Student Perceptions and Effectiveness of an Innovative Learning Tool: Anatomy Glove Learning System

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A trend in anatomical education is the development of alternative pedagogical approaches to replace or complement experiences in a cadaver laboratory; however, empirical evidence on their effectiveness is often not reported. This study aimed to evaluate the effectiveness of Anatomy Glove Learning System (AGLS), which enables students to learn the relationship between hand structure and function by drawing the structures onto a worn glove with imprinted bones. Massage therapy students ($n = 73$) were allocated into two groups and drew muscles onto either: (1) the glove using AGLS instructional videos (3D group); or (2) paper with palmar/dorsal views of hand bones during an instructor-guided activity (2D group). A self-confidence measure and knowledge test were completed before, immediately after, and one-week following the learning conditions. Self-confidence of hand anatomy in the 3D group gradually increased (3.2/10, 4.7/10, and 4.8/10), whereas self-confidence in the 2D group began to decline one-week later (3.2/10, 4.4/10, and 3.9/10). Knowledge of hand anatomy improved in both groups immediately after learning, ($P < 0.001$). Students' perceptions of AGLS were also assessed using a 10-pt Likert scale evaluation questionnaire (10 = high). Students perceived the AGLS videos (mean = 8.3 ± 2.0) and glove (mean = 8.1 ± 1.8) to be helpful in improving their understanding of hand anatomy and the majority of students preferred AGLS as a learning tool (mean = 8.6 ± 2.2). This study provides evidence demonstrating that AGLS and the traditional 2D learning approach are equally effective in promoting students' self-confidence and knowledge of hand anatomy. Anat Sci Educ 00: 000–000. © 2014 American Association of Anatomists.

Key words: gross anatomy education; anatomy teaching; allied health professions education; innovative teaching tool; experiential learning; 3D learning; low-fidelity simulation

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INTRODUCTION

Anatomy is fundamental to health sciences education (Finnerty et al., 2010). Traditionally, teaching anatomy has involved cadaver dissection, which provides students with a three-dimensional (3D) construct of the human body (Dinsmore et al., 1999; Aziz et al., 2002; Granger, 2004; McLachlan et al., 2004, McLachlan and Patten, 2006). However, factors such as a significant reduction in the number of hours dedicated to teaching gross anatomy, fewer trained gross anatomists, and the high costs associated with maintaining a cadaver laboratory have contributed to the decline of using dissection to teach human anatomy in North America (Collins et al., 1994; Mattingly and Barnes, 1994; Jones, 1997; Drake et al., 2009). In Ontario, only one of the 24 publically funded community colleges has a cadaver laboratory (Humber College, 2013). Due to the decline of using cadavers to teach anatomy, many institutions have introduced alternative pedagogical approaches (Sugand et al., 2010).

Advances in computer technology and medical imaging have allowed for the creation of computer-generated 3D anatomical models based on cadaveric specimens (Garg et al., 1999a; Tang et al., 2010). These models have been designed specifically for anatomical education and have been used to create virtual reality applications (Nguyen and Wilson, 2009; Sergovich et al., 2010; Venail et al., 2010; Adams and Wilson, 2011). A common belief is that the multiple views presented by 3D models simulate reality more accurately and that this enhanced realism improves educational effectiveness (Garg et al., 1999b). However, empirical evidence of the effectiveness of these computer-assisted instruction applications is conflicting and sparse. For example, studies using dynamic 3D computer models have shown that providing students with multiple views of an anatomical object was not advantageous compared to only providing standardized key views (Garg et al., 1999a, 1999b, 2002; Levinson et al., 2007). In contrast, Nicholson et al. (2006) reported that the inclusion of an interactive 3D model of the inner ear in a web-based tutorial significantly ($P < 0.001$) improved medical students' understanding of structural relationships. The authors attributed the positive effect on learning in this study to the high level of interactivity of the 3D model. In a different study, Hariri et al. (2004) found that there was no difference on transfer of learning to a clinical setting when medical students studied shoulder joint anatomy using a virtual reality 3D simulator or 2D textbook images. At first glance it seems intuitive that learning anatomy using computer-generated 3D models would be advantageous over standard 2D static images. However, the effectiveness of using 3D visualizations is not consistent in the literature.

In addition to virtual reality applications, low-fidelity physical models are also used as complementary tools for teaching anatomy with the aim of providing students with an accurate representation of important spatial relationships (Gangata, 2008; Oh et al., 2009; Estevez et al., 2010; Kooloos and Vorstenbosch, 2013). Low-fidelity models tend to focus on a limited number of structures within a region, often generalize the shape and surface details of these structures, and may not closely resemble the human body (Chan, 2010; Cloud et al., 2010). For example, to reinforce spatial relationships in the femoral triangle, Zumwalt et al. (2010) described a laboratory activity in which students reconstructed the triangle onto a skeleton utilizing foam, wiring, and tubing. In a comparative study of eleven low-fidelity physical models, Chan and Cheng (2011) suggested that these models had educational value in facilitating problem solving, stimulating students' enthusiasm and participation, reducing cognitive overload, and acting as memory aids. Despite their suggested educational value, low-fidelity models have primarily been studied in the context of student feedback. For example, students rated laboratory activities such as, body painting and clay modeling as enjoyable, useful, and clinically relevant learning tools; however, the effects of these laboratory activities on knowledge acquisition was not investigated (McMenamin, 2008; Skinder-Meredith, 2010).

