKM, Huang R, Jemni M, Chen NS, Sampson DG (eds) Innovations in smart learning, 1st edn. Springer Science+Business Media, Singapore, pp 13–18

Cooke L (2010) Assessing concurrent think-aloud protocol as a usability test method: a technical communication approach. IEEE Trans Prof Commun 53(3):202–215

Doubleday EG, O'Loughlin VD, Doubleday AF (2011) The virtual anatomy laboratory: usability testing to improve an online learning resource for anatomy education. Anat Sci Educ 4:318–326

Dunleavy M, Dede C (2014) Augmented reality teaching and learning. In: Spector JM, Merrill MD, Elen J, Bishop MJ (eds) The handbook of research for educational communications and technology, 4th edn. New York, Springer Science+Business Media, pp 735–745

Falloon G (2013a) Young students using iPads: app design and content influences on their learning pathways. Comput Educ 68:505–521

Falloon G (2013b) Creating content: building literacy skills in year 1 students using open format apps. Comput New Zeal Schools Learn Teach Tech 25:77–95

Ferrer-Torregrosa J, Torralba J, Jimenez MA, García S, Barcia JM (2015) ARBOOK: development and assessment of a tool based on augmented reality for anatomy. J Sci Educ Tech 24:119–124

Fraunhofer MEVIS (2018) Fraunhofer Institute for medical image computing MEVIS. Liver surgery. Bremen, Germany. https://www.mevis.fraunhofer.de/en/solutionpages/liver-surgery.html. Accessed 20 May 2019

Gelman DL (2014) Design for kids: digital products for playing and learning, 1st edn. Rosenfeld Media, New York. 248 p

Gopalan V, Bakar JAA, Zulkifli A (2017) A brief review of augmented reality science learning. AIP Conf Proc 1891(1). https://doi.org/10.1063/1.5005377

Gould DJ, Terrell MA, Fleming J (2008) A usability study of users' perceptions toward a multimedia computer-assisted learning tool for neuroanatomy. Anat Sci Educ 1:175–183

Hornecker E, Dünser A (2009) Of pages and paddles: Children's expectations and mistaken interactions with physical–digital tools. Interact Comput 21:95–107

Kamphuis C, Barsom E, Schijven M, Christoph N (2014) Augmented reality in medical education? Perspect Med Educ 3:300–311

Kerawalla L, Luckin R, Seljeflot S, Woolard A (2006) "Making it real": exploring the potential of augmented reality for teaching primary school science. Virtual Reality 10:163–174

Koohang A (2004) A study of users' perceptions toward E-learning courseware usability. Int J E-Learn 3(2):10–17. Norfolk, VA: Association for the Advancement of Computing in Education (AACE)

Koohang A, Paliszkiewicz J (2014) Empirical validation of an learning courseware usability model. Issues Inf Syst 15:270–275

Kreps GL, Neuhauser I (2010) New directions in health communication: opportunities and challenges. Patient Educ Couns 78:329–336

Küçük S, Kapakin S, Göktaş Y (2016) Learning anatomy via mobile augmented reality: effects on achievement and cognitive load. Anat Sci Educ 9:411–421

Liarokapis F, Anderson EF (2010) Using augmented reality as a medium to assist teaching in higher education. In: Kjelldahl L, Baronoski G (eds) Proceedings of the 31st annual conference of the European Association for Computer Graphics (Eurographics 2010); Norrköping, Sweden: 2010 May 3–7. European Association for Computer Graphics, Geneva, pp 9–16

Markopoulos P, Bekker M (2003) On the assessment of usability testing methods for children. Interact Comput 15:227–243

McQueen A, Cress C, Tothy A (2012) Using a tablet computer during pediatric procedures: a case series and review of the "apps". Pediatr Emerg Care 28:712–714

Mitsuhashi N, Fujieda K, Tamura T, Kawamoto S, Takagi T, Okubo K (2009) BodyParts3D: 3D structure database for anatomical concepts. Nucleic Acids Res 37:D782–D785

Mott J, Bucolo S, Cuttle L, Mill J, Hilder M, Miller K, Kimble RM (2008) The efficacy of an augmented virtual reality system to alleviate pain in children undergoing burns dressing changes: a randomised controlled trial. Burns 34:803–808

Nielsen J (2010) Children's websites: usability issues in designing for young people. Evidence-Based User Experience Research, Training, and Consulting. Nielsen Norman Group (NN/g), Fremont, CA. https://www.nngroup.com/articles/childrens-websites-usability-issues/. Accessed 20 May 2019

Peddie J (2017) Augmented reality: where we will all live, 1st edn. Springer, New York. 323 p

Rohrer C (2014) When to use which user-experience research methods. Evidence-Based User Experience Research, Training, and Consulting. Nielsen Norman Group (NN/g), Fremont, CA. https://www.nngroup.com/articles/which-ux-research-methods/. Accessed 20 May 2019

