


Mixed-methods exploration of students' motivation in using augmented reality in neuroanatomy education with prosected specimens

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Abstract

The use of augmented reality (AR) in teaching and studying neuroanatomy has been well researched. Previous research showed that AR-based learning of neuroanatomy has both alleviated cognitive load and was attractive to young learners. However, how the attractiveness of AR effects student motivation has not been discovered. Therefore, the motivational effects of AR were investigated in this research by the use of quantitative and qualitative methods. Motivation elicited by the GreyMapp-AR, an AR application, was investigated in medical and biomedical sciences students ($n = 222$; mean age: 19.7 ± 1.4 years) using the instructional measure of motivation survey (IMMS). Additional components (i.e., attention, relevance, confidence, and satisfaction) were also evaluated with motivation as measured by IMMS. Additionally, 19 students underwent audio-recorded individual interviews which were transcribed for qualitative analysis. Males regarded the relevance of AR significantly higher than females ($P < 0.024$). Appreciation of the GreyMapp-AR program was found to be significantly higher in students studying biomedical sciences as compared to students studying medicine ($P < 0.011$). Other components and scores did not show significant differences between student groups. Students expressed that AR was beneficial in increasing their motivation to study subcortical structures, and that AR could be helpful and motivating for preparing an anatomy examination. This study suggests that students are motivated to study neuroanatomy by the use of AR, although the components that make up their individual motivation can differ significantly between groups of students.

KEYWORDS

augmented reality, biomedical sciences education, gross anatomy education, medical education, medical student, motivation survey, undergraduate education

Drs. Anne-Marie van Cappellen van Walsum and Dylan J. H. A. Henssen contributed equally as senior authors.

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INTRODUCTION

Anatomy education has traditionally been facilitated by the study of cadavers (McLachlan and Patten, 2006). However, substantial financial, logistical, and ethical constraints are attached to the use of cadavers, as it can be difficult for medical facilities to obtain and maintain cadavers (McLachlan and Patten, 2006). In addition, a growing number of students and curricular changes (Frenk et al., 2010) have resulted in less time dedicated to anatomy education (Drake et al., 2009; Louw et al., 2009; Bergman et al., 2011), which has resulted in a deterioration in the knowledge of anatomy in junior doctors (Farey et al., 2018). This decline in anatomy education in (bio) medical sciences is unacceptable, because it can prove hazardous not only to the medical profession but also to patients at large (Singh et al., 2015). The majority of junior medical doctors use anatomical knowledge at all phases of consultation but use it most prominently during the physical examination (Sbayeh et al., 2016).

The challenges of declining knowledge of anatomy have propelled the exploration of innovative technologies in anatomy teaching. These explorations have prominently included augmented reality (AR) and virtual reality (VR). Both AR and VR have overcome the constraints of cadaver-based teaching while providing an immersive experience for the learners. When using VR, the user is fully immersed in a synthetic environment which mimics properties of the real world by using sensory (visual/acoustical) and motor (motion) feedback (Bin et al., 2020). Dedicated VR systems often use high-resolution, high refresh rate head-mounted displays, stereo-headphones, and motion-tracking systems. AR, on the other hand, uses a camera and screen (e.g., a tablet) in order to overlay a digital model onto real world. With AR, the learner is able to interact with both the virtual model and elements of the real world (Billinghurst, 2002).

Many publications have shown that AR and VR techniques are capable of promoting intrinsic benefits such as increased learner immersion and engagement (Moro et al., 2017; Bork et al., 2019) and require less student cognitive effort (Allen et al., 2016; Cheng 2018; Bork et al., 2019). Conversely, a 2002 study claimed that computer-based anatomy models offers minimal advantages, especially for students with lower visual-spatial abilities who could be disadvantaged (Garg et al., 2002). Others found that students prefer these new teaching methods because they are considered to be interactive, engaging, and widely available (Shen et al., 2008; Huang et al., 2010; Drapkin et al., 2015). These studies used various AR tools, including MagicBook (Küçük et al., 2016), *The Cerefy[®] Atlas of Cerebrovasculature* (Nowinski et al., 2005, 2009a, b, c), and screen-based three-dimensional (3D) tools (Pani et al., 2013; Allen, et al., 2016). In 2020, the first study of learning with a screen-based AR tool called GreyMapp-AR was published (Henssen et al., 2020). GreyMapp-AR is an easily accessible smartphone or tablet applications that allows students to navigate between a screen-based 3D model and the AR environment to facilitate the study of subcortical grey matter structures, white matter tracts, and the ventricular system (Figure 1) (Henssen and De Jong, 2021).

Yet, the effect of GreyMapp-AR and other AR tools on student learning motivation for learning neuroanatomy and broader

anatomical subjects has yet to be explored. In addition, factors that influence motivation in AR teaching contexts have not been identified. Extensive review of the motivational literature revealed four clusters of motivational concepts that have to be met in order for motivation to manifest in learners (Keller, 2010). The first concerns attention, thus teaching methods should stimulate and sustain curiosity. The second cluster pertains to relevancy to the learner where the learner has to believe that teaching methods and setting will relate to personal goals or motives. The third group describes the learner's confidence in their ability to learn effectively. Finally, students must experience satisfaction with the learning process and experience to ensure the continuation of the desire to learn (Keller, 2010).