Anatomy Glove Learning System (AGLS) is a new low-fidelity pedagogical tool developed for teaching hand anatomy to students and clinicians in medical and allied health professions. A comprehensive understanding of hand anatomy and its relationship to function is essential to clinical practice due to the hand's central role in daily activities and the prevalence of hand pathologies (Barr et al., 2004; IWH, 2009). However, the anatomical complexity of the hand makes it a particularly challenging region for students to learn. To address this challenge, a learner-centered, kinesthetic, 3D physical learning tool was developed. AGLS is comprised of (1) a glove imprinted with anatomically correct bones that is worn on the nondominant hand of the learner and (2) video clips showing the anatomy of the hand on dissected cadaveric specimens followed by a demonstration of how to draw the structures onto the glove using colored markers. The video clips provide a narrated description of the bones and joints of the hand, attachments for intrinsic hand muscles, distal tendon attachments for anterior and posterior forearm muscles, and general nerve distributions. AGLS reviews the function of the structures drawn onto the glove and also discusses the anatomical basis of various hand pathologies. The information in the video clips is organized by muscle group (wrist extensors, thumb extensors, wrist flexors, etc.) and builds up the layers of the hand from deep to superficial. The learner can control the order in which these videos are viewed and can also stop and start the videos to control the pace of viewing and drawing.

The development of AGLS was guided by Experiential Learning Theory (ELT) in which learning is defined as a "process whereby knowledge is created through the transformation of experience" (Kolb, 1984). A common belief of experiential learning theorists is that learning is rooted in constructivism and that the core condition for learning is participation (Yardley et al., 2012). Kolb's ELT proposes that the learner develops knowledge as they progress through a four-staged cycle that consists of: concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). Learning hand anatomy using AGLS can be understood using Kolb's theoretical model. It is proposed that the learner extracts knowledge from their direct experience of drawing the structures of the hand onto the glove. Once the glove drawing is complete, the learner can visually observe the structures and assimilate their observations into their existing knowledge base. For example, if the learner has drawn a muscle over a particular joint, they intuitively understand that the muscle could produce movement at that joint. Finally, through active experimentation, the learner can confirm their predictions by manipulating their own hand in 3D space while wearing the glove. Active experimentation with the glove can become very useful for understanding the complex mechanisms of the intrinsic hand muscles. For example, as the learner draws the lumbricals onto the glove, they observe that these muscles wrap from the palmar aspect of the hand into the extensor mechanism. Once the learner has finished drawing the lumbricals onto the glove, they can then observe how these muscles produce flexion of the metacarpophalangeal joints and extension of the interphalangeal joints. A unique feature of AGLS is the glove, which allows students to actively experiment with their own hand to consolidate their understanding of hand anatomy.

The purpose of this study was to explore the relationship between the use of AGLS and students' self-perceived

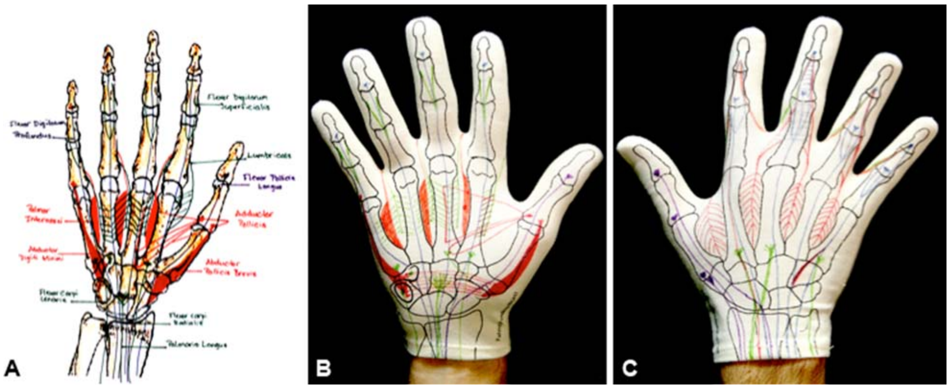

Figure 1.

Learning materials. **A**: 2D drawing activity; **B**: Palmar view of AGLS glove; **C**: Dorsal view of AGLS glove.

confidence and knowledge of hand anatomy using a pre-test/post-test/control group design. Students' perceptions of AGLS as a learning tool were also collected using a questionnaire that addressed overall learning value, usability, control, and effectiveness.

METHODS

Participants and Educational Context

All first-year massage therapy students ($n = 77$) from Humber College, Toronto, were eligible to participate. This study was integrated into the Human Anatomy course curriculum of the massage therapy program at Humber College, Toronto. This introductory course focuses on the musculoskeletal anatomy of the upper and lower limbs and takes place prior to the students starting their clinical training. The course has a total of 65 contact hours and the mode of delivery primarily consists of interactive lectures and small group learning. Students in the course did not have access to a cadaver laboratory. However, throughout the semester, students completed laboratory activities in the classroom using plastic bone, joint, and muscle models. At the time of this research study, students had completed a one-hour lecture on the bones and joints of the hand. The Research Ethics Board at Humber College approved ethics for this study and informed consent was obtained from all participants.

Learning Conditions

There were two learning conditions used in this study; a control learning condition and an intervention learning condition. In this article, the control learning condition will be referred to as the "2D group" and the intervention learning condition as the "3D group." Each learning condition is described below.