Rosset A, Spadola L, Ratib O (2004) OsiriX: an open-source software for navigating in multidimensional DICOM images. J Digit Imaging 17:205–216

Svensson PG (2002) eHealth applications in health care management. eHealth Int 1:5

Taylor AM, Diggle P, Wessels Q (2018) What do the public know about anatomy? Anatomy education to the public and the implications. Anat Sci Educ 11:117–123

Trundle KC (2015) The inclusion of science in early childhood classrooms. In: Trundle KC, Saçkes M (eds) Research in early childhood science education, 1st edn. Dordrecht, Springer, pp 1–6

Valerio G, Galle F, Mancusi C, Di Onofrio VD, Colapietro M, Guida P, Liguori G (2010) Pattern of fractures across pediatric age groups: analysis of individual and lifestyle factors. BMC Public Health 10:656

Vines A (2012) Helping your wrist recover after a fracture: information for patients, 3rd edn. Oxford University Hospitals NHS Trust, Oxford. 5 p

Vuforia (2017) Vuforia object scanner. Vuforia developer portal. PTC Inc., Massachusetts, USA. https://developer.vuforia.com/. Accessed 20 May 2019

Wan Yahaya WA, Salam SN (2008) Smiley faces: scales measurement for children assessment. In: Proceedings of the 2nd international Malaysian educational technology convention: smart education: converging technology, pedagogy and content; Kuantan, Pahang Darul Makmur, Malaysia, 2008 November 4–7. Malaysian Educational Technology Association (META), Penang, pp 1–7

White B (2016) Designing for kids is not child's play. Smashing Magazine. 20 January 2016. Smashing Media AG, Freiburg im Breisgau, Germany. https://www.smashingmagazine.com/2016/01/designing-apps-for-kids-is-not-childs-play/. Accessed 20 May 2019

Wojciechowski R, Cellary W (2013) Evaluation of learners' attitude toward learning in ARIES augmented reality environments. Comput Educ 68:570–585

Wrench J, Punyanunt-Carter N, Ward M Sr (2015) Corporate training. In: Wrench J, Punyanunt-Carter N, Ward M (eds) Sr. organizational communication: theory, research, and practice, 1st edn. FlatWorld, Boston. 528 p. https://catalog.flatworldknowledge.com/bookhub/reader/7635?e=wrenchorgcomm-27115-20150226-114842-208230. Accessed 20 May 2019

Yilmaz RM, Kucuk S, Goktas Y (2017) Are augmented reality picture books magic or real for preschool children aged five to six? Br J Educ Tech 48:824–841

Yuen SC, Yaoyuneyong G, Johnson E (2011) Augmented reality: an overview and five directions for AR in education. J Educ Tech Dev Exchange 4:119–140

Zhu E, Hadadgar A, Masiello I, Zary N (2014) Augmented reality in healthcare education: an integrative review. Peer J 2:e469

10 Using Technology to Engage the Public in Biomedical Sciences

Adam M. Taylor and Quenton Wessels

Abstract

Biomedical research is a diverse and rapidly evolving subject area. The research and development that takes place as part of the field is aimed at understanding subjects such as diseases, disease progression, their treatment(s), treatment impact on patients as well as the general increase in understanding of the advancement of health sciences. The money and time invested in research is vast and discovery of novel data and production of publication(s) is seen as success. However in today's connected world scientists have to do more to ensure that their research and the impact thereof, is better communicated to the wider audiences. One of the major means to do this is via public engagement, of which there are many ways to achieve this. Advances in technology have led to interactive and immersive visual technologies that enable the next phase of public engagement to be available to a greater audience.

Keywords

Public engagement · Technology · Visualisation · Interactive · Community

10.1 Background

Biomedical research and innovation underpins the knowledge of medical and allied health professions, treatment/intervention options and technological advances across the globe. Biomedical research is a multi-billion pound trade around the world; with much of what goes on being "behind the scenes" and only a small amount actually visible to the patient and the public. It is important at this point to distinguish between "the public", a heterogeneous group and every person in society, and the "lay public". The latter refers to individuals in society, including scientists, who are non-experts in a specific field (Levy-Leblond 1992). The use of "public" when referring to public engagement is this chapter should be viewed as the lay public as well as the "attentive public" (members of the general community interested and who are fairly well informed), the "interested public" (interested but not well informed individuals), and the "general public" (mediators, scientists, decision makers, school children and charity workers) (Miller 1992).

Recent years has seen a move to ensure transparency of the projects of biomedical research laboratories, and why it is important for those

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P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7_10

outside academia, subject speciality and sector to understand what is being done (National Co-ordinating Centre for Public Engagement 2018). Advances in biomedical research have become equally important to the public and the scientific community.