To purposefully implement AR in anatomical education, the effects of this innovative technology on students' motivation must be described. For this reason, qualitative and quantitative analysis was performed to gauge student motivations for studying anatomy when using a novel AR program. Additionally, it has been hypothesized that motivation components differ in sex and study choice. Moreover, face-to-face interviews have been conducted to distill common experiences qualitatively from students. This study investigated qualitatively and quantitatively the different elements of motivation engaged during learning neuroanatomy when using GreyMapp-AR application.

MATERIALS AND METHODS

Participants

This study was conducted at the Faculty of Medical Sciences (Radboud University Medical Center) at Radboud University in Nijmegen, the Netherlands. In the Netherlands, basic sciences, including anatomy, are primarily taught during the bachelor's program in medical and biomedical sciences curricula. Second-year bachelor's students from medicine and biomedical sciences were recruited after their first station-based gross anatomy session in the dissection rooms for study neuroanatomy. Therefore, students had visited the dissection rooms prior to these sessions, but they had not studied brain specimens. During the second year of the bachelor's program at Radboud university, all students ($N = 278$), including medical students ($N = 204$) and biomedical sciences students ($N = 74$), received 15 hours of neuroanatomy education, 10 hours of individual assignments, and 2 hours of lectures. All students then received educational assignments in the dissection rooms during two-hour laboratory session (Radboud Health Academy, 2019).

Materials and practice room

In the dissection rooms, student-centered practical assignments with teacher-written instructions helped students study prosected specimens, cross-sections, and plastic models. Plastinated white matter prosections (Arnts et al., 2014) and atlases were also available for students

