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RESEARCH REPORT

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Effects of tablet-based drawing and paper-based methods on medical students' learning of gross anatomy

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Abstract

The way medical students learn anatomy is constantly evolving. Nowadays, technologies such as tablets support established learning methods like drawing. In this study, the effect of drawing on a tablet on medical students' anatomy learning was investigated compared to drawing or summarizing on paper. The quality of drawings or summaries was assessed as a measure of the quality of strategy implementation. Learning outcome was measured with an anatomy test, both immediately afterward and after 4–6 weeks to assess its sustainability. There were no significant group differences in learning outcome at both measurement points. For all groups, there was a significant medium strength correlation between the quality of the drawings or summaries and the learning outcome ($p < 0.05$). Further analysis revealed that the quality of strategy implementation moderated outcomes in the delayed test: When poorly implemented, drawing on a tablet (M = 48.81) was associated with lower learning outcome than drawing on paper (M = 58.95); The latter (M = 58.89) was related to higher learning outcome than writing summaries (M = 45.59). In case of high-quality strategy implementation, drawing on a tablet (M = 60.98) outperformed drawing on paper (M = 52.67), which in turn was outperformed by writing summaries (M = 62.62). To conclude, drawing on a tablet serves as a viable alternative to paper-based methods for learning anatomy if students can make adequate use of this strategy. Future research needs to identify how to support student drawing, for instance, by offering scaffolds with adaptive feedback to enhance learning.

KEYWORDS
anatomy learning, educational technology, gross anatomy education, learner-generated drawing, medical education, mobile learning, tablet, technology-based learning

Daniela Kugelmann and Markus Berndt shared last authorship, both authors contributed equally to this work.

INTRODUCTION

Anatomy is an important part of various medical specialties and there are different ways to learn it.[1] Pictures are better remembered than words.[2] This can also be shown by the fact that the effect of directed forgetting, that is, forgetting information that should be forgotten, is smaller with pictures than with words.[3] The production of pictures also leads to better memory than the production of words,[4] so drawing seems to be an engaging learning method. Drawing to learn can improve anatomical knowledge as it supports the retention[5] and understanding of anatomical facts.[6] In addition, this method can result in a more enjoyable learning process for students[7] and for teachers,[8] helping to sustain motivation to engage in anatomy learning. Visual arts such as drawing, sketching, painting, are also recognized by students in histology as a valuable learning method to learn medicine.[9] Similarly, drawing can also be incorporated into lectures of gross anatomy by asking students to create drawings on the chalkboard together with the teachers. This technique focuses attention on the content to be learned and makes the students think, giving them the impression of being able to remember the content better and to visualize positional relationships more easily.[10]

Various learning theories focus on explaining the potential benefits of visual representations such as pictures or drawings for learning. Dual coding theory assumes that verbal and non-verbal information is received and processed through different channels.[11] Thus, when words and pictures are presented in combination, learning can be enhanced and the ability to recall the information is increased. A combination of words and visual representations can strengthen learning and support students' comprehension and memorization skills. Based on this, the cognitive theory of multimedia learning[12] was developed, which additionally considers the three memory storages of humans, namely sensory, working, and long-term memory. In sensory memory, information is stored for a short time. In working memory, which has a limited capacity, relevant information is selected and organized into different models. These models are then integrated with prior knowledge in long-term memory, a necessary cognitive process for lasting learning. Dual coding theory and the cognitive theory of multimedia learning are both focused on explaining learning from pre-given pictures (and text). As an extension, the cognitive theory of drawing construction[13] addresses how students learn when generating pictures (drawings) on their own. According to this theory, learners are forced to integrate verbal and nonverbal information from a text when they are asked to draw. They must select, organize, and integrate the relevant information from the text and externalize the mental model by drawing. Furthermore, cognitive load theory is of interest. The cognitive load theory[14] deals with cognitive overload. This theory distinguishes between three types of cognitive load: intrinsic load, extraneous load, and germane cognitive load.[15] The intrinsic load arises from the complexity of the content to be learned and is difficult to influence by the design of the learning task. In addition, it depends on the prior knowledge of the learner. The extraneous cognitive load results from the presentation of the information to be learned. Finally, there is the germane cognitive load, which represents the learning-related load that is necessary for the learning process. To support the learner in the best possible way and to avoid cognitive overload, the intrinsic and extraneous load should be reduced, and the germane cognitive load should be increased. However, the total capacity should not be exceeded. According to these theories, pictures in addition to words should promote learning especially when they are self-generated, but care should be taken not to overload working memory. A well-designed learning method that involves drawing could therefore have a positive effect on learning.

In the literature, there are several studies that present drawing as a powerful learning method. Learner-generated drawing can facilitate learning in elementary school already.[16] Another benefit that enhances learning is the improved detection of comprehension errors through drawing.[17] Learners can identify the material which they did not fully understand and look at that again to foster their understanding. Another study asserts that not only the generation of the drawing itself aids the learner to acquire knowledge, simply the process of preparing to draw has a positive effect on the memory.[18] Thus, drawing can lead to a high level of comprehension.[19–21] It has been suggested that drawing can have a positive effect on learning but only if it is well applied,[22] so the study implies that a high quality of drawing is essential to benefit from this learning method while there was no difference from other methods when the quality was poor.

Due to the development of technology, researchers have been investigating the role of technical devices in learning and teaching. The tablet is a highly researched mobile device which is a useful tool for both students and teachers and mostly preferred over the traditional chalkboard.[23] Other than laptops, tablets also allow the learner to take notes by typing and by handwriting, which makes it easier for them to capture all the important information.[24] In addition, students use tablets for lectures during the semester to write notes or to access learning resources.[25]

Overall, technical devices are very common in medical education. Students mostly make use of digital resources rather than traditional textbooks, especially shortly before examinations.[26] Even in clerkships with clinical context, students make use of tablets to develop self-regulatory skills.[27] With mobile devices, students have the opportunity to learn whenever and wherever they want.[28] At the same time, students nowadays display a high familiarity with mobile devices, due to daily use.[29] This flexibility contributes to the fact that mobile learning improves the perceived efficiency of working in clinical learning environments in medical students.[30] In line with the new learning approaches, technology can not only be used for student learning but also for student assessment in anatomy classes.[31] More advanced technologies can also be used to learn anatomic content. Augmented reality applications, such as those tested on medical students in two studies at LMU Munich, Germany, can be used in gross anatomy courses. Virtual 3D models can be shown[32] or students can scroll through different anatomical slices using gesture input,[33] and both methods resulted in positive feedback from students. Especially in a post-Covid 19 pandemic era, perspectives on teaching have changed. While face-to-face teaching is still very important for learning anatomy, digital learning formats are sometimes very useful for protecting student health.[34] Also, the decline in body donors due to the pandemic is leading to a rethinking of gross anatomy courses and an approach to virtual learning.[35]