Biomedical scientists are considered experts in their fields; spending years researching, understanding and advancing the knowledge about their relevant area(s) of expertise; time served is believed to make them holders of extensive knowledge and ability. Whilst experience and knowledge are needed to determine whether the science is feasible and scientifically worthwhile, there is evidence that the usefulness of this research may not be completely understood or valued by the public. Funding councils, charities and many other bodies have appointed "lay-members" to their awarding panels to ensure that the usefulness of funding submissions is seen as worthy to those beyond the so-called experts.

Researchers, academic institutions and other entities are under increasing pressure to demonstrate the societal impact of their work due to the nature of the funding of these projects. In most cases, the funding originates through taxes and donations (Engagement 2018a; I. S. E. a. M. T. Force 2019) (www.informalscience.org/em-task-force, www.publicengagement.ac.uk, 2019). The need for the public to understand the usefulness and objectives of scientific research, and ultimately the value of their investment, is paramount. The provision of this understanding often comes from the scientists who communicate their progress and findings. Prime examples of poor communication are most famously seen in the field of climate change where adverse consequences of weak communication between scientists and the public occurred, leading to mistrust and misunderstanding of scientists and their research (Somerville and Hassol 2011). In biomedicine, the vaccination programmes for the human papilloma virus (HPV), Measles, Mumps and Rubella (MMR) have similarly damaged trust between scientists and the public (Kahan 2013).

Scientists understand that they need to communicate their findings to the public, but many are accused of confusing their audience with scientific jargon and struggle to communicate to lay people (Illes et al. 2010).

10.2 The Need for Public Engagement

The need for public engagement, in part, was driven by a shift from the public understanding of science and its communication via media platforms to the creation of a dialogue through engagement (Stilgoe et al. 2014). Effective science communication, i.e. the use of specific activities, appropriate skills, dialogue and media, has the potential to address the public's rejection of validated scientific findings (Burns et al. 2003; Fischhoff and Scheufele 2014). The quality of science communication, whether through outreach, public engagement or knowledge exchange, is pivotal in addressing possible misconceptions such as the role of evolution in the biological sciences and the advantages of childhood vaccinations (Fischhoff and Scheufele 2014).

Public engagement is a useful and worthwhile vehicle to build trust and understanding between the scientific community and the wider audience. It is viewed as being interactive and usually has five main objectives to exhibit (Engagement 2018b):

1. Accountability – for the public money, the researchers/academics are spending.
2. Value and purpose – institutions need to live the values they stand by and offer purpose to their communities.
3. Trust – difficult to gain and easy to lose.
4. Relevance – discussion and dialogue with stakeholders about what institutions do and why it is important.
5. Responsiveness to the wider public and policy makers in an ever-changing environment.

As engagement in biomedical science grows, more individuals and institutions are keen to display their work outside the conventional laboratory or conference setting. This delivery of science and integration into non-specialists' daily lives is important, particularly in times where the acceptance of scientific evidence can be lacking conviction (Wolinsky 2008). However, such engagement exercises should not aim to gain consensus or reinforcement of an institution's motives. It should rather aim to encourage meaningful dialogue which challenges and accommodates various views on a topic (Stilgoe et al. 2014). These discussions should aim to exchange information with as many and as diverse a group of individuals as possible to give the best representation of end users. This is important given that the direct end users of most academic research efforts are the public; through education of professionals who may treat them in the future or for recipient of treatments or resources in biomedical or healthcare contexts. Academic institutions are increasing their efforts to engage the public. Yet, literature of the value and impact of such endeavours are sparse (Bowler et al. 2012), similarly there are questions that remain unanswered regarding what constitutes effective engagement and what would be the best metric to measure this by. The Knowledge Exchange Framework (KEF) which is intended to increase efficiency and effectiveness in use of public funding for knowledge exchange (KE), to further a culture of continuous improvement in universities by providing a package of support to keep English university knowledge exchange operating at a world class standard (England 2019). The framework may give some clarity to metrics that will be measured but given the diversity of engagement activities, it may prove difficult to find a one set of metrics to fit all.