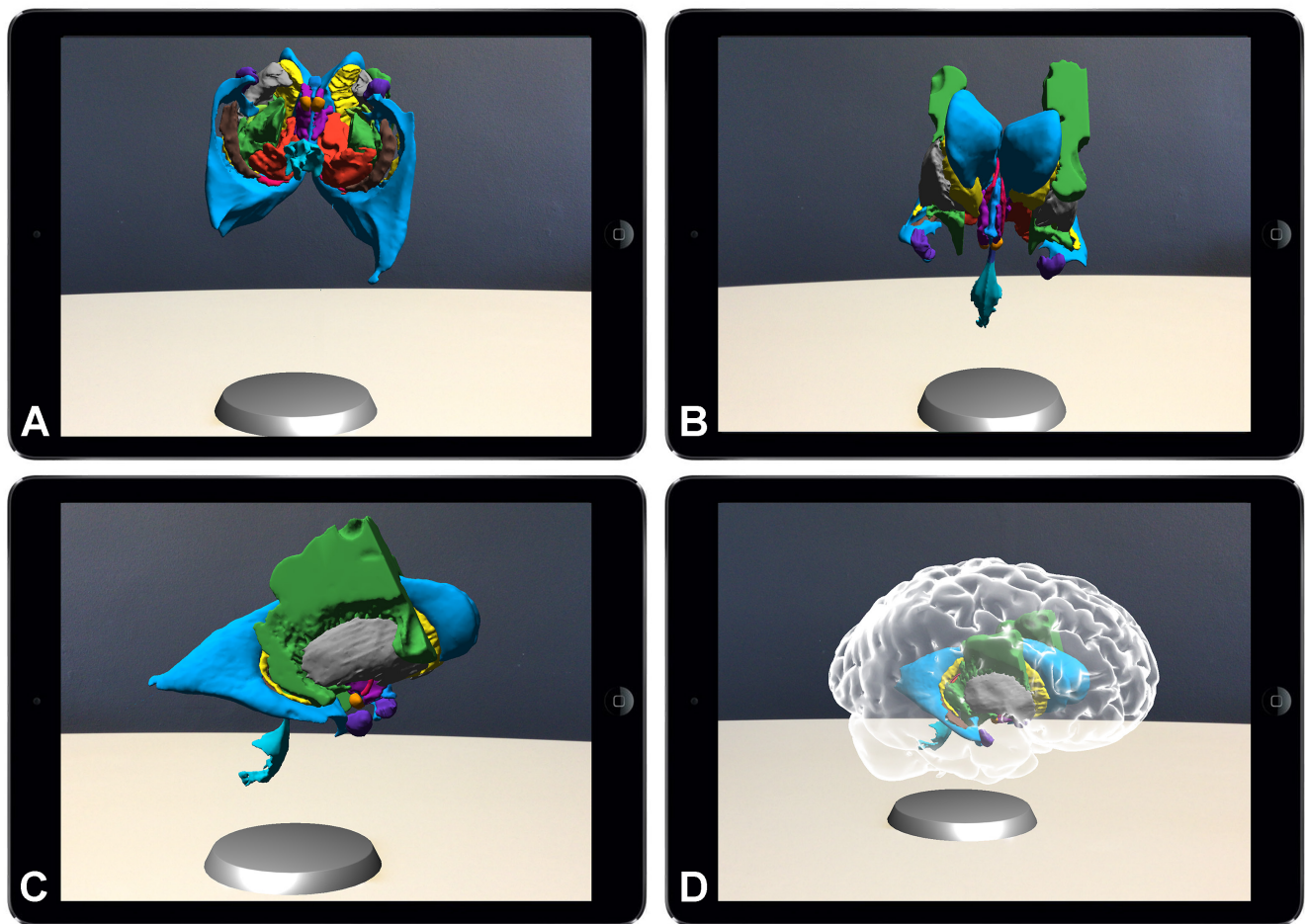


FIGURE 1 Examples of screen captures from the GreyMapp-AR application. The cortical outline in the first three screen captures have been removed to visualize the models of the subcortical structures and ventricles. (A) Inferior view; (B) anterior view; (C) right lateral view; and (D) the cortical outline of the brain has been made transparent to allow the learner to view subcortical structures (anterolateral view). The model is comprised of the ventricles, basal ganglia, limbic system, and part of the internal capsule. (A) Inferior view; (B) anterior view; and (C) right lateral view

in the dissection rooms. Study materials were distributed over five different stations, one was dedicated to working with GreyMapp-AR on tablets. The study materials consisted of questions that quiz students on their anatomical knowledge by asking them to find specified structures.

Study design of the quantitative measurements and the contents of the instructional measure of motivation survey

Students participated voluntarily in this cross-sectional study and were recruited through announcements in the dissection rooms. At the dissection room sessions, students could sign up for the experiment, after reading the information letter. Students could sign up for two elements. The first element required that the students filled out the instructional measure of motivation survey (IMMS), directly after their learning session in the dissection rooms. The IMMS was designed to measure the four motivational goals for learning (i.e., attention, relevance, confidence, and satisfaction)

(Keller, 1987, 2010). The version of the IMMS used in this study is provided in the Supplemental Material File 1. The IMMS is a 36-item survey consisting of four components (i.e., attention, relevance, confidence, and satisfaction). According to Keller (2010) “each of the four components can be used and scored independently.” “Attention” describes a tool's ability to elicit perceptual arousal, activate inquiry, and incorporate a range of media to meet learners' varying needs. “Relevance” pertains to the immediate applicability or future usefulness (i.e., goal orientation) and reflects congruence between the learners' needs and the presented tool. “Confidence” considers whether the tool provides guidance and/or feedback that was based on learning requirements and meaningful opportunities for successful learning. “Satisfaction” expresses learners' experiences with (positive) outcomes, unexpected rewards, and is based on reinforcement/acknowledgment of the learners' experiences. It is therefore a reflection of the intrinsic reinforcement, extrinsic rewards, and consistent standards that define success (Figure 2). The total score of the IMMS can be used to measure motivation. Since there are no norms for this survey,

there were no benchmarks for whether the motivational scores were low or high. The maximum score of the IMMS was 180 points. Maximum scores of the subscales (i.e., attention, relevance, confidence, and satisfaction) were 60, 45, 45, and 30 points, respectively (Loorbach et al., 2015).

The second element consisted of students participating in a qualitative, face-to-face interview. During this interview, the students' experiences and perceptions of using AR tools and the effects on their motivation for learning was assessed qualitatively and coded into common themes seen across students.

Study design of the qualitative measurements and recruitment of interviewees

After the session in the dissection rooms and reading the information letter, students who were willing to participate filled out the informed consent form, which permitted the researchers to use their IMMS data. In the information letter, students were asked to send an email to one of the investigators (either A.v.C.v.W. or D.H.) if they were interested in participating in an interview. In addition, purposive sampling was enacted in the student population by a peer student and junior researcher (K.B.) in order to include both the motivated and less motivated students within this study. After informed consent, the IMMS was provided for them to answer.

A new information letter was sent to the students and prior to the interview, a new informed consent form was signed.

Face-to-face, semi-structured in-depth interviews were held to obtain detailed insights into the experienced motivation of students when working with GreyMapp-AR. The topic list was derived from discussions between the researchers. The topic list included: (1) functionality, (2) experiences, (3) advantages, (4) disadvantages, (5) the role of AR in anatomical education, (6) the role of AR in the dissection rooms specifically, (7) self-examination with AR, and (8) motivation to work with AR. An inductive iterative process was performed during the interviews using the constant comparative method which indicating that the interview could be steered in a different direction when a new topic arose. A tablet or smartphone with GreyMapp-AR was brought to students in order to refresh their memory on the specifics. The interviewer (D.H.) conducted the interviews as near to normal conversation as possible by using open-ended questions. Participants were encouraged to express their feelings and to elaborate on aspects that they considered important. When answers were unclear to the interviewer, additional questions were asked to ensure a clear understanding of the participants. The interviews were audio-recorded and transcribed verbatim. Participants were included until saturation was achieved, after which two additional interviews were planned.