However, traditional approaches to learn in medical education are not replaced by modern methods, they complement each other. Tablets can be used as a laboratory manual during anatomical dissection, thereby students are more engaged and stay actively involved in the learning task.[36] Besides the subjective benefits of tablets, objective measurable benefits can be also found. In another study, the use of an application on tablets to support learning of anatomical and physiological topics was investigated.[37] The students who learned with this application showed improved grades and felt that the application helped them learn. Anatomy drawing screencasts are a preferred learning tool to improve students' performance[38] and to increase their learning outcome. Students also find such computerized screencasts very helpful and felt that comprehension was enhanced. The ability to pause the video was also a positive effect of this online application for the students.[39] In addition to such screencasts, however, other forms of technology can be found in anatomy courses. Mixed reality-supported learning, where learning was done with holograms, shows potential to become an equivalent learning method, at least for neuroanatomy.[40] One way to implement drawing is by the use of tablets with three-dimensional software, to present visual–spatial learning material in an appropriate manner for the students,[41] or interactive applications.[42,43]

Although, the medical curriculum is evolving, traditional teaching methods like chalkboard drawings are still utilized to teach anatomy[44] like they used to be decades ago.[45] However, modern methods can facilitate traditional approaches such as completing the traditional cadaveric dissection with drawings of dissected cadaveric specimens by the students.[46] Drawing in particular is a well-proven learning method and students themselves acknowledge the benefits as a learning aid.[47] Drawing improves the retention of the knowledge over time[48,49] and it also supports students in medical education to improve their comprehension of specific subjects in anatomy, like the musculoskeletal system.[50] Furthermore, drawing can be combined with other learning methods, such as haptically exploring anatomical models. The combination of simultaneous drawing and haptics leads to deeper learning and promotes remembering of the model.[51] Besides the traditional form of drawing on paper or similar surfaces, body painting seems to help students increasing their anatomical knowledge in an enjoyable and effective way.[52] The three-dimensionality and the requirement that the students actively participate in the learning process makes body painting a valuable learning and teaching method.[53]

In addition to learning methods, there are other influencing factors that can have an impact on learning achievement. According to studies, motivation is one of these factors. Both, intrinsic and extrinsic motivation are positively associated with self-efficacy and learning engagement. But only intrinsic motivation has a positive influence on academic performance.[54] This finding is supported by other studies.[55] Our study seeks to combine these two important aspects, drawing and technology, by examining the effect of drawing on a tablet to learn gross anatomy in comparison to paper-based learning methods. Previous work has especially focused on comparing drawing to other learning methods but not the different forms of implementing it like drawing on paper or on a tablet.[56] In one study, authors compared performance on tablet and paper but only for handwriting.[57] There has been a meta-analysis interested in whether there is a difference between computer-based drawing and paper-pencil-drawing with no advantage for the computer-based method so, the effects are still unclear.[20] Studies specifically investigating the use of drawing on a tablet to learn gross anatomy are lacking. Therefore, this study aimed to fill this gap in research by placing emphasis on the differences between drawing on a tablet to learn anatomy and paper-based methods. Specifically, four research questions were addressed. First, if drawing with a drawing application on a tablet leads to better knowledge of anatomical structures and better skills in applying anatomical knowledge compared to paper-based learning methods (drawing on paper; writing summaries on paper) and if there is a difference between the methods in terms of the sustainability of this learning outcome. Furthermore, it should be explored whether this learning outcome depends on the quality of strategy implementation (i.e., the quality of the drawings and summaries, respectively). Finally, this study aimed to reveal how the learning methods affect students' subjective appraisal of the learning situation (i.e., ease of learning, motivation, effort, self-efficacy) as well as their ability to accurately judge their own learning. It was hypothesized that the students who draw on the tablet would achieve a higher learning outcome than the other groups and that this learning outcome would show a higher sustainability. In addition, a higher quality of strategy implementation should lead to a higher learning outcome, and drawing on the tablet should promote the subjective appraisal of the learning situation and the ability to accurately judge the own learning.

MATERIALS AND METHODS

Participants

The participants were medical students of LMU Munich and Technical University Munich. An a priori power analysis was conducted with $\alpha = 0.05$, $\beta = 0.95$ and an expected effect size of Cohen's $f = 0.25$. It suggested that a total of 66 participants were required. For safety, 105 participants were recruited (78 females and 26 males). The distribution of the sex corresponds to the overall student population. The average age was 23.18 years (SD ± 3.22). To participate in the study, the participants had to be medical students and a completed gross anatomy course was required, which at LMU Munich took place in the first and second semester and contained a practical laboratory part which included a dissection course with cadavers and a theoretical part with 90 h of lectures. In addition to the dissection course, students had the possibility to deepen their knowledge with anatomy models and advanced technologies such as magic mirror[33] or Anatomage tables (Anatomage Inc., San Jose, CA). Students were encouraged to study with anatomy atlases and textbooks. Recruitment was conducted through anatomy courses, in which the study was presented to students by members of the working group, with help from lecturers, who have also presented the study to the students in their courses, and social media. An informational flyer for the study was created and shared it on Facebook, Instagram, and WhatsApp platforms.

Ethics statement

Written informed consent was obtained from all participants before the study. They were informed about the study, chances, risks, rights, obligations, and the voluntariness of the study. Data were collected in pseudonymized form. They also agreed to the publication of the data in anonymized form. Students could revoke their consent without incurring any disadvantage. Ethical approval for this study was obtained from the ethics committee at LMU Munich (decision # 20-145).

Procedures

Participants were randomly assigned to one of three groups ($n = 35$ students per group) reflecting different learning methods, that is, drawing on tablet, drawing on paper, and writing summaries. At the beginning of the study, all participants completed a questionnaire about their demographic data and their experience with tablets and drawing. Examples of the questions for their experience were "How often do you use a tablet in your everyday life?" and "How often do you learn by making drawings (drawings of structures, not mind maps, flow charts, or similar)? (When you need to learn)." Furthermore, they filled out a motivation questionnaire about their learning behavior and attitude toward anatomy and took an anatomy knowledge test. An example statement of the motivation questionnaire, which the students had to rate, was "I am interested in learning about anatomy." They all went through the same learning phase using one of the three different learning methods. The groups that wrote summaries and drew on paper were provided with sheets of paper, pens, and crayons. The group that drew on a tablet received an iPad (6th Generation, 32GB model; Apple Inc., Cupertino, CA) running iPadOS, version 13.6 (Apple Inc., Cupertino, CA) with a Logitech Crayon (Version number 914-000034, Logitech International S.A. Lausanne, Switzerland) for a drawing pen, which could be used to draw on the tablet. In order to suit the needs of the study, the workgroup developed a custom web-based application for participants to draw in, which was accessible via the iPad's browser. The drawing functionality was implemented using html canvas, a web application programming interface using code to create forms to appear in the browser. Similar to the group that used pen and paper, the application allowed users to vary the color and thickness of their pen.