The learning material for the 2D group consisted of a short didactic lecture (15 minutes) and an instructor-guided drawing activity (60 minutes). The didactic lecture introduced the compartments of the hand, general nerve distributions, and the movements of the wrist and hand. For the drawing activity, each student was provided with a palmar and a dorsal view of the hand and distal forearm bones printed on 8.5 × 11 inch paper and a set of colored markers. Using an interactive iPad application projected onto a large screen, the instructor drew the distal tendon attachments of the anterior and posterior forearm muscles and the intrinsic hand muscles one at a time, from deep to superficial. Simultaneously, students drew the same structures onto their paper copy (Fig. 1A). As each tendon or muscle was drawn, the instructor described its function and innervation. This learning condition has been the standard educational approach used for teaching hand anatomy to massage therapy students at Humber College. It is important to note that for the purpose of this study the time dedicated to this topic was shortened to allow for student evaluation and feedback.

The learning material for the 3D group consisted of the same didactic lecture used in the 2D group (15 minutes) and the interactive AGLS (60 minutes). Each participant put the glove on their nondominant hand and made sure that the bones on the glove were aligned with their own. Using the AGLS videos, each participant drew the distal tendon attachments of the anterior and posterior forearm muscles and the intrinsic hand muscles one at a time, from deep to superficial on their glove (Figs. 1B and 1C). The AGLS videos included a demonstration of each tendon/muscle on a cadaveric specimen, step-by-step demonstration of how to draw the structure(s) onto the glove, and a summary of the function and innervation of each muscle. Participants worked in pairs at their own pace, viewing the videos on individual laptop computers to complete the AGLS (Fig. 2).

Assessments Materials

To compare the effectiveness of the 2D and 3D groups, a self-perceived confidence measure and an anatomy test were used. The self-perceived confidence measure asked participants to rank their level of confidence in hand anatomy knowledge on a 10-point Likert scale, where 1 represented "low self-confidence" and 10 represented "high self-confidence."

The anatomy test consisted of five multiple-choice and 18 short-answer questions. The questions assessed participants' knowledge of the structural relationships of the hand

Figure 2.

Students working at their own pace, in pairs, to complete AGLS.

including bones, joints, nerves, and muscles. The test also included questions on the attachments and actions of the muscles. For counterbalancing purposes, three versions of the test (A–C) were created and matched for difficulty. Since this study used a within-subjects design, three versions of the tests were created to avoid practice effects. Examples of test questions are provided in Table 1. The tests were collaboratively developed by an anatomist, a hand therapist, and a massage therapist. The course instructor did not participate in the development of the tests and was blinded to the test content.

To gather evidence for the validation for their use, tests A and B were piloted by fifteen second and third-year massage therapy students and eight registered massage therapists. The tests piloted consisted only of multiple-choice questions. The results of the pilot data indicated that the multiple-choice format of the tests was too easy and thus to avoid ceiling effects, the majority of the questions were changed to short-answer.

An evaluation questionnaire was also used to collect participants' perceptions of the AGLS as a learning tool. The evaluation questionnaire consisted of eight closed and three open-ended questions that addressed issues such as effectiveness, usability, preference, and suggestions for improvement. Closed-ended questions that addressed participants' overall impression and effectiveness of the AGLS used a 10-point Likert scale, where 1 was "not helpful" and 10 was "very helpful." Closed-ended questions that addressed usability, future use of the tool, and preference, used a 10-point Likert scale, where 1 was "strongly disagree" and 10 was "strongly agree." Of the eight closed-ended questions, only one asked participants to directly compare the two learning conditions. Thus, a comparison of the participants' perceptions of the two learning conditions is limited.

Study Protocol

The entire study protocol is outlined in a flow chart in Figure 3. All aspects of this study were completed in a classroom setting and the timing of this study was aligned with the course curriculum. Upon consent, participants provided demographic information (gender, handedness, and previous exposure to hand anatomy) and completed baseline measures including the self-perceived confidence measure and the anat-

Table 1.

Examples of Anatomy Test Questions

Test A	Test B	Test C
What muscles are responsible for abduction of the finger metacarpophalangeal joints?	What muscles are responsible for adduction of the finger metacarpophalangeal joints?	The palmar interosseous muscles produce which action at the metacarpophalangeal joints?
Over which aspect of the hand would you palpate flexor digiti minimi? a. Palmar–Medial b. Palmar–Lateral c. Dorsal–Medial d. Dorsal–Lateral	Over which aspect of the hand would you palpate abductor digiti minimi? a. Palmar–Medial b. Palmar–Lateral c. Dorsal–Medial d. Dorsal–Lateral	Over which aspect of the hand would you palpate adductor pollicis? a. Palmar–Medial b. Palmar–Lateral c. Dorsal–Medial d. Dorsal–Lateral
 What joint is indicated by the circle above (be specific)?	 What joint is indicated by the circle above (be specific)?	 What joint is indicated by the circle above (be specific)?