Qualitative assessment

The audio-recording of each interview was transcribed verbatim and analyzed using direct content analysis by two researchers

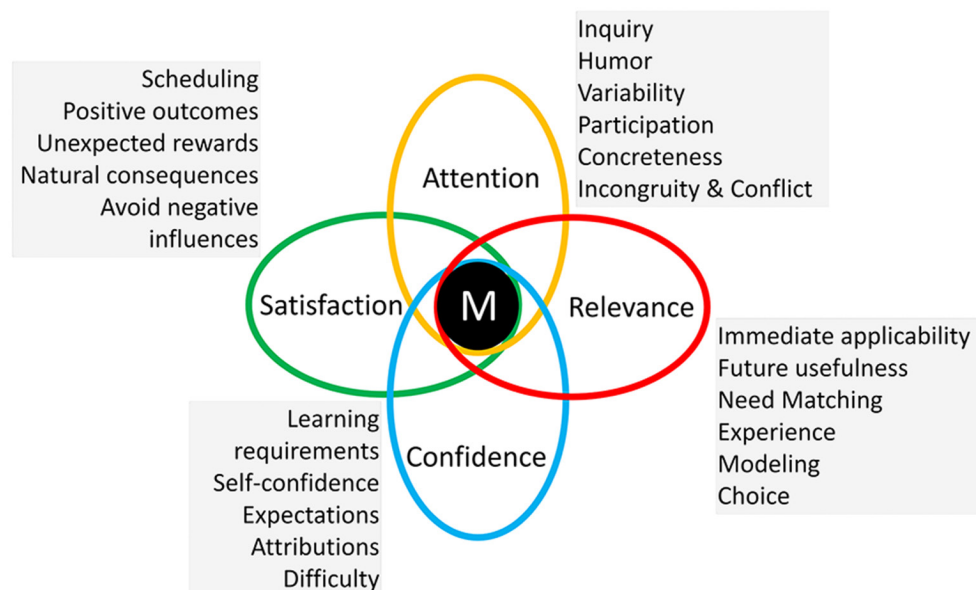


FIGURE 2 Attention, relevance, confidence, and satisfaction (ARCS) model as proposed by Keller (1987, 2010). Review of the motivational literature by Keller led to the clustering of four motivational concepts which are depicted in this figure. These concepts have to be met in order for motivation to be manifested among learners. The first goal concerns attention, as a teaching method should stimulate and sustain people's curiosities and interests. The second goal concerns the learner's belief that the learning method and setting is related to personal goals or motivations (relevance). The third goal entails the students' confidence in their ability to learn effectively. Together, attention, relevance, and confidence should be adequately addressed in order for people to be motivated to learn. Finally, students must experience a feeling of satisfaction with the learning process to ensure a continuation in the desire to learn (Keller, 2010)

independently (D.H. and K.B.). The coding process was performed using ATLAS.ti software, version 8.2.29.0 (ATLAS.ti Scientific Software Development GmbH., Berlin, Germany). The interviews were coded by reading the interviews and distilling the meaning of the words into specific coded themes (e.g., enhancement to the education process, user experience, insightful). A codebook was developed to organize the interviews into categories and themes. In addition, discrepancies in the coded language were periodically discussed and emerging patterns were debated. During the deductive process, discrepancies and interpretations were regularly discussed by the research team. After a consensus was reached, the codes were then grouped into families in order to analyze the emergent of patterns.

Statistical analysis

The statistical package SPSS Statistics, version 25 (IBM Corp., Armonk, NY) was used for the statistical analyses of data of the IMMS questionnaire. Descriptive statistical analyses were represented as mean with \pm standard deviation (\pm SD) if normally distributed, or as a median with range (minimum-maximum) if not normally distributed. Paired student's *t*-tests were applied to compare mean test scores between the different groups of students. When data were not specified, these participants were excluded from the corresponding analyses. Statistical significance was assumed when $P < 0.05$. Cronbach's alpha test was used to assess the internal consistency (i.e., validity and reliability) of the IMMS scores. Internal consistency is generally regarded acceptable when ≥ 0.7 .

RESULTS

Participants

The IMMS surveys from 222 students provided substantial motivational data, permitting analysis of the internally valid questionnaire. Participants (74 males/128 females/20 unspecified) had a

mean age of 19.7 ± 1.4 years. In total, 131 participants (59.0%) studied medicine and 32 of the participants (14.4%) studied biomedical sciences. The study direction was not specified in 59 cases (26.6%). This study yielded a total IMMS score of 131.0 (± 16.6) points. Attention was scored at 45.9 (± 6.2) points. Students scored 31.2 (± 4.3) points on the Relevance component. Confidence was measured to be 32.3 (± 4.9), and finally, the mean Satisfaction was measured to be 21.1 (± 4.0) points (Table 1). The IMMS questionnaire was found to have an internal validity of $\alpha = 0.857$.

Males show higher relevance score

When comparing males and females, there were no significant differences in the total Attention, total Confidence, and total Satisfaction scores ($P < 0.428$, $P < 0.429$, and $P < 0.209$, respectively). In the group of 74 males and 128 females, from both study directions, no significant difference was found in the total IMMS Questionnaire scores between sexes ($P < 0.171$). However, the Relevance subscore was significantly higher in males when compared to females ($P < 0.024$; Figure 3A).