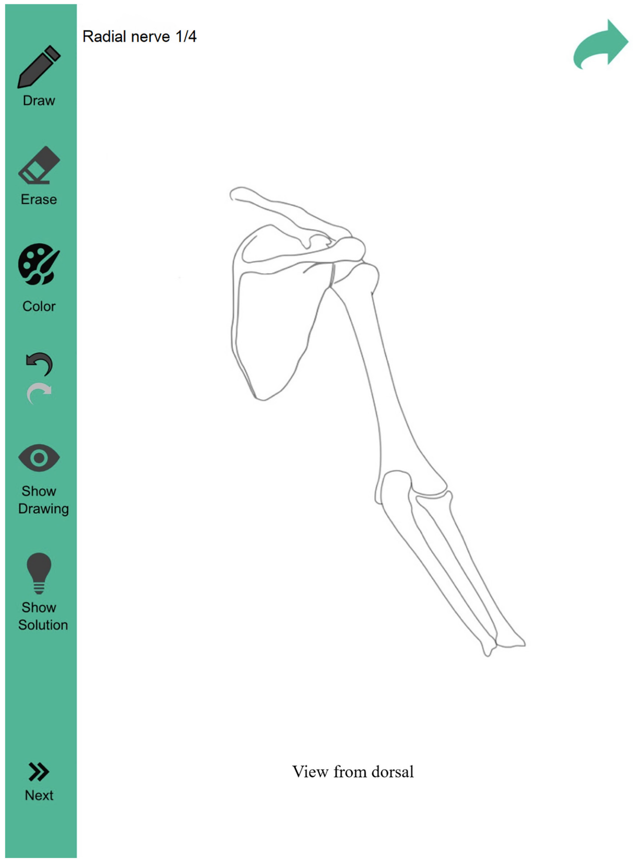

FIGURE 1 Screenshot of the drawing application on a tablet. The bone template was designed by the workgroup. On the left there is the bar with the buttons for operation, in the middle the template for drawing, on the top left the name of the nerve and the section and on the top right the arrow to switch between the bone and the skin template.

Additionally, participants were provided with a digital eraser, they could undo and redo individual lines, and they could completely fade out their own drawing (Figure 1).

Before starting the learning phase, the procedure was practiced on an example with explanation videos, which was not included in the evaluation. For the learning phase, the participants were given a script, which was prepared by the workgroup. The script consisted of a revised learning text from an anatomy textbook[58] with the corresponding pictures from an anatomy atlas.[59] The topic was the nerves of the arm in their function, topography, and area of sensory supply. Structures that are important for the path of the nerves were also covered. The text was divided into eight different sections. The learning phase consisted of the participants reading these sections and studying the corresponding pictures. After each section, they closed the text and the pictures and made a suitable drawing or summary with the help of an explanation on how to construct them. The drawing or summary should contain the nerve, important structures in its course and the area of sensory supply (Figure 2). The contents to be included were highlighted in the preceding learning text. However, the explanation on constructing the drawings or summaries did not mention these contents by name, but only specified the

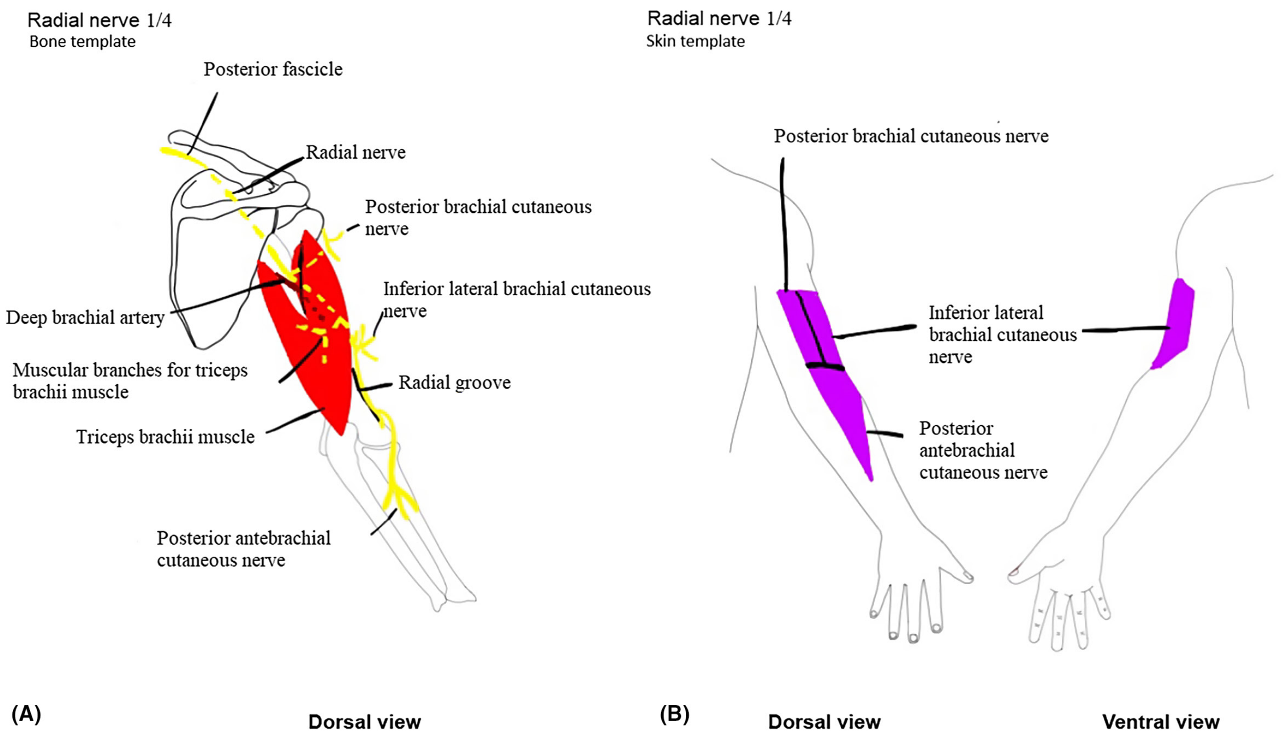

FIGURE 2 Sample solution of the first section of the radial nerve. Shown are screenshots from the drawing application with the solution drawing of the bone template (A) and the skin template (B). Bones and skin were given as templates. The solution drawing and the templates were designed by the workgroup.

number of structures to be drawn or mentioned. The group that drew on the tablet had to switch to the tablet after drawing each section. The groups that drew also received templates, which consisted of a black-and-white schematized line drawing, showing either bones (Figure 1) or the skin depending on whether the course or the area of sensory supply needed to be drawn (Figure 2). The group that wrote summaries was given a white sheet of paper to write on. After the students had finished their drawing or summary, they were allowed to look at a sample solution, a drawing, or summary provided by the working group with all the specified contents and compare it to their own work to identify any mistakes or inaccuracies. For viewing solutions on the tablet, there were two different viewing options. One was to view the drawing next to one's own drawing, the other was to view it superimposed onto one's own drawing. When the participants felt that they had sufficiently compared their drawing or summary to the solution, they closed the solution and could make corrections to their drawings or summaries with a differently colored pen. The participants repeated this procedure for each section. The students had a total of 105 minutes for the learning phase. They could decide for themselves how much time they would like to spend on each individual section. After all sections had been worked on, the participants were allowed to look at all of their own drawings or summaries for a short amount of time to rehearse them.

