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User Experience of a 3D Interactive Human Anatomy Learning Tool

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ABSTRACT: Embodiment is particularly relevant for learning anatomy as the knowledge to be acquired is related to the body itself. Several tools using three-dimensional (3D) anatomical structures and avatars (e.g. augmented reality; virtual reality; immersive anatomy; 3D animations) were developed to enrich students' experience by including gestures and body movements into learning anatomy. We developed a new interactive 3D tool that allows personal body experience and enhances spatial representation of musculoskeletal functional anatomy. Students can analyze and recreate a series of movements in real-time 3D interactive settings. This paper shows our research and development approach. Following the development of our anatomy tool, we conducted a pilot and one experiment. The pilot study aimed at evaluating users' experience (UX) of our first prototype. Experiment I aimed at evaluating the UX of the second version of the tool two times in a pretest-training-posttest design. Students' spatial and motor imagery abilities as well as anatomy examination results were also collected. Our results provided evidence of UX enhancement. Accordingly students appreciated mainly the tool's hedonic (enjoyment) qualities. Overall, significant interactions were observed between students' UX, anatomy scores and motor imagery abilities. Finally, students' mental rotation ability predicted the increase of anatomy score. Cognitive sub-processes underlying functional human anatomy learning as well as students' identification through the avatar are discussed.

Keywords: 3D tool, Anatomy, User experience, UX, Spatial ability, Motor imagery

1. Introduction

Computing technologies have transformed anatomical sciences education during the last decade (Trelease, 2016). Numerous programs worldwide have integrated online digital learning tools as supplementary resources: e.g. eBooks (Pickering, 2015), social media (Pickering and Bickerdike 2016), massive open online courses (Swinnerton et al., 2017), 3D animations (Hoyek et al. 2014), smartphone and tablet applications (Lewis et al., 2014), 3D-printed specimens (McMenamin et al., 2014; Lim et al., 2016), augmented, mixed and virtual reality (Küçük et al., 2016; Moro et al., 2017).

The results of the studies that have investigated the impact of such digital resources on learning outcomes have proven to be variable. For instance, Khalil et al. (2005) did not report significant differences in learning outcomes when comparing computer-based interactive and paper-based static instructional materials. Several other studies did not find any beneficial pedagogical effects of 3D stereoscopic models or videos on anatomy learning outcomes (Saxena et al., 2008; Hopkins et al., 2011; Tan et al., 2012). Conversely, Nicholson et al. (2006) as well as Abid et al. (2007) reported that 3D-computer-based anatomy graphics enhanced medical students' learning outcomes. More recently, Hoyek et al. (2014) demonstrated the effectiveness of 3D digital animation compared to 2D drawings embedded into PowerPoint® slides in an authentic classroom context. Regarding X-reality or XR applications (augmented, virtual and mixed reality) there remains a paucity of robust empirical evidence to justify the efficiency of such resources on learning outcomes (Clunie et al., 2018). While Moro et al. (2017) found that learning outcomes remained unchanged and that students exhibited blurred vision headaches and dizziness, Küçük et al. (2016) found a positive effect of augmented reality on learning outcome as well as a reduction of cognitive load after using the resource.

Several reasons may explain such confounding results: (i) the difficulty and specificity of the anatomical topic to be studied; (ii) students' individual differences, notably spatial and motor abilities; and finally, (iii) the interaction between the learner's abilities and the instructional tool (Nguyen et al., 2012; Hoyek et al., 2014). According to the compensating hypothesis, 3D-multimedia resources allow students with low spatial ability to better build their mental model of the anatomical structures (Mayer, 2002; Hegarty & Kriz, 2008). Conversely, the enhancer hypothesis (Hegarty & Sims, 1994; Hegarty, 2005) states that high spatial students are better equipped to process 3D resources as they have enough cognitive capabilities for building efficient mental models. In line with the above-mentioned hypotheses, researchers have been suggesting that learning requires a strong interaction with the environment in general and with digital tools in particular (Nguyen et al. 2012). This is called embodied cognition and it includes all cognitive processes that are linked to the body's interaction with the environment (Jang, 2010).