Biomedical sciences students show higher confidence scores

Students studying biomedical sciences scored higher on Confidence based on the IMMS questionnaire. From the 222 participants, 163 reported their study direction. Of these, 131 studied medicine and 32 biomedical sciences. When comparing their IMMS scores and subscores, no significant difference in total IMMS scores was noted for students in differing study directions ($P < 0.602$). However, when comparing the two groups of students (medical vs. biomedical sciences), students studying biomedical sciences reported significantly higher total Confidence scores when using GreyMapp-AR ($P < 0.011$; Figure 3B). The other components did not show discrepancies between the two groups of students.

TABLE 1 Total scores of the instructional measure of motivation survey questionnaire and its different components

Characteristics	Attention score	Relevance score	Confidence score	Satisfaction score	Total IMMS score
Mean (\pm SD)	45.9 (± 6.2)	31.7 (± 4.3)	32.3 (± 4.9)	21.1 (± 4.0)	131.0 (± 16.6)
Males; $n = 74$	46.1 (± 5.8)	32.6 (± 4.2)	32.6 (± 4.6)	21.5 (± 3.6)	132.9 (± 14.9)
Females; $n = 128$	45.4 (± 6.4)	31.2 (± 4.4)	32.1 (± 4.9)	20.8 (± 4.3)	129.5 (± 17.4)
Medical students $n = 131$	45.3 (± 6.3)	31.3 (± 4.5)	31.7 (± 4.7)	21.0 (± 4.3)	129.4 (± 17.1)
BMS students; $n = 32$	46.7 (± 6.6)	32.1 (± 4.2)	34.1 (± 4.3)	21.1 (± 3.9)	133.9 (± 15.3)
Median [Min–Max]	47.0 [26.0–59.0]	32.0 [19.0–44.0]	32.0 [12.0–43.0]	21.0 [8.0–30.0]	132.0 [75.0–168.0]
Males; $n = 74$	47.5 [32.0–59.0]	32.0 [22.0–44.0]	33.0 [22.0–43.0]	22.0 [9.0–28.0]	133.0 [93.0–167.0]
Females; $n = 128$	46.0 [26.0–57.0]	31.0 [19.0–44.0]	32.0 [12.0–41.0]	21.0 [14.0–28.0]	131.0 [75.0–168.0]
Medical students $n = 131$	46.0 [28.0–57.0]	31.0 [19.0–44.0]	32.0 [12.0–41.0]	22.0 [8.0–30.0]	131.0 [75.0–167.0]
BMS students; $n = 32$	48.0 [26.0–57.0]	31.0 [23.0–44.0]	34.0 [25.0–43.0]	21.0 [10.0–29.0]	134.0 [97.0–168.0]

Note: All scores are reported in points. Total number of participants ($n = 222$). Abbreviations: BMS, biomedical sciences; IMMS, instructional measure of motivation survey; Min–Max, minimum–maximum range.

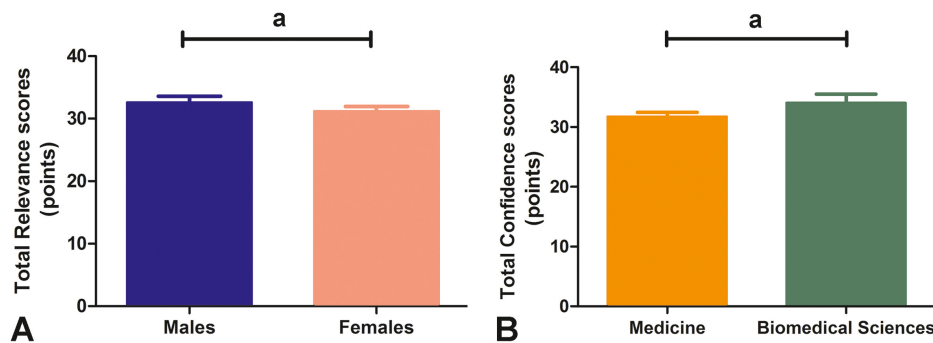


FIGURE 3 Relevance and confidence scores based on the instructional measure of motivation survey (IMMS). Males show higher scores on relevance, whereas students in biomedical sciences show higher scores on confidence. (A) Comparison of the total relevance scores between males and females. Score ranges from 0 to 45 points; (B) Comparison of the total confidence scores between the medical and biomedical sciences students. Score ranges from 0 to 45 points; Total number of participants ($n = 222$); $^aP < 0.05$

Results from the face-to-face interviews

Three themes on the use of GreyMapp-AR to study neuroanatomy were derived from the qualitative interviews. Nineteen students participated in an audio-recorded, face-to-face interviews which were later coded. Participants (8 males/11 females) had a mean age of 19.6 ± 0.8 years. Seventeen of participants (90%) studied medicine, and the remaining two of the participants (10%) studied biomedical sciences. Interviews lasted for a maximum of 25 minutes. Three themes arose from the face-to-face interviews: (1) Learning neuroanatomy by combining GreyMapp-AR with specimens, (2) Technical disadvantages of GreyMapp-AR that hindered learning, and (3) GreyMapp-AR as a preparatory tool for the dissection room sessions and/or as examination preparation.