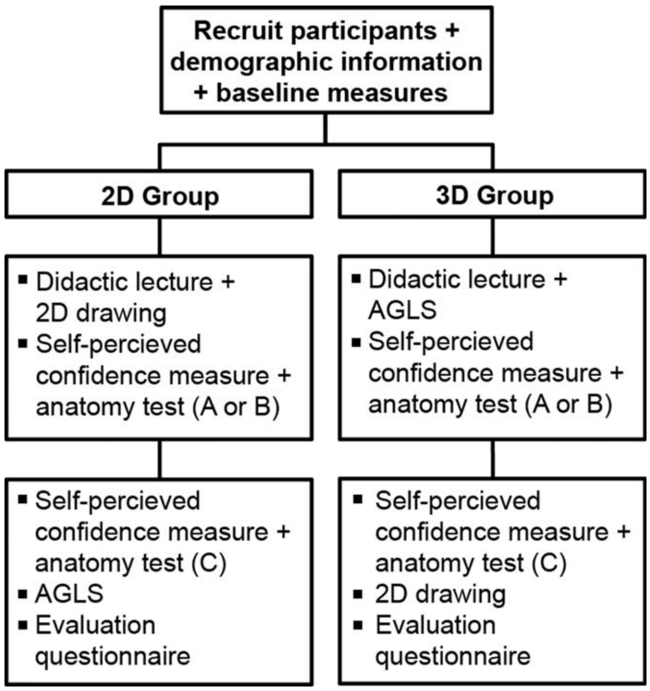

Figure 3.

Study protocol. Note that baseline measures include the self-perceived confidence measure and the anatomy test (**A** or **B**).

omy test (test A or B). In both course sections (section 1 and 2), half of the participants completed test A and half of the participants completed test B. Participants were allocated into the 2D and 3D learning conditions based on their assigned course section. A coin was flipped one day before the learning conditions to determine which section would be the 3D group. Seven weeks after baseline testing, participants completed either the 2D or 3D learning condition immediately followed by the self-perceived confidence measure and the anatomy test. Those who had completed test A at baseline took test B after the learning condition, and vice versa. Participants in both learning conditions were not permitted to take home their completed learning tool (paper or glove) until after the study was complete. One-week following initial learning, all of the participants returned to the classroom and were given 15 minutes to review the anatomy of the hand using their completed learning tool (paper or glove). Following this review opportunity, participants in both groups completed the self-perceived confidence measure and the anatomy test (test C).

After these assessments were completed, participants in the 2D group completed AGLS and those in the 3D group completed the instructor-guided drawing activity. Following these learning activities, participants in both groups evaluated the effectiveness of AGLS by completing the evaluation questionnaire.

Data Analysis

Fischer's exact tests were used to determine if there were different distributions of demographics (gender, handedness, and previous exposure to hand anatomy) between groups. For each participant, the number of correct responses on the anatomy tests was calculated. Anatomy knowledge and self-perceived confidence for all participants were analyzed separately using a 2×3 repeated measures ANOVA with the learning group (2D vs. 3D) as the between-subject factor and time (before, immediately after, one-week later) as the within-subject factor. To measure reliability, internal consistency (Cronbach's alpha) was calculated for each test. Quantitative data were analyzed using SPSS statistical software package, version 20 (SPSS, Chicago, IL).

The mean and standard deviation values were calculated for participants' responses to the closed-ended questions on the evaluation questionnaire. To measure reliability of the evaluation questionnaire, internal consistency (Cronbach's alpha) was calculated. Open-ended responses were analyzed using a line-by-line open coding method with NVivo software, version 10 (QSR International Pty Ltd., Doncaster, VIC, Australia). The coding scheme was based on knowledge of the topic and familiarization with the data. Summary reports of the themes were generated to illustrate the findings.

RESULTS

Demographics

Ninety-five percent of the class consented to participate in this study ($n = 73$). Of the 73 participants, 64 (88%) completed all aspects of this study. The nine participants who did not complete the study were either not present on the day the study took place or had withdrawn from the course. The 2D group consisted of 10 males and 20 females and the 3D group consisted of 13 males and 21 females. Twenty-nine (97%) of the participants in the 2D group and 29 (85%) of the participants in the 3D group were right-handed. The number of participants in the 2D and 3D group who had previous exposure to hand anatomy at the community college or university level was 8 (27%) and 9 (26%), respectively. Fischer's exact tests showed that the 2D and 3D groups were comparable in gender, handedness, and previous exposure to hand anatomy at the community college or university level ($P > 0.05$).

Self-Perceived Confidence and Anatomy Knowledge

Participants completed a self-perceived confidence measure and an anatomy test before, immediately after, and one-week following the learning conditions. As shown in Figure 4, participants' self-perceived confidence of hand anatomy in the 2D group began to decline one-week following initial learning (3.2 ± 2.1, 4.4 ± 1.6, and 3.9 ± 1.4), whereas self-perceived confidence in the 3D group gradually increased (3.2 ± 1.6, 4.7 ± 1.4, and 4.8 ± 1.3). The ANOVA showed a significant main effect of time F (1, 63) = 23.8, $P < 0.001$, and post hoc t-tests confirmed that self-perceived confidence significantly improved immediately after learning ($P < 0.001$). No difference was observed for self-perceived confidence between the 2D and 3D groups, F (1, 63) = 1.85, $P = 0.18$, and no significant interaction was observed between time and group, F (1, 63) = 3.08, $P = 0.08$.