Embodied cognition is gaining traction and its efficiency in learning has been demonstrated in a wide variety of sciences (e.g., Barsalou, 2008; Cook et al., 2017). This embodied perspective is particularly relevant for learning anatomy as the knowledge to acquire is related to the body itself. Augmented reality (Jain et al., 2017) and virtual reality and immersive anatomy (Weyhe et al., 2018) tools were developed to enrich students' experience resulting in a positive feedback (Hoang et al., 2017). Bauer et al. (2017) developed a mirror-like augmented reality allowing students to move while observing their anatomical structures reaction in real time. Such educational technologies enable researchers and teachers to include more gestures and body movements into learning anatomy. Nevertheless, such initiatives remain scarce and their logistics and developments are expensive.

Triggering embodied cognition during anatomy learning does not necessarily require sophisticated multimedia tools, e.g.: tracing an arrow on a diagram or pointing a word in a text (Macken & Ginns, 2014), facial expressions and hand or forearm movements (Cherdieu et al., 2017; Dickson & Stephens, 2015; Oh et al., 2011), body painting (McMenamin, 2008), drawing on t-shirts (Skinder-Meredith, 2010). All these techniques enhanced learning outcomes. In the STEM (Science Technology Engineering Mathematics) field, Johnson-Glenberg and colleagues (Johnson-Glenberg, 2018; Johnson-Glenberg & Megowan-Romanowicz, 2017) proposed a taxonomy to assess the amount of embodiment in STEM lesson, ergo the amount of sensori-motor engagement, the congruency between gesture and content, and the amount of immersion experienced by the user.

This embodied perspective is particularly relevant for learning musculo-skeletal functional anatomy as the knowledge to be acquired is the movement itself. Movement execution (enacted encoding) during learning and memorizing action sentences results in better performance than simply memorizing the sentences (verbal encoding) (Macedonia & Mueller, 2016). Understanding musculo-skeletal functional anatomy requires not only spatial abilities but also motor imagery which is the ability to imagine a human movement without any real movement execution (Jeannerod, 1994). We used spatial abilities and motor imagery processes to design, develop and validate the efficiency of hundreds of 3D anatomy animations (Hoyek et al., 2014; Berney et al., 2015). However, our 3D animations lacked interaction as they are passively visualized by students. Based on all previous studies and given the place of both movement and interaction in functional anatomy learning we developed a new interactive 3D tool called Antepulsio®. While there are hundreds of applications that provide animations of muscle movement, Antepulsio® is the first application that allows student to analyze and recreate a movement and see feedback on the correctness of the choice. Such manipulation of anatomical structures helps learners to map structures to their own bodies' coordinate systems (Amorim et al., 2006). As stated by Jang and colleagues (2017), "objects that are perceived to be anatomical in nature may prime a more embodied approach to mental imagery than abstract figures." (p. 152). In this perspective, Antepulsio® exercises have a strong potential to trigger embodied cognition. The aim of this paper is to present Antepulsio® instructional design and its research and development approach. Users' experience (UX) tests using the Attrakdiff questionnaire (Hassenzalh, 2003; Lallemand et al., 2015) were conducted. Students' spatial and motor imagery abilities as well as their anatomy examination results were collected. Based on our theoretical and literature review, our research aims to study the relationship between users' experience, anatomy score and spatial and motor imagery abilities.

It is noteworthy to state that this paper does not study the impact of implementing Antepulsio® or to measure embodiment as a mediating variable for students' learning outcomes. Rather, we focus on how improving UX may impact students' performance and how it interacts with some embodied cognition-related variables such as spatial and motor imagery. Hence, the following research questions (RQ) were developed:
RQ1: Does enhancing the application impact the UX?
RQ2: Does the UX have any impact on anatomy scores?
RQ3: Do students' spatial and motor imagery abilities interact with their UX?
RQ4: Do students' spatial and motor imagery abilities interact with their anatomy examination results?
Answering these questions will help teachers and developers in their general Research and Development (R&D) process especially through introducing UX when designing an anatomy 3D tool.

2. General method

2.1. An iterative design process using UX

We used an evidence-based tool design strategy. This process is at the core of our agile manufacturing. Following the development of Antepulsio®, we conducted two experiments. The pilot study aimed at collecting the baseline UX (Baseline 1 – B1) from our first prototype using the Attrakdiff2 (Hassenzalh, 2003; Lallemand et al., 2015) questionnaire (T0). This first version of the tool was evaluated by students enrolled in our functional anatomy course (2018–2019 academic year). Students' official anatomy exam scores were collected before the UX experiment to verify if previous knowledge yielded any effect on UX. Based on UX evaluation and students' feedback, we improved the tool during a redesign process.