After this brief review period, participants answered the anatomy post-test and the second motivation questionnaire. After an interval of 4–6 weeks, participants were asked to complete the anatomy delayed post-test and the third motivation questionnaire. The average time between the two appointments was 35.62 days ($SD \pm 3.50$). Each of the knowledge tests or questionnaires differed from the others.

Measures

Prior anatomical knowledge

The prior anatomical knowledge of the participants was measured by the pre-test. The test contained 20 questions and one point could be scored per question, for a total of 20 points. The questions dealt with the nerves of the arm with their course and the area of sensory supply, so knowledge that the participants had obtained from the gross anatomy course. The questions were created with the help of two anatomy instructors and were based on the learning text. They consisted of open and multiple-choice questions. An example of an open-ended question was, “Along which muscle does the superficial ramus of the radial nerve run on the forearm?” The internal consistency as a measure of the reliability of the test was determined using Cronbach's alpha ($\alpha = 0.71$).

Anatomical knowledge

The anatomical knowledge of the participants was assessed by the post-test immediately after the learning phase and by the delayed post-test at an interval of 4–6 weeks after the first appointment. These tests were similar to the pre-test, but they each consisted of different questions. The post-test contained 24 questions and 30 points were to be achieved. In the delayed post-test there were 28 questions, which differed from the questions of the pre- and post-test, and a maximum of 30 points could be reached. The reliability of the tests was again determined by Cronbach's alpha (α = 0.77 and α = 0.72, respectively). The results of the knowledge tests were z-standardized to make them comparable.

Quality of strategy implementation

To assess the quality of the drawings and the summaries, a scoring sheet was created by experts of the workgroup, which was used to evaluate the completeness and correctness of drawn or named structures and their labels (Table 1). One point could be achieved for each criterion. In total, 299 points could be achieved for the drawings and 248 points for the summaries because the structures in the drawings must be named in addition to being drawn, which was not the case with the summaries because there, the structures must be only mentioned by name, so there were more criteria for the drawings and more points. Quality was recorded for the original drawings or summaries and again after the participants had viewed the solution and had the opportunity to make corrections. The reliability of the test was measured using Cronbach's alpha (α = 0.89 for drawings and α = 0.95 for summaries). To ensure the objectivity of the evaluation of the drawings and summaries, the evaluation was performed by two people. The interrater reliability was determined by intra-class-coefficient (ICC) and was very good with ICCs >0.80 for each individual criterion. Again, the strategy quality scores were z-standardized to make them comparable despite the (slight) differences in scoring criteria, since participants in the groups that drew and the group that wrote summaries could score differently in total.

Subjective appraisals

Three different questionnaires about the participants' motivation were handed out—one before and one after the learning phase, and one at an interval of 4–6 weeks after the first appointment together with the anatomy knowledge tests. The first and second questionnaires each consisted of nine different questions on learning behavior and attitudes toward anatomy, which could be answered with "does not apply at all," "rather does not apply," "rather applies," and "completely applies." The second questionnaire, however, focused more on questions about the learning method used in the study. In addition, the participants were asked to assess their performance in the post-test and to answer what particularly motivated or did not motivate them about this learning method. The third questionnaire consisted of a question about whether they had continued to use the learning method they used since the last appointment. The questionnaire data served only internal purposes and will not be reported here except for the questions regarding students' subjective appraisals of the learning method and the assessment of their performance as measured with the second questionnaire.

With these questions, students were asked to rate the ease of learning (2 questions), their motivation/enjoyment (4 questions, Cronbach's alpha = 0.89), the effort that they had invested into learning (termed goal-driven effort, see Scheiter et al.[60]; 1 question), the effort that the task required (termed data-driven effort, see Scheiter et al.[60]; 1 question), and their self-efficacy with respect

TABLE 1 Scoring sheet for drawings and summaries for the fourth section of radial nerve.

Completeness	Number of points	Correctness	Number of points	Total score (points)
Drawings				
Deep branch of radial nerve	2	All structures correctly labeled (deep branch, muscular branch, supinator muscle, supinator tunnel)	4	17
Muscular branch of radial nerve	2	Deep branch of radial nerve through supinator muscle in the supinator tunnel, then releases muscular branches	3	
Supinator muscle	2	Supinator muscle from lateral epicondyle of humerus (and olecranon) to radius	2	
Supinator tunnel	2			
Summaries				
Deep branch of radial nerve	1	All structures correctly labeled (deep branch, muscular branch, supinator muscle, supinator tunnel)	4	13
Muscular branch of radial nerve	1	Deep branch of radial nerve through supinator muscle in the supinator tunnel, then releases muscular branches	3	
Supinator muscle	1	Supinator muscle from lateral epicondyle of humerus (and olecranon) to radius	2	
Supinator tunnel	1			

Note: Example of the scoring sheet for drawings and summaries, fourth section of radial nerve, description of the course of the nerve, bone-template (skeleton). Drawing's completeness: 1 point for completely drawn +1 point for structures or areas labeled.

to anatomy (i.e., their beliefs in their understanding of anatomy, see Bandura[61]; 1 question). The ratings were provided on a scale from 0 (not easy/motivating/effortful/confident at all) to 3 (very easy/motivating/effortful/confident).

Moreover, students were asked to rate the percentage of items that they expected to solve correctly in the upcoming post-test (judgment of learning, see Thiede et al.[62]). This rating was used to determine the accuracy of their monitoring by subtracting their actual performance from their expected performance.[63] Values larger than zero indicate that students overestimate their learning, while values less than zero suggest that they underestimate it. Being able to accurately monitor one's learning is seen as an important aspect of a student's self-regulation.[64] Generative learning tasks such as drawing or writing summaries have been shown to improve monitoring accuracy.[62,65]

Statistical analysis

The analyses were completed using SPSS Statistical package for Windows, version 26 (IBM Corp., Armonk, NY). To compare the three groups regarding their performance in the post-test and the delayed post-test, an ANCOVA was performed with the prior knowledge (score in the anatomy pre-test) as a covariate. To investigate the influence of the quality of drawings and summaries on the learning outcome (immediate and delayed), first an ANOVA was conducted to examine whether there was a difference between the groups in terms of quality. Then, a Pearson correlation was used to examine the relationship between quality and learning outcome. A partial correlation controlling for participants' pre-test scores was used to rule out that observed relationships are due to prior knowledge (i.e., students with better pre-test scores producing higher-quality drawings or writings, respectively). Finally, a regression analysis was used to examine whether the quality of strategy implementation moderated the effect of the learning method on learning outcome. The significance level for all statistical analyses was set to $\alpha < 0.05$.