Theme 1: Learning neuroanatomy by combining GreyMapp-AR with specimens

Students expressed satisfaction with regard to the use of GreyMapp-AR in combination with specimens. By combining these two learning sources, students were capable of comparing the different learning assistances. Particularly, students stated that the well-defined borders of neuroanatomical structures and their colorful representation in GreyMapp-AR helped them to distinguish different structures and functional units. After analyzing the qualitative interviews, students were found to work with GreyMapp-AR either before or after they worked with specimens. This was due to the organization of the practical assignment. However, regardless of the sequence of GreyMapp-AR and specimens, GreyMapp-AR aided in their elucidation of subcortical neuroanatomy. In general, students expressed frustration after studying the vaguely subcortical structures in specimens. Students who worked with GreyMapp-AR before working with specimens expressed that the application helped them to delineate the subcortical structures in specimens. Students furthermore mentioned that they used GreyMapp-AR, although briefly, to position the projected

specimens in an anatomical orientation, which aided in specimen navigation. One student expressed that GreyMapp-AR functioned as an explanatory tool when the teacher was busy answering others' questions.

"We used GreyMapp-AR at the dissection rooms after having studied the anatomical drawings and cross-sectional anatomy of the basal ganglia and I think that was just perfect. Some structures were really not visible on the cross-sections, let alone their three dimensional structures or individual relationships. Then we switched to GreyMapp-AR and then you thought: "Oh, that is how it should look like!". [Participant 1]

"GreyMapp-AR helped me to understand the three dimensional structure of the brain. I really enjoyed using it, although I am really bad at studying anatomy". [Participant 9]

"The combination of GreyMapp-AR with specimens was really fun. You could go back and forth to see which structures were brightly colored in the application and then correlate that with the corresponding structure within the brain specimens". [Participant 19]

Theme 2: Technical disadvantages of GreyMapp-AR that hindered learning neuroanatomy

Students experienced problems while using GreyMapp-AR. They conveyed that the AR environment was difficult to operate stably, meaning that small movements made by the learner caused the displayed model to disappear. Students had to shift their focus on properly positioning the tablet, rather than on the displayed model. This averted learning temporarily, as students needed time to fine-tune the function of the application on the tablets. Subsequently, when

familiarization had taken effect, students expressed the benefits of the AR environment. Additionally, some students suggested adding a quizzing feature to GreyMapp-AR as they found it difficult to incorporate the assignments into GreyMapp-AR and would like to have a more interactive way of studying neuroanatomy.

"The digital projection of GreyMapp-AR was unstable when moving the tablet". [Participant 5]

"I must admit, I really was not that well-prepared when starting the practical assignments at the dissection rooms. Therefore, I thought the assignments were difficult and I could not really answer all of them when using GreyMapp-AR". [Participant 11]

Theme 3: GreyMapp-AR as a preparatory tool for the session at the dissection rooms and/or as a preparation for the examination

Students conveyed that they would like to use GreyMapp-AR as preparation for dissection room activities. With the exception of one student, all students expressed that preparation without directive assignment questions would be too difficult and random, which would cause them to learn ineffectively. Thus assignments that utilized GreyMapp-AR is needed. Multiple students stated that they would like to use GreyMapp-AR as a preparation for their examination because it was interactive, easy, and fun to use. Contrary to other materials presented at the dissection rooms, GreyMapp-AR could be used at home and provides 3D model in contrast to two-dimensional (2D) anatomical atlases. Therefore, students expressed that using GreyMapp-AR would increase their attention and learning achievement as a preparatory tool. Students also expressed that applications like GreyMapp-AR appealed to them, more than video-recorded sessions and/or E-learning modules due to the interactive nature of GreyMapp-AR. One participant disclosed that he would use GreyMapp-AR as an easy learning tool while studying the anatomy of the brain from an anatomical atlas. Nevertheless, this desire was not expressed by every participant. However, GreyMapp-AR enabled students to create their own anatomical figures by turning the anatomical model in any desired position after which the students could save by taking a screenshot with their tablet. Customization could have provided students with the freedom to find their way through the complex anatomy of the brain at their own pace.

"My baseline motivation to study neuroanatomy was high, although I think GreyMapp-AR really contributed to increasing my motivation to study. I thought it would have been a great preparation tool to prepare for my anatomy examination" [Participant 4].

"A quizzing feature would have been superb for me!" [Participant 13]

DISCUSSION

This study demonstrated that (1) males found GreyMapp-AR more relevant than females, (2) students studying biomedical sciences were more confident when working with GreyMapp-AR as compared to medical students, and (3) qualitative interviews revealed a number of interesting themes related to motivation as expressed by students after working with AR.