Engagement broadens involvement in the STEM (Science, Technology, Engineering and Mathematics) subjects and encourages youngsters into these fields as it is important for the economy (Accounts 2018) in cultivating curiosity for learners as well as empowering future generations. Whilst there is a growing demand for engagement from the public (Taylor et al. 2018) and the need to do so by institutions and their academics, there are still challenges around the diversity of individuals undertaking engagement and involvement in STEM subjects. Engagement is becoming more and more important in ensuring scientific integrity and gaining accountability to the funders of scientific efforts. However, the undertaking of engagement comes at a cost. The costs to academics are double-fold; they must undertake these activities to meet impact requirements as part of their compulsory duties, which takes them away from their research, teaching and administrative duties. Furthermore, such engagement activities also adds more work to them, which in turn may impact on the work-life balance. There are still questions about whether these engagement activities will be recognised with the same significance as teaching, research and administrative achievements when pursuing a promotion (King and Rivett 2015). Where engagement is not properly accounted for and recognised; it may add to the struggles academics, particularly of minority groups and women in academia in progressing through their careers. If their participation in engagement is problematic to the extent that they cannot afford the time to undertake engagement to demonstrate impact then their successes in obtaining funding may be affected, having a further detrimental impact on their career. The presence and ability of individuals from minority groups and female academics in the engagement setting is extremely important in attracting the next generation of STEM scientists from these backgrounds into the field. Despite significant efforts to mitigate these issues, there is still a lag in minority and women PhDs progressing into top postdoctoral and Faculty roles within STEM (Fisher et al. 2019).

The STEM strategies of many countries face challenging times as the uptake of STEM subjects is falling in relative terms against rising number of higher education institutions (Forum 2006). The figures suggest that children may develop a negative attitude to STEM subjects in primary school and beyond, often coinciding with declining grades (George 2000; Mihladiz et al. 2011). This is further compounded by teachers lacking the resources, skills and knowledge to be able to teach and maintain a programme that develops as the children develop. There are a number of outreach and engagement programmes that have been developed to tackle this (E. R. Burns 2002, 2008, 2012). However it is difficult to roll this out on a wider scale due to a multitude of factors; resource availability, lack of free time in school curricula, lack of spare time for academics, differing curricular and curricular focuses from country to country and the financial costs, are just a few.

This makes the engagement activities of Universities fundamentally important on a civic level and building innovative and engaging activities that bring out the curiosity in the public and spark exchange of information are more important than ever.

In recent years, engagement has brought ingenious methods of educational delivery out of the teaching environment and into the public domain (Taylor et al. 2018). This is also coupled with the availability of specialist equipment that resonates with the public; often being seen as the latest technology. The availability of specialist educational equipment is often limited to the public, existing only in institutions with budgets to support the purchase, maintenance and the expertise to utilise it in an educational context. These novel modalities of visualisation of biomedical subject matter bring a new means of undertaking engagement; resonating with all demographics and furthering the ability to raise curiosity in the subject matter with technology rather than lecture or didactic methods. Equally important; scientists are provided with an opportunity to listen to and learn from the public (Gregory and Lock 2008). These novel means of engagement bring complex and intricate science to the public enabling them to interact and learn, as well as enabling scientist to improve their communication in science and build positive relationships with the end users of their information.

Engagement comes in many forms and there is no right or wrong way to undertake it, ensuring it is educational, catchy and meets the needs of your audience. This gets you a long way down the road to success. Many scientists use engagement to display their work, or build impact, whilst others utilise it for research, educational and scholarship purposes, feeding back into their own curriculum and educational offerings to students. Regardless of reason for undertaking, it is clear that engagement is critical to the success of higher education in the future (Fitzgerald et al. 2016).

Defining engagement is difficult, but in its simplest terms, it is a 2 way exchange of information. Whilst there may be multiple reasons for academics to participate, actually planning and undertaking engagement has its challenges. Many institutions are now developing their own public engagement agendas and platforms, with dedicated staff appointed to facilitate these events. The benefit for academic staff is huge, it takes away the pressures of having to sources venues, advertise events, organise logistics and monitor sign-up and attendance, giving freedom to academics to focus on content and delivery (Taylor et al. 2018).

More and more funders are requiring academics to prove that there is benefits to Society from their research (Perkmann et al. 2013); much of the way to do this is through engagement, both qualitative and quantitative to add strength to applications. However, this engagement may have to come before the actual funding bid is made to get something that is useable and convincing. Funding of participation in engagement is often problematic, depending on the number of participants and the types of activities being undertaken, there can be a large amount of resources that are used and these are often taken away by participants incurring significant costs. Where academic institutions have developed their own agenda and team to support engagement, there may be institutional funding to support engagement. Academics may also consider the significance of their professional society's in funding their engagement activities, the success of funding support from society's is usually linked to showcasing the field and the benefit that wider engagement with the knowledge can bring in highlighting the importance of the field whilst providing wider educational opportunities.

Engagement activities may also provide a development opportunity for PhD and Undergraduate students to experience first-hand how the subject area(s) that they are studying in is viewed by the wider public. The involvement in engagement also enables them to see the relevance of the material to individuals who are not associated with the subject area. The development opportunity enables them to experience the forum of communicating science to the public, outside lectures or labs, as well as build on their own communication skills. They may also experience how to deal with queries and questions that they may not have been expecting in relation to the activity, due to the fact that the diversity and varying knowledge and understanding in the general population enables many different interpretations of a single subject to be present.