Regarding students' subjective appraisals of the learning method (ease of learning, motivation, effort) and their own performance (self-efficacy, monitoring accuracy) it was analyzed how these variables (except for monitoring accuracy) were correlated to learning outcome; moreover, ANOVAs were conducted to compare the three learning methods to each other. In addition, it was tested whether monitoring accuracy was significantly different from zero using one-sample *t*-tests.

RESULTS

In total, the participants were more familiar with using a tablet than with drawing, whether for leisure or for learning. The majority of the participants owned a tablet or had regular access to it ($n = 64$, 61%). In addition, most students used a tablet daily in everyday life ($n = 45$, 42.9%) and 37 (35.2%) students also used it for learning daily if they currently are in a learning phase. Drawing was less common. Most students never drew in their free time ($n = 36$, 34.3%) and 32 (30.5%) students drew less than once a month to learn during a learning phase. Means and standard deviations of anatomy knowledge test scores and quality of drawings and summaries in percent per group are reported in Table 2. An example of a drawing on paper is shown in Figure 3 and for a summary in Figure 4.

Learning outcome

All three learning methods appeared to be equally effective. To compare the difference in learning outcome between the groups, two ANCOVAs were performed with the learning method as a between-subjects factor, the test results as the dependent variable, and the results of the pre-test as a covariate. There was no significant difference between the groups regarding either the immediate post-test ($F(2, 101) = 0.356$, $p = 0.701$, partial $\eta^2 = 0.007$) nor the delayed post-test ($F(2, 101) = 0.271$, $p = 0.763$, partial $\eta^2 = 0.005$).

Quality of strategy implementation

Overall, the effectiveness of drawing on tablet crucially depended on students' ability to implement the learning method in a good way. To investigate whether the quality of strategy implementations matters for learning, it was first examined with an ANOVA whether it differs

TABLE 2 Students' performance in the anatomy knowledge tests and quality of strategy implementation within the different groups.

Anatomy knowledge test/quality of strategy implementation	Drawing on tablet	Drawing on paper	Writing summaries
	Mean % (±SD)	Mean % (±SD)	Mean % (±SD)
Pre-test (prior knowledge)	51.86 (±17.45)	56.57 (±18.70)	51.00 (±18.94)
Post-test (learning outcome)	65.62 (±16.74)	68.48 (±13.63)	67.81 (±18.92)
Delayed post-test (learning outcome)	54.95 (±14.78)	56.00 (±14.28)	56.38 (±17.83)
Quality of strategy implementation (before correction)	72.19 (±9.48)	73.53 (±9.29)	77.07 (±12.19)
Quality of strategy implementation (after correction)	82.63 (±6.54)	84.54 (±6.48)	84.76 (±9.60)

Note: This table shows the means and ± standard deviations (±SD) of the anatomical knowledge tests and the quality of the drawings and summaries in percent as a measure of the quality of strategy implementation.

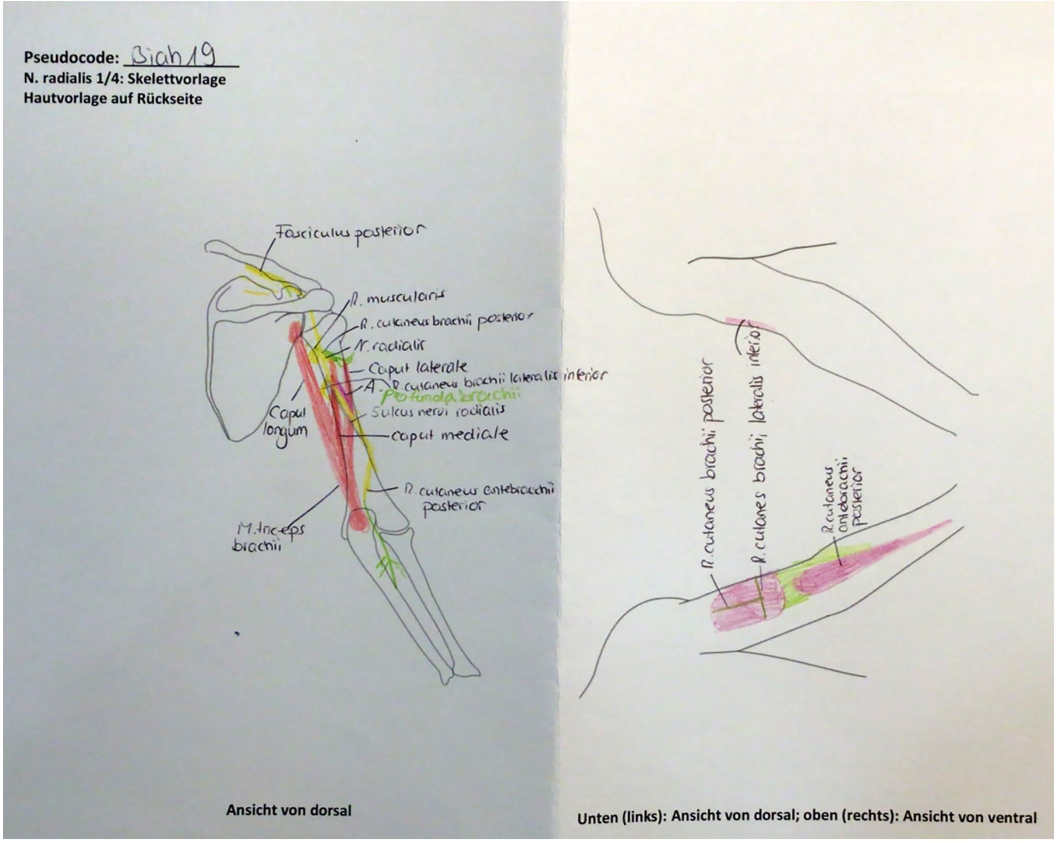

FIGURE 3 Example of the first section of radial nerve of a participant of the group that drew on paper. On the left, the radial nerve is drawn in its course with its important structures and on the right, its area of sensory innervation is shown. The structures and areas shown in green were drawn by the participant as a correction after viewing the solution. The bone template was provided.

between the groups. For this analysis, the strategy implementation scores for drawings and writings prior to correcting them after having received feedback were used. There was no significant difference between the groups ($F(2, 102) = 2.056$, $p = 0.133$, $\eta^2 = 0.039$).

In a second step, Pearson correlations were determined to examine the relationship between strategy quality and learning outcome within each group. To ensure that these relationships were not affected by students' prior knowledge, students' pre-test knowledge was controlled. The resulting partial correlations reflected the true relation between strategy quality and learning outcome, controlling for the fact that students who knew more might also have produced better drawings or writings. As can be seen in Table 3, these partial correlations were significant in all three groups and both for the immediate and the delayed post-test However, there was one exception, there was no significant correlation between the strategy quality and performance in the delayed post-test when drawing on paper. In the remaining cases, students who produced higher-quality drawings or summaries, also scored higher in the post-tests—independent of their prior knowledge.