Gender differences when using augmented reality tools

Males were shown to have a significantly higher total score on the Relevance component as compared to females. This indicates that, for males, GreyMapp-AR was more closely matched to their personal objectives, needs, and motives. Simultaneously, this suggests that males were more familiar with the presentation of the AR content, stemming from the fact that they were more prone to intuitively explore GreyMapp-AR. This might be caused by the male tendency to intuitive explorations (Beltz et al., 2011). Differences in interest between the sexes could play a significant role, as the literature suggest males tend to gravitate toward things, while women find people more interesting (Su et al., 2009), which was hypothesized to be influenced by prenatal testosterone (Beltz et al., 2011). Another possible explanation for the here described gender differences could be the earlier described tendency of lower visual-spatial abilities of females as compared to males (Garg et al., 1999a, b, 2002; Gonzales et al., 2020). As GreyMapp-AR uses monoscopic visualization of 3D anatomy, this could have had a disadvantageous effect on students with lower visual-spatial abilities (Bogomolova et al., 2020). This could have explained why female students found GreyMapp-AR less understandable, although this was not tested within the present study. In addition, there are two hypotheses on how visual-spatial abilities could influence cognitive load when using 3D models for anatomy education. Ability-as-compensator (AAC) and ability-as-enhancer (AAE) have been proposed. AAC favors students with low visual-spatial abilities, while AAE favors students with better visual-spatial abilities (Huk et al., 2006). Possibly, the effect of AAE has been observed, as males who have higher mental rotation test (MRT) scores found the AR models to be more relevant, while the females showed less relevance. Other studies in the field of AR in neuroanatomical education did not report such differences, although some studies used MRT-based stratification, occasionally in combination with the gender, in an attempt to create similar groups (control vs. intervention) with regard to visual-spatial ability (Bork et al., 2019; Henssen et al., 2020). Gender differences in the use of AR in general remain an understudied field of research. In 2013, Hou and Wang reported that AR helps both male and female trainees learn, and that AR training is equally effective for both male and female trainees (Hou and Wang, 2013). Dirin et al. (2019) showed that females were more enthusiastic about using of novel technologies, including AR, than male participants. Also, the user experience of these technologies triggered

more positive emotions among females than males (Dirin et al., 2019). Prior research on gender differences in the use of mobile technologies in general, however, could also provide some insights in the phenomenon observed in the present study. It was found that males had higher perceived ease of use and fun when using mobile technology as compared to their female peers (Hamza and Shah, 2014). Riquelme and Rios (2010), on the other hand, reported that females had higher perceived ease of use as compared to males when using mobile technology. The same mobile technology, however, had a stronger effect on perception of usefulness on male respondents (Riquelme and Rios, 2010), which is in agreement with current results.

Feeling confident with augmented reality tools

When comparing the two groups of students (medical vs. biomedical sciences), it was found that students studying biomedical sciences appreciated GreyMapp-AR with significantly higher total Confidence scores. This might be explained by the fact that students studying Biomedical Sciences tend to be more research oriented, whereas medical students learn by using a more practical and patient-oriented approaches. These differences in interest could explain the higher confidence, as this interest translates into engagement and learning, which causes biomedical students to feel more comfortable when working with AR features. This might be a big factor in deciding how intuitively students gravitate toward a more high-tech innovation. Further research is warranted to investigate this hypothesis. However, no significant differences were found between students studying Biomedical Sciences and medicine on the total IMMS scores. This indicates that different students can see varying advantages and disadvantages when working with AR features. This agrees with AR work carried out by others (Hou and Wang, 2013; Cabero-Almenara et al., 2019).

Motivation and augmented reality tools in education

In the early 2010s, various studies on AR in different fields have shown improvements in motivation, interactivity, and learning of study material (Liu and Chu, 2010; Iwata et al., 2011; Jara et al., 2011; Di Serio et al., 2013; Erbas and Demirer, 2019). Based on the anatomical literature, it was expected that GreyMapp-AR would be attractive to students and that the effectiveness of learning processes would improve (Lee, 2012), thus increasing students' motivation to study neuroanatomy (Shen et al., 2008; Huang et al., 2010). Three articles explored the potential of AR to motivate learners to study anatomy as a primary outcome. Kugelmann et al. (2018) reported that 62% of their respondents noticed that AR enhanced their motivation to studying anatomy. However, no statistical analyses could be performed (Kugelmann et al., 2018). Another study showed that learners working with AR reported to be motivated to study anatomy significantly more than students receiving standard sessions with lectures, slides, and video recordings of cadaveric material. However, this study is limited by the fact that AR was hands-on, whereas the other materials constituted of more