The results of the baseline anatomy test demonstrate that both groups had almost no clinical anatomy knowledge prior

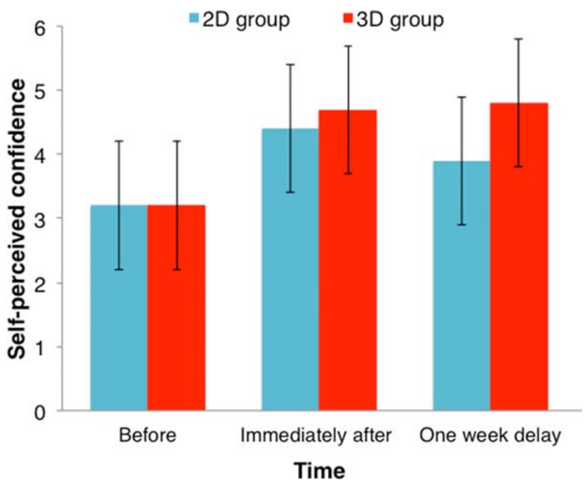

Figure 4.

Participants' self-perceived confidence. Self-perceived confidence improved for both groups after the 2D and 3D learning conditions, F (1, 63) = 23.8, $P <$ 0.001.

to learning conditions. At baseline, the 2D and 3D group mean scores were 1.5 ± 1.8 out of 23 and 0.97 ± 1.3, respectively. The results on the anatomy test for the 2D group immediately after learning and one-week later were 9.6 ± 3.9 and 9.7 ± 4.3 out of 23, respectively. The results on the knowledge test for the 3D group immediately after learning and one-week later were 8.6 ± 3.3 and 8.7 ± 3.7 out of 23, respectively. The ANOVA showed a significant main effect of time F (1, 63) = 240.4, $P < 0.001$, and post hoc t-tests confirmed that knowledge significantly improved immediately after both learning conditions ($P < 0.001$). Similar to the self-confidence measure, there was no significant difference observed for knowledge between the 2D and 3D groups F (1, 63) = 1.92, P = 0.17, and no interaction was observed between time and group, F (1, 63) = 0.26, P = 0.61. Although the gains in knowledge for both groups appears to be relatively small, it is important to note that this was participants' first exposure to hand anatomy and participants were instructed not to study the material until all testing was complete. All three versions of the anatomy test were found to be reliable. Cronbach's alpha for tests A, B, and C was 0.90, 0.85, and 0.73, respectively.

Evaluation of AGLS

Closed-ended questions revealed that participants perceived AGLS to be a positive learning experience, with an overall impression mean score of 8.1 ± 1.6 out of 10 (Table 2). The videos of AGLS were reported to be helpful in improving participants' understanding of hand anatomy (mean = 8.3 ± 2.0 out of 10). Similarly, participants also found that the exercise of drawing the extrinsic tendons and intrinsic muscles onto the glove helpful in improving their understanding of structures and functions of the hand (mean = 8.1 ± 1.8 out of 10). Participants agreed that they intended to use the glove and/or the videos to prepare for upcoming examinations (mean = 8.7 ± 1.7 out of 10), and they also had a preference for using AGLS to learn hand anatomy over the instructor-guided drawing activity (mean = 8.6 ± 2.2 out of 10). The responses to the questions that assessed user friendliness and learner control of AGLS were similarly high, with mean scores of 8.8 ± 1.3 and 9.1 ± 1.5 out of 10, respectively. Participants also strongly agreed that they would recommend the AGLS as a learning tool for future massage therapy students (9.0 ± 1.7 out of 10). The closed-ended questions were found to be highly reliable (α = 0.87).

The open-ended questions on the evaluation questionnaire were designed to collect participants' perceptions of the effectiveness of AGLS as a learning tool and suggestions on how it could be improved. Responses to these questions were analyzed and the following five themes emerged: anatomical content, useful learning tool, interactivity, enjoyable learning experience, and learner preference. The five themes are summarized below, with examples of participants' reasoning on how AGLS improved their understanding of hand anatomy (Table 3).

Anatomical content. Sixty-six percent (n = 42) of participants commented that the anatomy glove-drawing experience improved their understanding of hand anatomy. Participants reported that the act of drawing the structures onto the worn glove helped them identify the exact location and attachment sites of tendons and muscles in the hand. Many of these participants also mentioned that manipulating the glove on their

Table 2.

Participants' Perceptions and Evaluation of AGLS as a Learning Tool

Statements	Mean (±SD)
Q1. Please rate your overall impression of AGLS.	8.1 (±1.6)
Q2. Overall, how helpful were the videos in helping you to understand the anatomy of the hand and to draw the anatomy of the hand?	8.3 (±2.0)
Q3. Overall, how helpful was drawing the muscles/tendons on the glove in helping you to understand the anatomy of the hand?	8.1 (±1.8)
Q4. The AGLS was user friendly.	8.8 (±1.3)
Q5. I could easily control the pace of the videos.	9.1 (±1.5)
Q6. I intend to use the glove and/or videos of AGLS to study hand anatomy.	8.7 (±1.7)
Q7. I preferred drawing the muscles and tendons of the hand on the glove versus drawing the structures on paper.	8.6 (±2.2)
Q8. I would recommend AGLS to future massage therapy students.	9.0 (±1.7)

For statements 1–3 a 10-point Likert scale was used with 1 = not helpful and 10 = very helpful (n = 64); for statements 4–8 a 10-point Likert scale was used with 1 = strongly disagree and 10 = strongly agree (n = 64); Cronbach's alpha = 0.87.

Table 3.