Finally, a regression analysis was used to examine whether the quality of strategy implementation moderated the effect of learning method on learning outcome. For this purpose, two dummy variables were created. Dummy variable 1 reflected the comparison between the group that drew on paper (coded −1) and the group that wrote summaries on paper (coded +1). Dummy variable 2 was used for comparing the group that drew on tablet (coded +1) to the group that drew on paper (coded −1). The group comparisons were done in separate regression analyses. In each regression analysis, the dummy code (reflecting one of the two comparisons), the quality of strategy implementation (z-standardized), and the interaction between the dummy code and the quality of strategy implementation were entered as predictors and regressed onto one of the two post-test scores. In the case of significant interactions (suggesting that the quality of strategy implementation moderated the differences between groups), these were followed up by simple slope analyses at −1 standard deviation (SD) and +1 SD relative to the mean of the continuous variable.[66] This analysis allowed to estimate the effect of learning method at different levels of strategy quality. To determine group differences for students with lower quality of strategy implementation, the effect was estimated at −1 SD relative to the mean of the continuous variable, whereas for students with better strategy quality it was estimated at +1 SD.

Regarding the comparison between drawing on paper versus writing summaries, the overall regression models were significant for both the immediate post-test, $R^2 = 0.47$, $F(3,69) = 19.14$, $p < 0.001$, and the delayed post-test, $R^2 = 0.20$, $F(3,69) = 5.56$, $p = 0.002$.

With respect to the immediate post-test, there was no effect of learning method, $Beta = -2.27$, $\beta = -0.14$, $p = 0.13$, and no reliable

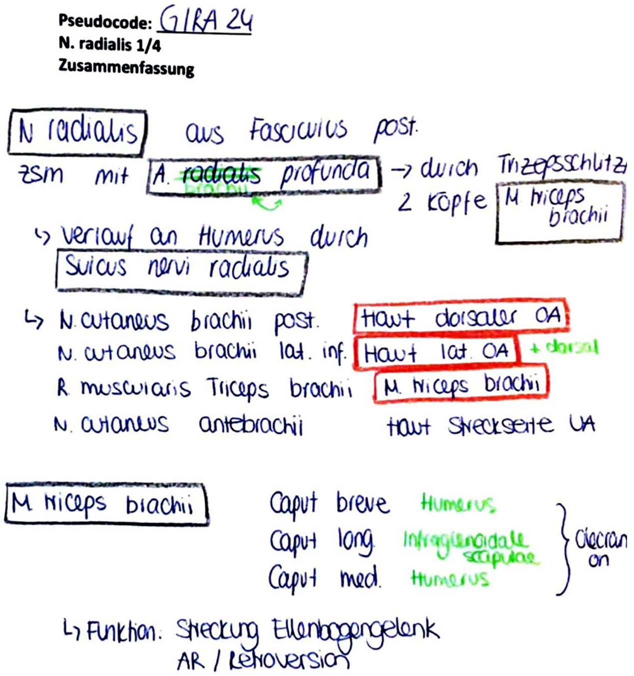

FIGURE 4 Example of the first section of radial nerve of a participant of the group that summarized. The terms outlined in black describe the nerve in its course with its important structures and the terms outlined in red describe its area of sensory supply. The structures and skin areas written with green were added as a correction by the participant after looking at the solution.

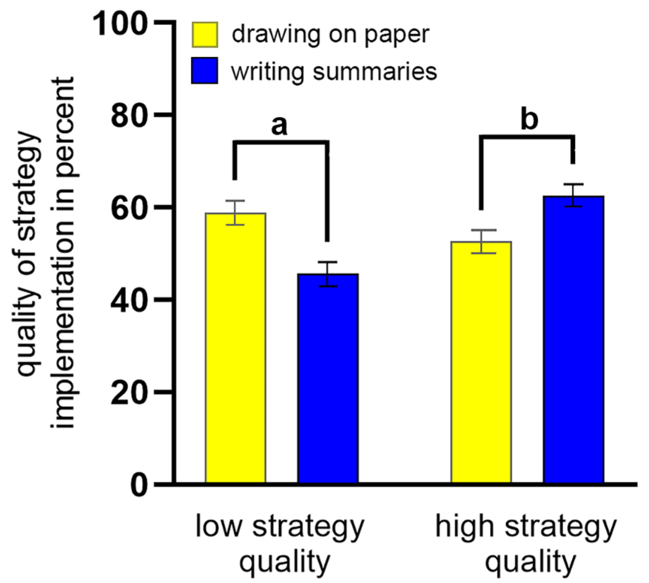

FIGURE 5 Quality of drawings and summaries as a measurement for quality of strategy implementation. The bars show the comparison of the group that drew on paper ($n = 35$) and the group that wrote summaries ($n = 35$). The results were classified into low and high quality and the quality of strategy implementation in percent is shown on the y-axis. Error bars represent standard errors. p-values show the significance of the differences between the groups. [a]$p = 0.01$; [b]$p = 0.046$.

TABLE 3 Partial correlations (Pearson) between the quality of strategy implementation and learning outcome within each group.

Group	Post-test	Delayed post-test
Drawing on tablet	$r = 0.541$[a]	$r = 0.431$[c]
Drawing on paper	$r = 0.408$[c]	$r = -0.322$
Writing summaries	$r = 0.736$[a]	$r = 0.448$[b]

Note: [a]Significant at the level of $p < 0.001$; [b]$p < 0.01$; [c]$p < 0.05$.

interaction with the quality of strategy implementation, *Beta* = 2.90, $\beta = 0.18$, $p = 0.056$. As had been already revealed in the correlational analyses, the better students had implemented either learning method, the better their learning outcome was in the first post-test, *Beta* = 9.77, $\beta = 0.62$, $p < 0.001$.

With respect to the delayed post-test, a slightly different picture emerged: There were no effects of either the learning method, *Beta* = −0.84, $\beta = -0.05$, $p = 0.64$, or the quality of strategy implementation, *Beta* = 2.71, $\beta = 0.18$, $p = 0.14$. However, there was significant interaction, *Beta* = 5.81, $\beta = 0.37$, $p = 0.002$. Simple slope analyses conducted at −1 SD and +1 SD of the continuous moderator strategy quality resolved this interaction as follows: For students who had implemented their respective strategy with low quality only, drawing on paper ($M = 58.89$) was more effective than writing summaries ($M = 45.59$), *Beta* = −6.65, $\beta = -0.42$, $p = 0.01$. For students with a high strategy quality, on the other hand, writing summaries ($M = 62.62$) led to better test performance than drawing on paper ($M = 52.67$), *Beta* = 4.98, $\beta = 0.31$, $p = 0.046$ (Figure 5). Accordingly, drawing on paper was effective even when poorly implemented, whereas good learning outcomes when writing summaries depended on students making good use of that learning method.