Experiment I aimed at testing Antepulsio®'s UX enhancement in a pretest-posttest paradigm. A new student cohort enrolled in our functional anatomy course (2019–2020 academic year) assessed Antepulsio®'s UX (T1: pre-test). They were then enrolled into a one week-long training session using Antepulsio®. The tool's UX was finally tested at (T2 post-test) after the training sessions to verify if any differences with T1 were to be observed. All participants signed an informed-consent form before starting the study. Our local management and ethics committee approved the experimental design after the experimenters presented the objectives and procedures to the scientific board council.

2.2. Anatomical and pedagogical content of Antepulsio® application

The game engine Unity® was used to develop Antepulsio®. A real-time physical simulation model of the human body allowing realistic motions was used to replicate muscle contraction. The three types of muscular contraction could be reproduced by the model: eccentric, static and concentric. The following presentation of the tool is a general description of the four different types of exercises that were developed. More information on the differences between the first and second version of the tool and design decisions is available in section 3.2 and 6.2.

2.2.1. Exercise 1: Muscle understanding

The aim of this exercise is to associate a muscle to a movement that it produces. The learner has to identify a muscle on a static position of the 3D model and then to visualize the different muscular insertion points. This allows for displaying the details of the muscle localization and or users to predict its movement following contraction. Lastly, the student can observe the muscle action in motion.

2.2.2. Exercise 2: Movement analysis

The learner must observe a movement and its kinematics and then execute the movement. The learner has to divide the movement into several components by using the appropriate movement terminology and locating the mobile against the immobile body segment. In the second stage the learner has to analyze the type of muscle contraction needed for that movement. Finally, the learner needs to identify the agonist responsible muscles.

2.2.3. Exercise 3: Movement reproduction

The knowledge and skills outlined in the two previous exercises (i.e., kinematics, type of contraction, muscles function, terminology) need to be acquired to complete this exercise. After watching a movement, the learners have first to execute the movement and then to reproduce it precisely in the application. After choosing all the appropriate muscles with their respective contraction type the student can launch the 3D simulation in order to verify whether the movement they reproduced is identical to the original one (see Figure 1).

2.2.4. Exercise 4: Assessment

This summarizing exercise is a multiple-choice questionnaire. It allows the learners to evaluate themselves and get feedback on their comprehension level.

Retrouver quel(s) muscle(s)/régime(s) de contraction sont sollicité(s) en le(s) sélectionnant sur le mannequin si dessous.

postérieurs du tronc (droit)
concentrique
oblique externe (droit)
concentrique
oblique interne (droit)
concentrique

Mauvaise réponse:
- il manque un ou plusieurs muscles effecteurs
- des muscles non effecteurs ont été ajoutés
- le régime de contraction de certains muscles effecteurs est faux

Figure 1. Validation step of the exercise 3: Movement reproduction. The student here made a mistake by choosing the wrong muscles and wrong contraction type while analyzing slow trunk flexion in standing position