Themes and Examples of Participants' Reasoning on How AGLS Improved Their Understanding of Hand Anatomy

Theme	Examples
Anatomical structure	"I was more able to grasp the concept that the tendons wrap around from the palmar to the dorsal side of the hand" "It helped me identify where all the muscles, nerves, and tendons were on my hand making it more realistic than a labeled 2D diagram"
Learning preference	"I am a visual learner, so being able to draw them and picture exactly where they are in respect to the actual hand was very helpful and easier to understand" "Doing it step by step at my own pace gave time to really locate/understand each structure"
Interactivity	"The experience enhanced my understanding of hand anatomy by making things more 3D as well as 'real life' so I could locate on my hand" "The fact that you can see what each muscle does when using the glove"
Useful learning tool	"I ended up with a complete glove to study with" "It helped me visualize where those muscles actually go and what they can do"
Enjoyable learning experience	"I enjoyed viewing the video and drawing on the glove with a partner" "It was a nice change from lectures"

own hand was useful in visualizing and understanding muscle function.

Useful learning tool. Forty-seven percent ($n = 30$) of participants indicated that once all of the structures were drawn onto the glove it became a very useful tool to use to visualize or palpate the exact location of muscles. Six participants also indicated that the anatomy glove provided them with an opportunity to create a useful learning tool.

Interactivity. Thirty-one percent ($n = 20$) of participants indicated that the AGLS experience was interactive and hands-on. Nine of these participants indicated that the glove improved their understanding of muscle function, because they were able to manipulate the glove on their own hand, while simultaneously watching the muscles produce movement at the hand joints.

Enjoyable learning experience. Overall, 28% ($n = 18$) of participants specifically indicated that they enjoyed the AGLS learning experience. Many of these participants reported that the anatomy glove drawing activity was a different, fun, or cool way to learn hand anatomy. Two participants indicated that it was not only a creative way to learn, but also an easier way to learn the structures compared to using 2D pictures from a textbook.

Learning preference. Twenty-two percent ($n = 14$) of participants stated a preference for learning using visual learning materials and hands-on activities. These participants commented that being able to draw the structures onto their own hand and thus visualize the location of the muscles deep to their skin allowed for a better understanding of the specific location and function of the muscles in the hand.

Participants also provided valuable feedback on how AGLS could be improved. Thirty-three percent ($n = 21$) of participants indicated that they either felt rushed to complete the glove drawing activity in class or suggested that more time would have been beneficial. Some participants ($n = 8$) also suggested that it would have been helpful if the videos included instructions on how to label all of the structures once they had been drawn onto the glove. Twenty-two percent ($n = 14$) of participants also suggested that the voice used in the videos should be louder and use more inflection.

DISCUSSION

The traditional 2D learning approach and AGLS (3D) had the same had the same effect on students' self-perceived confidence and knowledge of hand anatomy; however, students had a strong preference for AGLS. These results are consistent with other studies that have compared 2D and 3D anatomy learning tools. Keedy et al. (2011) reported that a 3D multimedia module on hepatobiliary anatomy neither enhanced nor inhibited medical students' learning. However, medical students were more satisfied with the 3D multimedia module in comparison to a module that used textbook images. Likewise, no difference was observed in medical students' ability to learn shoulder joint anatomy using a virtual reality 3D simulator or images from a textbook. However, students who used the 3D simulator rated it significantly more effective and more claimed they would use it as a learning tool if it were available to them (Hariri et al., 2004). It should be noted that in both of these studies (Hariri et al., 2004; Keedy et al., 2011) the 3D learning tools were presented on a 2D computer screen and thus were not physical 3D models.

Cognitive load theory (CLT) can be used to interpret the results of the knowledge test in this study. CLT assumes that the learner's cognitive system has limited working memory capacity available for novel learning tasks and that working memory is affected by various aspects of instructional materials (Sweller et al., 1998; van Merriënboer and Sweller, 2010). These include the intrinsic nature of the task itself (intrinsic load), the presentation of the instructional materials (extraneous load), and the learning processes that contribute to construction of knowledge (germane load) (Sweller et al., 1998; van Merriënboer and Sweller, 2010). In this study, acquisition of hand anatomy knowledge after learning was the same in both groups and the gains in knowledge were relatively small. It is plausible that the intrinsic complexity of the learning task itself contributed to the minimal impact on knowledge gain. During both learning conditions, students were required to deal with several interacting elements simultaneously. These included drawing numerous structures (17) on specific bony attachment sites and learning the function and nerve supply for each of these structures. Thus, intrinsic load imposed by the learning activity itself may have resulted in cognitive overload and thereby limited learning. Furthermore, since students' working memory was consumed by the high element interactivity inherent to the task, extraneous load differences between the two learning conditions may have been masked. Contrary to our findings, a recent study found that students did significantly better on nominal type questions when they used a plastic physical 3D model to learn pelvic anatomy in comparison to using a virtual reality 3D model or textbook images (Khot et al., 2013). However, they observed no difference in students' ability to answer functional type questions. Khot et al. (2013) suggested that the differences observed were the result of the extraneous load inherent to the learning modalities themselves. Given these results, future experimental studies involving AGLS need be simplified to determine whether AGLS affects extraneous load and as a result impacts learning.