10.3 Utilising Engagement in Biomedical Sciences for Research and Education

Engagement activities can be used to enable researchers to answer questions that require input from a wider audience. These studies generally fall into two broad categories; those that are purely engagement-based and those where engagement is being used as a means to undertake research. The latter typically aims to add to a particular body of knowledge but often leads to more questions. The relational aspect of engagement and its reliance on living human participants necessitates ethical approval (S. R. Davies 2013). The researcher should make a conscientious effort to highlight the potential benefits and harms of participation, ensure the confidentiality and anonymity, the rights of the participants to the information and to act with academic integrity (Black et al. 2018).

During the engagement activity it is important to be open and receptive to all manner of questions from potential participants. Given the diverse population, there are endless possibilities of levels of knowledge and interest in any activity that may arise during an event. Consideration should also be given that there may be individuals who come to events having been informed by misconceptions or less than sound knowledge and so it is important to attempt to clarify their understanding and information source(s) before attempting to rectify this. In these situations it can be embarrassing and uncomfortable for individuals, so tact and understanding should be shown to build confidence in receiving sound and correct knowledge.

Taylor and colleagues have used a 3D projector system, as part of Lancaster University's "Campus in the City" initiative and public engagement program to provide the local public with the opportunity to view the human body in 3D (Taylor et al. 2018). This setting provided the authors with an opportunity to highlight the fascinating field of gross anatomy, whilst providing an opportunity to evaluate the public's knowledge and observations of anatomy and anatomical structures, and demystify erroneous concepts.

The authors overall aim was to provide an interactive platform for the public to learn anatomy, to see and hear about things that they may have encountered in life, or the media. Additionally, the public were given the opportunity to participate in a study to assess their knowledge on the location of various organs of the human body and to examine trends associated with the various parameters.

The visualisation opportunity was provided to explore any structure of interest as deemed by members of the public. The structure or region of interest was then projected in 3D via a Cyber-Anatomy Med software (Cyber-Anatomy Corp., Coralville, IA) connected to an Optoma GT 1080 short throw projector (Optoma Europe Ltd., Watford, UK). As part of the event participants also had the opportunity to explore the structures of the human body through plastic anatomical models, including; a detailed torso and heart, a skull, an articulated skeleton, and a model of the pelvic viscera. Whilst these were of interest to many because they could be picked up and held, they were limited in their content. In contrast, the diversity in material afforded by the software package provided the participants with an opportunity to discover more than 4300 high-resolution digital structures and over 13,000 identifiable landmarks. The level of detail and volume of material contained within the single software package would be impossible to take into the public domain for engagement purposes using any other resource due to logistical, time and legal constraints. However, this exercise served to build bridges and crossing gaps in participants' knowledge of their own body. It also provided an environment where the public felt comfortable to engage with scientists, thus breaking down barriers and rendering knowledge more accessible (S. R. Davies 2013).

Development of novel technologies to bring imaging of structures at the micro-level has been designed for educational purposes (Kim et al. 2016). This technology has been designed and implemented utilising smartphones which are a commonplace in most households globally and 3-D printed components which are easy to produce and cost-effective. This development is to engage individuals with specialist opportunities as well as making biological micro-structures more perceptible to society. Developments like these are aimed at bringing biological and biomedical sciences up to a similar level of advancement that enables the public to interact in various fields, those considered to be field leading in this respect include areas such as gaming and programming, which have pioneered and progressed at a much faster rate. Specific technological designs for engagement and education have made histological structures viewable and interactive to everyone, as seen in the work by Wicks and colleagues. Their work have demonstrated the development of a novel high-resolution smartphone microscopy platform for engaging the public and utilisation as an educational tool (Wicks et al. 2017). The pioneering work in the 1600s on microscopy has still not been made widely available to everyone, some researchers included. This new advance uses smartphones and their cameras, targeted at teenagers to engage them in the sciences and the world that surrounds them, taking a closer look at how it functions (Wicks et al. 2017).

The challenge remains to move science from the laboratory to homes and recreational spaces of the public that are not usually associated with learning. Even with this movement out of the laboratory, anything that is presented to the public must be clearly relevant and understandable. The relevance may not appeal to everyone, however utilising a modality that is familiar can overcome the relevance issue and get people involved in participating. An innovative way to achieve this is to make it contextual and in a format that is familiar to as many people as possible. One possible way to accomplish this is to make the learning part of a game or making it part of something that is widely utilised by the target audience (Coil et al. 2017). Educational gaming, through online platforms has been successfully used to educate the public about microbes and antibiotics. Whilst challenges at the inception around availability of computers and access to the internet may have been problematic, the availability of mobile phones and mobile internet make this visually engaging games useful educational tools (Kostkova et al. 2010). Analysis of engagement with these visually interactive platforms shows significant early engagement, but this decreases rapidly as the game progresses (Farrell et al. 2011). Interaction with platforms such as these often leaves questions about how much was learnt by participants and whether those who engaged would have learnt similar information through their traditional educational or recreational activities.