3. Pilot study

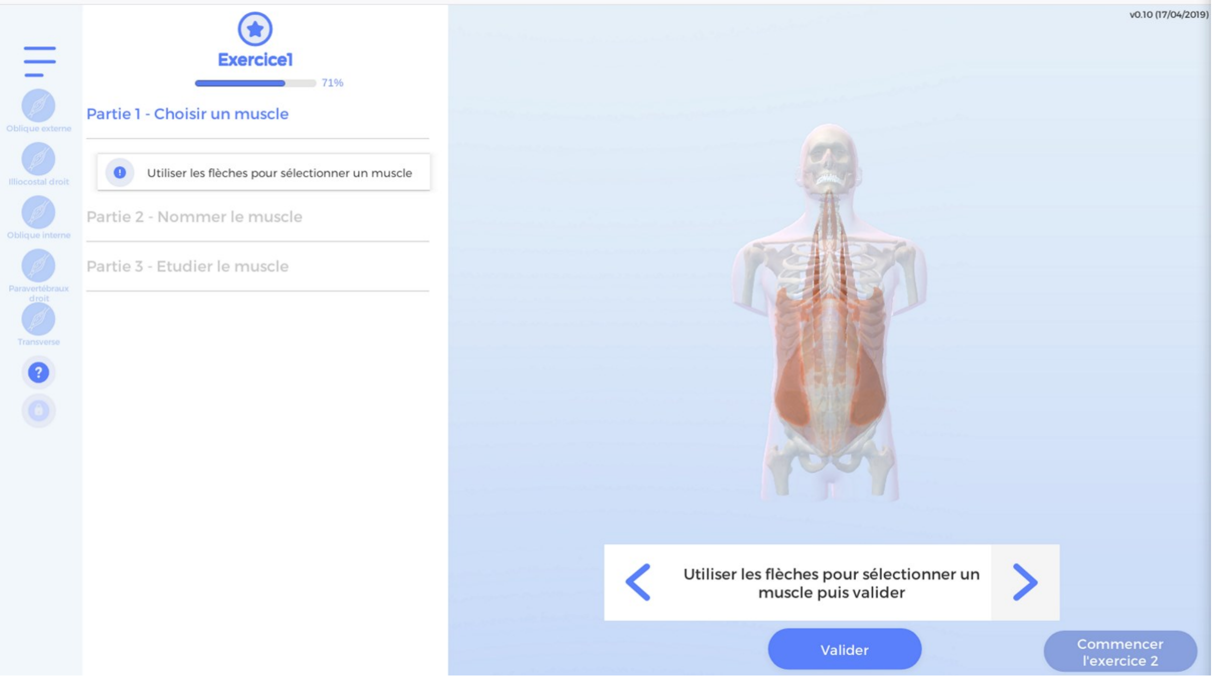
3.1. Sample and procedure

Forty-five students (7 females; age: 17.89 ± 0.83 years) enrolled in our first-year kinesiology program at Lyon 1 University (2018– 2019 academic year) participated on a voluntary basis in this first experience. After following an entire functional anatomy course (fall 2018) they tested the first version of Antepulsio® in April 2019 (B1). For more information on the curriculum design and the 3D tools used during the semester see Hoyek et al. (2014). None of them had previously tested the Antepulsio® tool. They tested the app individually in a quiet room. Students tested once all four types of exercises and their corresponding steps (see section 2.2). To pass to the following step/exercise they had to validate the previous one. They had no time constraint. They had an unlimited number of tries. An average of 20 minutes was needed to complete the exercises. Students' feedback on the tool's properties (ergonomics, usability, ease of use, etc.) was collected during focus groups after the completion of each exercise and at the end of the session. Finally, the Attrakdiff2 (Hassenzalh, 2003; Lallemand et al. 2015), UX measurement tool was administered.

3.2. Material

3.2.1. Antepulsio® version 1

The first version consisted of the above-mentioned exercises. The learning path was linear and progressive (see Figure 2). Students could not pass to the following exercise before validating the previous one. Students were guided in every single step through written instructions. Furthermore, the User Interface contained the following features: (i) buttons and textual information were positioned in several locations on the screen; (ii) different font types and sizes were used; (iii) the remaining steps of an exercise were permanently present on the screen.



Utiliser les flèches pour sélectionner un muscle

Utiliser les flèches pour sélectionner un muscle puis valider

Figure 2. Antepulsio® version 1-Exercise 1: Muscle understanding

3.2.2. Students' feedback

Oral feedback from the students was collected regarding each of the application exercises. The scientific assistant noted down the feedback given by each subject in a table. At the end of the session they had to answer the three following questions: (i) What is your general opinion regarding Antepulsio®; (ii) Would you use Antepulsio® for studying anatomy? (iii) What could be enhanced in the application? The answers/feedback for each question are used to support our quantitative findings.

3.2.3. UX

Attrakdiff2 (Hassenzalh, 2003; Lallemand et al. 2015), a quantitative UX measurement tool, evaluates the hedonic and pragmatic qualities of an interactive system. It is a standardized questionnaire with four subscales of seven items each, for a total of 28 items. The items are in the form of pairs of contrasting words to be assessed using 7-point Likert scales, ranging from -3 to +3. The order in which the items are administered is standardized and the items are mixed. The Attrakdiff subscales are as follows : Pragmatic Quality (PQ) describes the usability, the usefulness of the product and indicates how well the product enables users to achieve their goal in completing task ; Hedonic Quality-Stimulation (HQ-S) indicates the extent to which the product can support the need for stimulation ; Hedonic Quality -Identification (HQ-I) indicates the extent to which the product allows the user to identify with it; and the Appeal (APP) , or the global attractiveness is a value of the product based on the perception of pragmatic and hedonic qualities. We measured the average of each subscale for each completed questionnaire by the students.