Although AGLS and the traditional 2D learning approach were equally effective in promoting learning, the qualitative results suggest AGLS is a favorable learning tool. Students perceived using AGLS as a positive learning experience and highly recommended AGLS for future students. Students also perceived AGLS to be very helpful in teaching the anatomy of the hand and the majority of students strongly preferred AGLS as a learning tool. Experiential learning theorists would suggest this preference is the result of students being able to experiment actively with the learning tool (Kolb, 1984). While both the 2D glove and 3D drawing activity involved active participation, the direct manipulation of the glove on the learner's own hand allowed for active experimentation, which may have resulted in a better appreciation of hand structure and function. The results also revealed that the majority of students intended to use the glove and/or the videos to prepare for upcoming examinations. A recent study of first year medical students found that participation, such as optional study assignments outside of class, was positively associated with academic performance (Stegers-Jager et al., 2012). Thus, since students indicated that they intended to use AGLS to prepare for future examinations, it is possible that this increased engagement and effort during self-study could lead to better understanding and learning of anatomical knowledge.

This study has limitations that should be noted. All aspects of this study took place in a classroom setting within the time allowed by the curriculum. Participants in both groups had to complete their assigned learning activity and evaluations in a defined time (90 minutes). Many students in the 3D group reported that they felt rushed to complete the glove activity and many did not have time to thoroughly review the structures using the glove prior to writing the anatomy test. In addition, since this study took place in an uncontrolled classroom setting, some participants were not focused on reviewing the anatomy of hand once they had completed the learning activity. To prevent contamination between groups, neither group was allowed to review hand anatomy with their learning tool beyond the time permitted in the initial learning activity. It is plausible that students in both groups would have benefitted from additional exposure and experimentation with their assigned learning tool. In a normal course situation, students would not have to complete AGLS in a confined time period of 60 minutes, as the learning tool can be completed in stages and also at the student's own pace. In addition, the validity of the feedback questionnaire is unknown. The authors did not find a validated instrument that could be adapted from the educational literature and thus, the authors developed a feedback questionnaire for this purpose. The authors also acknowledge that feedback was not collected from the 2D group after learning. However, in future studies, a feedback questionnaire will be included to compare students' perceptions of the 2D drawing activity and 3D glove. Based on previous findings that have shown a relationship between the use of 3D computer models and spatial ability (Garg et al., 1999a, 1999b; Levinson et al., 2007; Stull et al., 2009; Nguyen et al., 2012), future research should explore the relationship between students' spatial ability and the use of AGLS. Further investigation should also aim to determine the efficacy of the different components of the AGLS (glove versus video).

An ongoing trend in anatomical education is the development of low-fidelity anatomy models and technology-based educational tools to replace or complement traditional experiences in a cadaver laboratory (Collins et al., 1994; Kim et al., 2003; Sugand et al., 2010; Chan and Cheng, 2011). Although these tools are designed specifically for anatomical education purposes, empirical evidence of their effectiveness is often conflicting and sparse. This study provides empirical evidence demonstrating that AGLS and the traditional 2D learning approach are equally as effective in promoting students' knowledge and self-confidence of hand anatomy. For the growing number of programs that have limited access to a cadaver laboratory, AGLS also provides an opportunity for students to view cadaveric hand prosections. In conclusion, the results of this study provide support for the use of AGLS in health professions' education curricula and for future research on this pedagogical tool.

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CONFLICT OF INTEREST

The authors Pat McKee and Anne M.R. Agur are inventors of the patent-pending Anatomy Glove Learning System and own stock in the Anatomy Softwear International, Oakville, Ontario, Canada.

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LITERATURE CITED

Adams CM, Wilson TD. 2011. Virtual cerebral ventricular system: An MR-based three-dimensional computer model. Anat Sci Educ 4:340–347.

Aziz MA, McKenzie JC, Wilson JS, Cowie RJ, Ayeni SA, Dunn BK. 2002. The human cadaver in the age of biomedical informatics. Anat Rec 269:20–32.

Barr AE, Barbe MF, Clark BD. 2004. Work-related musculoskeletal disorders of the hand and wrist: Epidemiology, pathophysiology, and sensorimotor changes. J Orthop Sports Phys Ther 34:610–627.

Chan LK. 2010. Pulling my gut out-Simple tools for engaging students in gross anatomy lectures. Anat Sci Educ 3:148–150.

Chan LK, Cheng MM. 2011. An analysis of the educational value of low-fidelity anatomy models as external representations. Anat Sci Educ 4:256–263.

Cloud BA, Youdas JW, Hellyer NJ, Krause DA. 2010. A functional model of the digital extensor mechanism: Demonstrating biomechanics with hair bands. Anat Sci Educ 3:144–147.

Collins TJ, Given RL, Hulsebosch CE, Miller BT. 1994. Status of gross anatomy in the U.S. and Canada: Dilemma for the 21st century. Clin Anat 7:275–296.

Dinsmore CE, Daugherty S, Zeitz HJ. 1999. Teaching and learning gross anatomy: Dissection, prosection or both of the above? Clin Anat 12:110–114.

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 2:253–259.

Estevez ME, Lindgren KA, Bergethon PR. 2010. A novel three-dimensional tool for teaching human neuroanatomy. Anat Sci Educ 3:309–317.

Finnerty EP, Chauvin S, Bonaminio G, Andrews M, Carroll RG, Pangaro LN. 2010. Flexner revisited: The role and value of the basic sciences in medical education. Acad Med 85:349–355.

Gangata H. 2008. An innovative approach to supplement the teaching of the spatial gross anatomy relationships of muscles to undergraduates in health sciences. Clin Anat 21:339–347.

Garg A, Norman G, Spero L, Taylor I. 1999a. Learning anatomy: Do new computer models improve spatial understanding? Med Teach 21:519–522.