Whilst biomedical sciences have developed various resources that promote engagement through visual software or hardware, chemistry has developed a similar online platform for visualisation of molecules and atomic structures using computers (Smith 1995).

The significance of visualisation in public engagement is not just through technological advances, it can also be seen it its ability to communicate complicated biomedical concepts and information to the public by visualising large, complex or difficult datasets in the form of graphical charts or images. This renders the content digestible to the lay reader. The significance of the visualisation is that it gives those without the specialist knowledge or understanding the ability to rationalise and relate to the material that is being described to them; this is seen in communicating through media outlets for outbreaks of disease or matters of public health (Alcibar 2018; McCrorie et al. 2016).

Whilst there are a huge variety of pioneering and established visualisation software and hardware platforms, that takes interesting and complicated educational material into schools and recreational forums, there is still little that ascertains whether these methods are in fact effective. The broader question is how do you determine the outcome or effectiveness of engagement?

The utilisation of technology is not without issue(s), these technologies can prove to be expensive and misinterpreted by the public. The misinterpretation of information by the public and non-specialists is hardly surprising given that guidelines are constantly changing or evolving about things like alcohol consumption, cancer causing foods and cancer screening age recommendations for breast cancer and cervical cancer (U. P. S. T. Force 2018; Nugawela et al. 2016; Oeffinger et al. 2015). These guidelines are relatively straightforward and are believed to be easy to follow, however it is clear that there is still work to do on educating people about how to interpret them (Taylor et al. 2018). These technologies have great opportunity but must be sure to add scientific rigour and honesty to the scientific agenda, which becomes more difficult in the era of availability of scientific information over social media that can be absent of fact checking or scientific expertise or review. This doubles the challenge of undertaking engagement by academics, they aim is to disseminate their work and give people the opportunity to learn, but they also face the challenge of standing out amongst the vast amounts of freely available information that is easily accessible on the internet.

Additional innovative approaches to public engagement could be through the use of augmented reality (AR) software applications. The Virtuali-Tee T-shirt by Curiscope, as an example, is combined with a software application allowing the users to view the internal organs in an augmented setting (Curiscope 2019). The use of AR and mixed reality in education is well documented and is gaining more interest (Nielsen et al. 2016; Swensen 2016; Weng et al. 2019). These technological advances lend themselves as possible visualisation aids in public engagement.

10.4 Engagement Setting

Engagement of participants can range from science and society, universities and communities to users and researchers; the coming of together of two discrete entities remains constant (Sarah R. Davies 2008; S. R. Davies 2013). It is important to note that there is no particular method or model that can be implemented for public engagement due to each engagement being situated differently and having a different focus (Measham et al. 2011). The setting of these engagements can include the following:

- Public
- Schools and other vocational and educational institutions
- Online visual/virtual platform(s)/Apps = citizen science, using visualisation
- Societies
- Communities

Anatomical education to the public is one area where the use of biomedical imaging has moved forward. The availability of resources has moved on to enable education to many (including the public) to occur in varied venues such as pubs, town centres and via online media.

Engagement is most commonly associated with academics visiting schools or public venues to deliver their specialised materials, one of the benefits of many of the technologies discussed here are that, in many instances, they remove the need for a formal venue. Visualisation technology that is accessible by home computer or mobile device increases the reach of this form of engagement. However, this comes at a cost of taking away the necessary expertise that may be available when staff members are present in typical engagement venues. Careful consideration should be given to ensuring appropriate user guidelines and interpretation of information is available.

The presence and utilisation of these technologies in engagement provide the opportunity for education, research and offering the potential to inform civic and government agendas.

10.5 Summary

The value of engagement initiatives with the public extends beyond the showcasing of research advances or conducting research. The public can be considered scientists, mediators and decision makers (Levy-Leblond 1992). It provides an opportunity for interactions which facilitate the accessibility of scientific information in a less formal milieu. This engagement and knowledge transfer would ideally be reciprocal in an effort to break down barriers and to build bridges, thus encouraging a dialogue. The uses of technological advances afford an array of engagement modalities in biomedical sciences. Biomedical researchers are necessitated to demonstrate the social and societal impact of their work in a bid to be more transparent and accountable. Novel technologies such as visual simulations, models, 3D imaging and printing, as well as virtual, augmented and mixed realities have the potential to impact diverse audiences. Staying abreast with current technologies has the potential to relay knowledge in a meaningful and relevant manner.