3.2.4. Anatomy score

We collected the scores obtained by each participant during their official anatomy exam (fall 2018 session) which happened before the student's use of the tool and their UX measurements. It is a standardized 20-item questionnaire with three possible answers: true, false and "don't know". We recorded the correct answers.

4. Results

4.1. UX properties

Attrakdiff constructs Cronbach's alphas ranges from .60 to .83. They yielded normal distributions ($.086 < D_{K\text{-}S} < .200$; $p > .05$). Anatomy Score (AS) also yielded a normal distribution: M = 11.59; SD = 3.98; $D_{K\text{-}S} = .110$; $p > .05$. Confirmatory Factorial Analyses to verify models fitness with our data couldn't be ran as the ratio between N and the model's number of parameters (9 in our case) should be from 5 to 10 cases for each parameter (Bentler & Chou, 1987; Bollen, 1989; cited by Kyriazos, 2018). As our ratios are 5 for B1 and 1.89 for T1 and T2, CFAs were not calculated. Furthermore, it is generally preferable to conduct CFAs with large samples (Brown, 2015; Kline, 2016; cited by Kyriazos, 2018). As in Hassenzahl and colleagues' original tool validation study (2013) and in Lallemand and colleagues' French validation study (2015), we found that both hedonic scales are correlated ($r = .422$; $p < .05$), PQ is also correlated with HQ-S ($r = .468$; $p < .05$) and HQ-I ($r = .439$; $p < .05$) hedonic scales. On the other hand, a regression analysis confirmed that PQ, HQ-S and HQ-I positively predict APP: $\beta = .465$; $p < .001$; $R^2 = .607$. Descriptive results and Kolmogorov-Smirnov normality tests ate shown in Table 1.

Table 1. Attrakdiff dimensions and Anatomy score descriptive results and Kolmogorov-Smirnov normality tests at Baseline 1 (B1)

	B1 ($N = 45$)			
	M	SD	$D_{K\text{-}S}$	α
PQ	1.02	.61	.086	.60
HQ-S	1.63	.79	.092	.78
HQ-I	.78	.74	.095	.72
UX	1.14	.54	.097	.80
APP	1.82	.69	.123	.83
Anatomy Score	11.59	3.98	.110	

UX subdimensions ranged from $M = .78$; $SD = .74$ (for HQ-I), to $M = 1.63$; $SD = .79$ (for HQ-S). The overall UX means is: $M = 1.14$; $SD = .54$ and the tool's overall appeal is $M = 1.82$; $SD = .69$. All values are above 0, which indicate a satisfying tool's UX assessment from the students.

4.2. UX and anatomy score

All correlation tests between the Attrakdiff dimensions (including global UX score) and Anatomy Score display non-significant results ($p > .05$). We further investigated for a potential link between anatomy scores and UX by breaking the sample down into a low-level group and a high-level group using the anatomy score median as a cutoff point ($Md = 11$). One-way ANOVA F-tests between group membership and all Attrakdiff dimensions yielded no significant differences ($p > .05$).

5. Discussion

Our first results provided evidence that all Attrakdiff subscales are intercorrelated; and pragmatic and hedonic qualities contribute to the tool's global appeal. These results are in line with the theoretical model description of Attrakdiff (Hassenzalh, 2003; Lallemand et al., 2015). Using the Attrakdiff2 is thus appropriate in our R&D process. Furthermore, our students found this first version attractive. It is noteworthy to point out that students had already attended a semester during which they learned anatomy using our classical 3D animations (see Hoyek et al., 2014). Giving the efficiency of our existing 3D animations (Hoyek et al., 2014), this gives more value to the global attractiveness of Antepulsio®.

Furthermore, students' verbal feedback was considered in the development of the second version of the application. The main positive feedback was: the interaction with the avatar enables a better 3D visualization of movement facilitating motor imagery; the interaction makes the students more active in their learning process; a good tool for revision and for assessments. The main negative feedback was: too much guidance in order to pass from an exercise to another; some guidelines were not clear; some exercises were lacking immediate feedback on the correctness of the response; legends explaining the colors associated to muscle contraction type were missing; exercises required a lot of time to be completed; small software bugs (see section 6.2).