Garg A, Norman GR, Spero L, Maheshwari P. 1999b. Do virtual computer models hinder anatomy learning? Acad Med 74:S87–S89.

Garg AX, Norman GR, Eva KW, Spero L, Sharan S. 2002. Is there any real virtue of virtual reality? The minor role of multiple orientations in learning anatomy from computers. Acad Med 77:S97–S99.

Granger NA. 2004. Dissection laboratory is vital to medical gross anatomy education. Anat Rec 281B:6–8.

Hariri S, Rawn C, Srivastava S, Youngblood P, Ladd A. 2004. Evaluation of a surgical simulator for learning clinical anatomy. Med Educ 38:896–902.

Humber College. 2013. School of Health Sciences: Biosciences lab. Humber College, Toronto ON, Canada. Available at: URL: http://healthsciences.humber.ca/resources/living-and-simulated-learning-environments/biosciences-lab.html [accessed 31 March 2014].

IWH. 2009. Institute for Work and Health. Do workplace programs protect upper extremity musculoskeletal health? Institute for Work and Health, Toronto, ON, Canada. Available at: URL: http://www.iwh.on.ca/system/files/documents/best_evidence_upper_extremity_2009.pdf [accessed 31 March 2014].

Jones DG. 1997. Reassessing the importance of dissection: A critique and elaboration. Clin Anat 10:123–127.

Keedy AW, Durack JC, Sandhu P, Chen EM, O'Sullivan PS, Breiman RS. 2011. Comparison of traditional methods with 3D computer models in the instruction of hepatobiliary anatomy. Anat Sci Educ 4:84–91.

Khot Z, Quinlan K, Norman GR, Wainman B. 2013. The relative effectiveness of computer-based and traditional resources for education in anatomy. Anat Sci Educ 6:211–215.

Kim S, Brinkley JF, Rosse C. 2003. Profile of on-line anatomy information resources: Design and instructional implications. Clin Anat 16:55–71.

Kolb DA. 1984. Experiential Learning: Experiences as the Source of Learning and Development. 1st Ed. Upper Saddle River, NJ: Prentice Hall. 256 p.

Kooloos JG, Vorstenbosch MA. 2013. A tool for teaching three-dimensional dermatomes combined with distribution of cutaneous nerves on the limbs. Anat Sci Educ 6:277–280.

Levinson AJ, Weaver B, Garside S, McGinn H, Norman GR. 2007. Virtual reality and brain anatomy: A randomized trial of e-learning instructional designs. Med Educ 41:495–501.

Mattingly CE, Barnes GE. 1994. Teaching human anatomy in physical therapy education in the United States: A survey. Phys Ther 74:720–727.

McLachlan JC, Patten D. 2006. Anatomy teaching: Ghosts of the past, present and future. Med Educ 40:243–253.

McLachlan JC, Bligh J, Bradley P, Searle J. 2004. Teaching anatomy without cadavers. Med Educ 38:418–424.

McMenamin PG. 2008. Body painting as a tool in clinical anatomy teaching. Anat Sci Educ 1:139–144.

Nguyen N, Wilson TD. 2009. A head in virtual reality: Development of a dynamic head and neck model. Anat Sci Educ 2:294–301.

Nguyen N, Nelson AJ, Wilson TD. 2012. Computer visualizations: Factors that influence spatial anatomy comprehension. Anat Sci Educ 5:98–108.

Nicholson DT, Chalk C, Funnell WR, Daniel SJ. 2006. Can virtual reality improve anatomy education? A randomised controlled study of a computer generated three-dimensional anatomical ear model. Med Educ 40:1081–1087.

Oh CS, Kim JY, Choe YH. 2009. Learning of cross-sectional anatomy using clay models. Anat Sci Educ 2:156–159.

Sergovich A, Johnson M, Wilson TD. 2010. Explorable three-dimensional digital model of the female pelvis, pelvic contents, and perineum for anatomical education. Anat Sci Educ 3:127–133.

Skinder-Meredith AE. 2010. Innovative activities for teaching anatomy of speech production. Anat Sci Educ 3:234–243.

Stegers-Jager KM, Cohen-Schotanus J, Themmen AP. 2012. Motivation, learning strategies, participation and medical school performance. Med Educ 46: 678–688.

Stull AT, Hegarty M, Mayer RE. 2009. Getting a handle on learning anatomy with interactive three-dimensional graphics. J Educ Pyschol 101:803–816.

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

Sweller J, van Merrienboer JJ, Paas, FG. 1998. Cognitive architecture and instructional design. Educ Psychol Rev 10:251–296.

Tang L, Chung MS, Liu Q, Shin DS. 2010. Advanced features of whole body sectioned images: Virtual Chinese Human. Clin Anat 23:523–529.

van Merriënboer JJ, Sweller J. 2010. Cognitive load theory in health professional education: Design principles and strategies. Med Educ 44:85–93.

Venail F, Deveze A, Lallemant B, Guevara N, Mondain M. 2010. Enhancement of temporal bone anatomy learning with computer 3D rendered imaging software. Med Teach 32:e282–e288.

Yardley S, Teunissen PW, Dornan T. 2012. Experiential learning: AMEE guide No. 63. Med Teach 34:e102–e115.

Zumwalt AC, Lufler RS, Monteiro J, Shaffer K. 2010. Building the body: Active learning laboratories that emphasize practical aspects of anatomy and integration with radiology. Anat Sci Educ 3:134–140.