Regarding the comparison between drawing on paper vs. on tablet, the overall regression models were significant for both the immediate post-test, $R^2 = 0.31$, $F(3,69) = 9.96$, $p < 0.001$, and the delayed post-test, $R^2 = 0.13$, $F(3,69) = 3.40$, $p = 0.02$.

With respect to the immediate post-test, there was no effect of learning method, *Beta* = −0.55, $\beta = -0.04$, $p = 0.73$, and no interaction with the quality of strategy implementation, *Beta* = 2.26, $\beta = 0.13$, $p = 0.20$. As had been already revealed in the correlational analyses, students who had implemented either learning method at a higher quality, scored better in the first post-test, *Beta* = 9.13, $\beta = 0.53$, $p < 0.001$.

With respect to the delayed post-test, again a different picture emerged: There were no effects of either the learning method, *Beta* = 0.35, $\beta = 0.02$, $p = 0.84$, or the quality of strategy implementation, *Beta* = 2.31, $\beta = 0.14$, $p = 0.22$. However, there was significant interaction, *Beta* = 5.42, $\beta = 0.34$, $p = 0.005$. Simple slope analyses conducted at −1 SD and +1 SD of the continuous moderator strategy quality resolved this interaction as follows: When the quality of strategy implementation was low (as indicated by inaccurate and incomplete drawings), drawing on paper ($M = 58.95$) was more effective than drawing on tablet ($M = 48.81$), *Beta* = −5.07, $\beta = -0.35$, $p = 0.03$. In the case students had produced high-quality

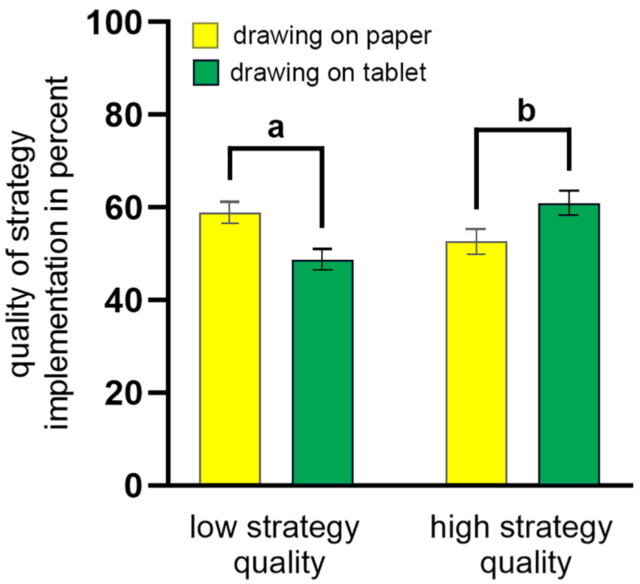

FIGURE 6 Quality of drawings as a measurement for quality of strategy implementation. The bars show the comparison of the group that drew on paper ($n = 35$) and the group that drew on tablet ($n = 35$). The results were classified into low and high quality and the quality of strategy implementation in percent is shown on the *y*-axis. Error bars represent standard errors. *p*-values show the significance of the differences between the groups. $^{a}p = 0.03$; $^{b}p = 0.03$.

drawings though, drawing on tablet ($M = 60.98$) was more effective than drawing on paper ($M = 52.67$), $Beta = 5.76$, $\beta = 0.40$, $p = 0.03$ (Figure 6).

Subjective appraisals

Means and standard deviations are shown in Table 4. Motivation correlated positively with the learning outcome and was higher in the students who were drawing on a tablet.

According to the correlational analyses, students who rated their learning as easy (ease of learning) and who were more confident in their own understanding of anatomy (self-efficacy), also performed higher in the immediate and delayed post-test (see Table 5). Moreover, students' motivation was related positively to higher learning outcome in the immediate post-test. Finally, those who reported more data-driven effort suggesting that the task required more effort of them, scored lower in the delayed post-test. There were no other significant correlations.

The ANOVAs revealed no differences between the learning methods for ease of learning, $F < 1$, self-efficacy, $F < 1$, goal-driven effort, $F < 1$, or data-driven effort, $F(2,102) = 2.07$, $p = 0.13$. However, there were differences between conditions with respect to the motivation and enjoyment experienced by the students, $F(2,102) = 4.60$, $p = 0.01$. Bonferroni-adjusted posthoc analyses revealed that students drawing on tablet found this method more motivating and enjoyable than writing summaries ($p = 0.009$). There were no further significant differences between the learning methods.

TABLE 4 Students' subjective appraisals of the learning method and assessment of their performance.

Motivational variables	Drawing on tablet Mean (±SD)	Drawing on paper Mean (±SD)	Writing summaries Mean (±SD)
Ease of learning	1.77 (±0.62)	1.67 (±0.66)	1.73 (±0.68)
Motivation	2.10 (±0.62)	1.88 (±0.72)	1.61 (±0.70)
Goal-driven effort	2.40 (±0.60)	2.46 (±0.61)	2.46 (±0.66)
Data-driven effort	1.66 (±0.84)	2.06 (±0.68)	1.89 (±0.93)
Self-efficacy (anatomy)	1.63 (±0.69)	1.60 (±0.65)	1.63 (±0.69)
Monitoring accuracy	1.67 (±15.54)	1.29 (±11.28)	2.01 (±15.10)

Note: This table shows the means and standard deviations (SD) of the students' subjective appraisals of the learning method and the assessment of their performance as measured with the second questionnaire. The mean ratings were calculated based on a scale from 0 (not easy/motivating/effortful/confident at all) to 3 (very easy/motivating/effortful/confident).

TABLE 5 Correlation between motivational variables and learning outcome.

Motivational variables	Post-test *r*	Delayed post-test *r*
Ease of learning	0.362[a]	0.259[b]
Motivation	0.225[c]	0.153
Goal-driven effort	0.167	−0.066
Data-driven effort	−0.106	−0.266[b]
Self-efficacy (anatomy)	0.403[c]	0.363[a]

Note: [a]Significant at the level of $p < 0.001$; $^{b}p < 0.01$; $^{c}p < 0.05$.

Finally, there were no differences between the learning methods with respect to students' monitoring accuracy, $F < 1$. One-sample *t*-tests within each condition revealed that students were highly accurate in judging their own learning, as their monitoring accuracy did not differ significantly from zero in any of the three conditions ($0.44 < p < 0.55$).

DISCUSSION

The way anatomy is taught is constantly evolving. New learning methods and the widespread use of mobile devices open new possibilities to learn anatomy. Therefore, it is important to investigate such new learning opportunities. The study aimed to investigate drawing on a tablet as a new learning method to learn anatomy and to compare it with paper-based learning methods. It was looked at whether the various methods differ in learning outcome and how sustainable this learning outcome is. It was also looked at whether this learning outcome depends on the quality of the learning method used.