passive forms of learning (Ferrer-Torregrosa et al., 2015). Another paper by the same group suggested that AR reinforced motivation to study anatomy (Ferrer-Torregrosa et al., 2016). Several other studies investigated various forms of student motivation as second or tertiary outcome measures. Allen et al. (2016) used a qualitative questionnaire to investigate trends in participants' subjective attitudes toward different learning modalities, including AR. They showed that students felt confident that learning with 3D models (including AR) could help them to understand anatomical concepts. In addition, most of the respondents would encourage the development of these learning sources (Allen et al., 2016). Küçük et al. reported that interviews with students showed that they thought that more permanent learning was achieved in a shorter time by using AR (Küçük et al., 2016). In the study of Moro et al. (2017), they found no differences between groups of students working with VR, AR, or 3D screen-based learning. Another study showed that students perceived AR as a valuable tool for increasing the 3D understanding of topographic anatomy (Bork et al., 2019). Despite the evidence on motivation elicited by AR, another publication using the IMMS in a small group of students showed no differences between students' motivation when working with AR or when working with cross-sections. In the qualitative interviews of this study, students who worked with traditional study materials envied the students who did work with GreyMapp-AR. In addition, students were disappointed when they did not get the opportunity to work with GreyMapp-AR (Henssen et al., 2020). The interviews mentioned using GreyMapp-AR as a preparatory tool for examinations, implying an increase in motivation. However, one should be cautious in concluding this increase is caused by the use of AR, as these assessments tend to be strong motivators for students to study. Future research should focus on a randomized controlled trials where AR users and anatomical atlas users prepare for an anatomy examination and are then surveyed on their reported motivation during the preparatory stage. Together, the literature strongly suggests that AR could be a promising method for motivating students to study anatomy (Chen, 2019; Khan et al., 2019; Sattar et al., 2020; Soto et al., 2020). However, no such decisive conclusion can be reached in this article.

Based on the qualitative results of this study, it can be concluded that students' motivation to work with AR features to study neuroanatomy is dependent on (1) the context of learning, (2) the learning strategy of the student, and (3) the usability of the application itself. Research has shown that, in line with the constructivist theory of learning, AR creates a learner-centered environment where students construct new information based upon their previous knowledge. Students use their interactions with new environments to create meaning (Delello et al., 2015). Within this study, this context was provided at the dissection rooms where students could combine specimens and other materials with GreyMapp-AR. Qualitatively, this was described to enhance learning. Others have shown that AR's high level of interactivity enhances learning, particularly for students who learn through kinesthetic, visual, and other nontext-based methods (for an extensive overview of the evidence, please see Billingham et al., 2015). Additionally, according to the scientific literature, registration and sensing errors are two of the biggest problems in building

effective AR systems (Billinghurst and Duenser, 2012; Billinghurst et al. 2015). Errors from poorly constructed AR systems can then lead to student disappointment and negatively influence learning. In general, the expectations of learners in regard to new technical teaching methods can often be too high (Chittano and Ranon, 2007).

Future directions and possibilities

Future application of AR for educational purposes includes further integration at earlier levels of training in anatomy curricula and for practicing procedural simulation. The overarching goal of utilizing these technologies is to increase rapid mastery of anatomical concepts and techniques. Therefore, continued large-scale assessment of the effectiveness of AR in learner satisfaction, comprehension, and retention is essential. However, to ensure satisfactory integration of AR in anatomical education, student characteristics should be taken into account, as some students are more inclined toward this innovation. To date, AR has not been shown to be a viable replacement for cadaveric learning; however, it does show promise for use when cadavers are not readily available or when studying at home. AR could be a solution to the challenges presented by the current pandemic, as normal anatomy courses often requires rooms with large groups. However, more research is warranted to test this hypothesis. The clinical use of AR in patient education and perioperative planning seems additionally promising (Uppot et al., 2019).

Limitations of the study

Limitations of the present study include the heterogeneity of the sequence of GreyMapp-AR and specimens. This could have a small impact on the results. However, it must be considered a limitation as a correction for this inconsistency cannot be made in the quantitative data. Qualitatively, students expressed that this did not hinder them. This inconsistency in the sequential presentation of learning materials is inherent to the practical assignments at the Radboud University (as described by Kooloos et al., 2012). Another limitation is that the IMMS scores allow us to analyze group differences, yet no decisive conclusions could be made with the general scores, unless a control is present. Future research should focus on randomized controlled trials where the IMMS scores are compared across AR and non-AR groups. The interviews were on a voluntary basis which could bias recruitment toward students with more positive experiences. To combat this, some participants were recruited using face-to-face purposive sampling. Finally, the missing data from the questionnaires on age, study direction, and gender are additional limitations in this study.

CONCLUSIONS

Differences in confidence and relevance were observed between study direction and sex, respectively. Males found AR to be more

relevant compared to women. Medical students were found to have less confidence when using the GreyMapp-AR. Technical errors were experienced which temporarily hinder neuroanatomy learning. Therefore, these should be considered to decrease motivation to learn neuroanatomy. However, when properly functioning, students reported that they felt AR was especially useful and motivating when examining structures invisible from the outer surface of the brain (i.e., the subcortical structures that form the basal ganglia and/or the limbic system) as they were made easily visible and graspable. However, the results of this study do not elucidate students' motivation to study neuroanatomy by the use of AR. Presently, AR manifests itself as a novel way for medical students to learn anatomy, which students report positive experiences with. It could not be established that using AR ensured more motivation for studying anatomy. Students did assert that GreyMapp-AR would be beneficial when preparing for anatomy examination. However, more research is warranted to study this effect.

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ETHICS STATEMENT

This study was carried out in agreement with the Statement on the Declaration of Helsinki and the Ethical Conduct of Clinical Studies. The study was part of a broader research file, which was approved by the Netherlands Association for Medical Education (NVMO) and registered as NERB file number 2018.8.2. All participants signed informed consent forms for either part of the study.

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SUPPORTING INFORMATION

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

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