References

Accounts, H. o. C. C. o. P (2018) Delivering STEM skills for the economy. Retrieved from https://publications.parliament.uk/pa/cm201719/cmselect/cmpubacc/691/691.pdf

Alcibar M (2018) Information visualisation as a resource for popularising the technical-biomedical aspects of the last Ebola virus epidemic: the case of the Spanish reference press. Public Underst Sci 27(3):365–381. https://doi.org/10.1177/0963662517702047

Black GF, Davies A, Iskander D, Chambers M (2018) Reflections on the ethics of participatory visual methods to engage communities in global health research. Glob Bioethics 29(1):22–38. https://doi.org/10.1080/11287462.2017.1415722

Bowler MT, Buchanan-Smith HM, Whiten A (2012) Assessing public engagement with science in a University Primate Research Centre in a national zoo. PLoS One 7(4):e34505. https://doi.org/10.1371/journal.pone.0034505

Burns ER (2002) Anatomy of a successful K-12 educational outreach program in the health sciences: eleven years experience at one medical sciences campus. Anat Rec 269(4):181–193. https://doi.org/10.1002/ar.10136

Burns ER (2008) Functional anatomy of the cardiovascular system: professional development for PreK-3 teachers using a “train and equip” method results in learning opportunities for students. Anat Sci Educ 1(3):119–125. https://doi.org/10.1002/ase.30

Burns ER (2012) Healthy lungs: cancer education for middle school teachers using a “train and equip” method. J Cancer Educ 27(1):179–185. https://doi.org/10.1007/s13187-011-0274-3

Burns T, O'Connor DJ, Stocklmayer SM (2003) Science communication: a contemporary definition. Public Underst Sci 12(2):183–202. https://doi.org/10.1177/09636625030122004

Coil DA, Ettinger CL, Eisen JA (2017) Gut check: the evolution of an educational board game. PLoS Biol 15(4):e2001984. https://doi.org/10.1371/journal.pbio.2001984

Curiscope (2019). Retrieved from https://www.curiscope.co.uk/

Davies SR (2008) Constructing communication: talking to scientists about talking to the public. Sci Commun 29(4):413–434. https://doi.org/10.1177/1075547008316222

Davies SR (2013) Constituting public engagement: meanings and genealogies of PEST in two UK studies. Sci Commun 35(6):687–707. https://doi.org/10.1177/1075547013478203

Engagement, N. C.-o. C. f. P (2018a) Health and life sciences funding. Retrieved from http://www.publicengagement.ac.uk/do-engagement/funding/health-and-life-sciences-funding

Engagement, N. C.-o. C. f. P (2018b) Why does public engagement matter. Retrieved from https://www.publicengagement.ac.uk/about-engagement/why-does-public-engagement-matter

England R (2019) Knowledge Exchange Framework (KEF). Retrieved from https://re.ukri.org/knowledge-exchange/knowledge-exchange-framework/

Farrell D, Kostkova P, Weinberg J, Lazareck L, Weerasinghe D, Lecky DM, McNulty CAM (2011) Computer games to teach hygiene: an evaluation of the e-bug junior game. J Antimicrob Chemother 66:V39–V44. https://doi.org/10.1093/jac/dkr122

Fischhoff B, Scheufele DA (2014) The science of science communication II. Proc Natl Acad Sci U S A 111(Suppl 4):13583–13584. https://doi.org/10.1073/pnas.1414635111

Fisher AJ, Mendoza-Denton R, Patt C, Young I, Eppig A, Garrell RL et al (2019) Structure and belonging: pathways to success for underrepresented minority and women PhD students in STEM fields. PLoS One 14(1):e0209279. https://doi.org/10.1371/journal.pone.0209279

Fitzgerald HE, Bruns K, Sonka ST, Furco A, Swanson L (2016) The centrality of engagement in higher education. J High Educ Outreach Engagement 20(1):223–244

Force, I. S. E. a. M. T (2019) Building understanding of and capacity for evaluation and measurement. Retrieved from http://informalscience.org/em-task-force

Force, U. P. S. T (2018) Screening for cervical cancer: US Preventive Services Task Force recommendation statement USPSTF recommendation: screening for cervical cancer USPSTF recommendation: screening for cervical cancer. JAMA 320(7):674–686. https://doi.org/10.1001/jama.2018.10897%JJAMA

Forum, O. G. S (2006) Evolution of student interest in science and technology studies policy report. Retrieved from http://www.oecd.org/science/inno/36645825.pdf

George R (2000) Measuring change in students' attitudes toward science over time: an application of latent variable growth modeling. J Sci Educ Technol 9:213

Gregory J, Lock SJ (2008) The evolution of 'public understanding of science': public engagement as a tool of science policy in the UK. Sociol Compass 2(4):1252–1265. https://doi.org/10.1111/j.1751-9020.2008.00137.x

Illes J, Moser MA, McCormick JB, Racine E, Blakeslee S, Caplan A et al (2010) Neurotalk: improving the communication of neuroscience research. Nat Rev Neurosci 11(1):61–69. https://doi.org/10.1038/nrn2773