Learning outcome and its sustainability

Two of the three main results of the study indicate that the applications like the one the workgroup developed can be used as an alternative learning method to paper drawings and paper summaries, as there is no significant difference in the learning outcome and its sustainability between the methods. Thus, the hypothesis that drawing on the tablet leads to a higher learning outcome and a higher sustainability of this learning outcome than the other learning methods cannot be confirmed. Drawing on a tablet does not lead to better or worse knowledge of anatomical structures or to better skills regarding the application of anatomical knowledge compared to the other learning methods and there is no difference between the methods regarding the sustainability of the learning outcome. The results show that learning outcome occurs through drawing, just as it does through other learning methods. These results are consistent with other studies that show that drawing has a positive impact on knowledge acquisition.[6,48,50] Furthermore, previous work in this field has focused on the difference between tablet and paper in terms of surface texture for writing on it, not drawing. It was noted that there is a difference in terms of handwriting performance as there is less friction on the tablet screen than on paper, but adults quickly get used to it.[57] However, other results cannot be supported with this study. In several studies, it was shown that drawing produces better learning outcome than summarizing,[56,67] not like this study where the two learning methods were equivalent.

There are several possible explanations for the results of this study, which are not fully consistent with other studies. In the context of cognitive load theory, one study has found that drawing can increase cognitive load such that comprehension of the material being learned is reduced because fewer cognitive resources are available.[68] Perhaps externalization, so the process of drawing, inhibited learning outcome, and drawing was only an equal learning method. Maybe the presentation of the content to be learned and the learning task increased the extraneous cognitive load to such an extent that a cognitive overload occurred. In addition, learner-generated drawing was found to support learner comprehension, especially when prior knowledge was relatively low. Students who already have a higher level of prior knowledge tend not to use this form of externalization to learn.[69] This could be a reason why the participants in the study did not benefit so much from this learning method since they had all already passed the anatomy course. Another reason why the tablet learning method did not perform better than the other methods could be the novelty of the application for the students. The participants first had to get used to using the tablet, digital pen, and the application, although they were already very familiar with crayons and paper. So, students probably need more support in implementing a new learning method. This can be seen from the fact that students accept drawing alone as a learning method, but often need encouragement and help from teachers before they can and want to implement it.[70] In addition, a study found that the positive influence of the tablet on learning outcome depends on the degree of exposure, so access to the tablet not only at the university but also at home.[71] Students should spend more time with the tablet, in and out of the university, to become familiar with it. Furthermore, the application as presented was aimed at closely replicating the experience of the paper group. It is reasonable to assume that when this method is adapted to take more advantage of the digital format, such as adaptive feedback, collaboration, and more granular drawing tasks, improvements in learning outcome could occur.

Moderation of learning outcome through quality of learning method

Our findings show that a drawing with high quality also leads to a high learning outcome. So, the learning outcome depends on the quality of the drawing made. Thus, the hypothesis that a higher quality of strategy implementation also leads to a higher learning outcome can be confirmed. Students whose work was of a higher quality also had a better learning outcome. This positive correlation has already been found in previous studies.[22,72]

Furthermore, it was also discovered that when the learning material is of high quality, writing summaries, compared to drawing on paper, and drawing on a tablet, compared to drawing on paper, both lead to better learning outcome in a delayed knowledge test. This shows that the quality of the learning method plays a role in the learning outcome and that one can benefit from drawing and from the tablet especially if the quality of strategy implementation is high. With these results, the study has made an incremental contribution to the field of teaching and learning anatomy.

Motivation

The results of the motivational questionnaires show that all three methods are equally suited from a motivational point of view. However, the participants who drew on the tablet considered that this method was a more motivating and enjoyable experience. So, the hypothesis that drawing on the tablet has promoted the subjective appraisal of the learning situation and the ability to accurately judge the own learning cannot be confirmed. Students in all three groups were very well able to judge their own learning as reflected in high monitoring accuracy. This confirms earlier research suggesting that engaging in generative learning activities improves monitoring accuracy.[62,65] Accordingly, generative learning tasks such as writing summaries or drawing may be particularly useful in scenarios where learners have to self-regulate their learning and where there is a particular need for accurate monitoring.[64]

Limitations of the study

The study has several limitations. First, there was no control group that did not use a learning method that requires constructing, such as a group that only reads. Thus, it could not be controlled whether externalization plays a role. In addition, the content to be learned was already known to the participants, as all had completed the gross anatomy course. Therefore, it could be said that the study refers to recap and consolidation of anatomical knowledge in a sense of deeper learning. In this context, however, this is acceptable as the participants had the same initial situation and are still in their studies, so it is ethically correct that everyone should have the same opportunity to learn. Furthermore, and as mentioned above, the participants in the group that used the tablet did not have additional time to familiarize themselves with the mobile device and the application. The other two groups knew the resources used for their learning strategies very well. In addition, the group with the tablet had to switch between the paper script and the tablet again and again during the learning phase. This constant switching could have distracted the participants too much. Some of the students also stated that the learning text was too long and that the learning phase, therefore, took too long. Perhaps the learning text could be shortened, or a break could be planned. Another limitation of the study is that the students had to draw or summarize from memory, since the structures or the names of the structures were not shown while they were drawing or summarizing. Perhaps, it would have been more effective if the participants had seen the structures or at least the names of the structures during the drawing or summarizing. However, reproducing learned content without help can also have a positive impact on the learning experience. Students gain insight into their abilities and can improve their self-awareness, it makes them think.[73] The last limitation is the lack of monitoring of the participants' learning behavior between the two post-tests. There were 4–6 weeks between the first and second appointment and it could not be controlled whether and how they learned the topic again themselves. This could have influenced the result of the delayed post-test.

Considering these limitations and the potential for improvement, the findings that drawing on a tablet can be considered an equivalent method for anatomy learning can be seen as a good indicator of the high future potential of this method. Future research can continue to focus on drawing on a tablet as a learning method. One could incorporate the tablet or application into the anatomy course to get students more accustomed to it. In addition, the application on the tablet could be further developed with features to support the learning process, such as learning texts that can also be displayed together with images on the tablet, thus eliminating the need to switch between the different learning media. Also, more complex topics can be presented in the future with the help of the application, but for this study, this less complex topic was chosen mainly because of its good representability and comparability and because of its clinical relevance.

CONCLUSIONS

This study aimed to find out to what extent drawing on the tablet can be used as a learning method in gross anatomy. The results suggest that drawing on the tablet can be considered equal to learning with paper-based methods and that the quality of drawings and summaries moderates the learning outcome of the students. Overall, these findings suggest that new technologies can be used to assist students in their learning. The drawing application the workgroup developed for this purpose is still in its infancy. It has the potential to be further optimized to take advantage of the unique properties of digital drawing, to facilitate the learning process, and therefore to positively affect learning outcome in anatomy.

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