Kahan DM (2013) Social science. A risky science communication environment for vaccines. Science 342(6154):53–54. https://doi.org/10.1126/science.1245724

Kim H, Gerber LC, Chiu D, Lee SA, Cira NJ, Xia SY, Riedel-Kruse IH (2016) LudusScope: accessible interactive smartphone microscopy for life-science education. PLoS One 11(10):e0162602. https://doi.org/10.1371/journal.pone.0162602

King L, Rivett G (2015) Engaging people in making history: impact, public engagement and the world beyond the campus. Hist Work J 80(1):218–233. https://doi.org/10.1093/hwj/dbv015

Kostkova P, Farrell D, de Quincey E, Weinberg J, Lecky D, McNulty C, eBug project, p (2010) eBug–teaching children hygiene principles using educational games. Stud Health Technol Inform 160(Pt 1):600–604

Levy-Leblond JM (1992) About misunderstandings about misunderstandings. Public Underst Sci 1(1):17–21

McCrorie AD, Donnelly C, McGlade KJ (2016) Infographics: healthcare communication for the digital age. Ulster Med J 85(2):71–75

Measham TG, Brake L, Robinson CJ, Larson S, Richards C, Smith TF (2011) NRM engagement between remote dryland communities and government agencies: success factors from Australia. J Arid Environ 75(10):968–973. https://doi.org/10.1016/j.jaridenv.2011.04.018

Mihladiz G, Duran M, Dogan A (2011) Examining primary school students' attitudes towards science in terms of gender, class level and income level. 3rd world conference on educational sciences. Procedia Soc Behav Sci 15:2582–2588. https://doi.org/10.1016/j.sbspro.2011.04.150

Miller JD (1992) Toward a scientific understanding of the public understanding of science and technology. Public Underst Sci 1(1):23–26

National Co-ordinating Centre for Public Engagement (2018) What is public engagement. Retrieved from https://www.publicengagement.ac.uk/about-engagement/why-does-public-engagement-matter

Nielsen B, Brandt H, Swensen H (2016) Augmented reality in science education – affordances for student learning. NorDiNa 12(2):157–174

Nugawela MD, Langley T, Szatkowski L, Lewis S (2016) Measuring alcohol consumption in population surveys: a review of international guidelines and comparison with surveys in England. Alcohol Alcohol 51(1):84–92. https://doi.org/10.1093/alcalc/agv073

Oeffinger KC, Fontham ETH, Etzioni R, Herzig A, Michaelson JS, Shih Y-CT et al (2015) Breast cancer screening for women at average risk: 2015 guideline update from the American Cancer Society. JAMA 314(15):1599–1614. https://doi.org/10.1001/jama.2015.12783

Perkmann M, Tartari V, McKelvey M, Autio E, Brostrom A, D'Este P et al (2013) Academic engagement and commercialisation: a review of the literature on university-industry relations. Res Policy 42(2):423–442. https://doi.org/10.1016/j.respol.2012.09.007

Smith TJ (1995) MolView: a program for analyzing and displaying atomic structures on the Macintosh personal computer. J Mol Graph 13(2):122–125, 115

Somerville RCJ, Hassol SJ (2011) Communicating the science of climate change. Phys Today 64(10):48–53. https://doi.org/10.1063/Pt.3.1296

Stilgoe J, Lock SJ, Wilsdon J (2014) Why should we promote public engagement with science? Public Underst Sci 23(1):4–15. https://doi.org/10.1177/0963662513518154

Swensen H (2016) Potential of augmented reality in sciences education a literature review. In: Chova LG, Martinez AL, Torres IC (eds) Iceri2016: 9th International Conference of Education, Research and Innovation. Iated-Int Assoc Technology Education a& Development, Valenica, pp 2540–2547

Taylor AM, Diggle P, Wessels Q (2018) What do the public know about anatomy? Anatomy education to the public and the implications. Anat Sci Educ 11(2):117–123. https://doi.org/10.1002/ase.1746

Weng C, Rathinasabapathi A, Weng A, Zagita C (2019) Mixed reality in science education as a learning support: a revitalized science book. J Educ Comput Res 0(0):0735633118757017. https://doi.org/10.1177/0735633118757017

Wicks LC, Cairns GS, Melnyk J, Bryce S, Duncan RR, Dalgarno PA (2017) EnLightenment: high resolution smartphone microscopy as an educational and public engagement platform. Wellcome Open Res 2:107. https://doi.org/10.12688/wellcomeopenres.12841

Wolinsky H (2008) Paths to acceptance. The advancement of scientific knowledge is an uphill struggle against 'accepted wisdom'. EMBO Rep 9(5):416–418. https://doi.org/10.1038/embor.2008.65

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P. M. Rea (ed.), *Biomedical Visualisation*, Advances in Experimental Medicine and Biology 1171,
https://doi.org/10.1007/978-3-030-24281-7