Finally, the pilot study does not reveal any correlation between the Attrakdiff dimensions and students' anatomy scores. Using a median split, lower and higher knowledge student rated Antepulsio® equally. More complex interaction between anatomy scores and the enhanced version of Antepulsio® is discussed in Experiment I.

6. Experiment I

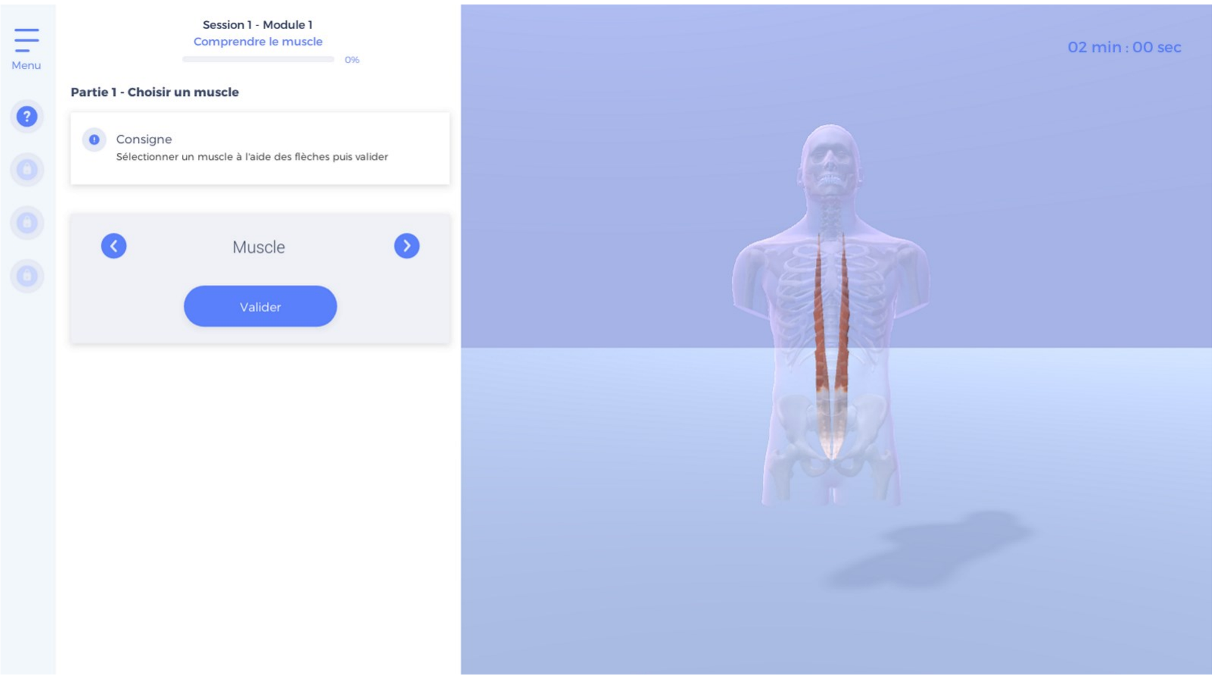
6.1. Sample and procedure

A year later, a second improved version of Antepulsio® was tested by a new cohort of 17 students (6 females; 18.07 ± 0.80 years) in October 2019. Students were enrolled into our functional anatomy course (2019–2020 academic year). They were also exposed to our previous 3D animations and were enrolled into similar curriculum design (see Hoyek et al. 2014). The experimental protocol consisted of a pre and post-training paradigm implemented into a semester. Students participated in three training sessions using Antepulsio®. They tested individually in a quiet room the application. At the beginning of session 1, students completed spatial ability and motor imagery tests. Session 1 consisted of 7 thematic modules (see 6.2 section below) and lasted 25 minutes and was programmed to stop automatically when time ran out. At the end of Session 1, the Attrakdiff2 questionnaire was administered (T1). Session 2 contained 8 different thematic modules and lasted 20'. Session 3 contained 7 new different thematic modules and lasted 20'. At the end of Session 3, the Attrakdiff2 questionnaire was administered (T2). Students had up to 3 tries/step to answer each question. One night, at least, separated each session.

6.2. Material

6.2.1. Antepulsio® version 2

Version 2 consisted of the same above-mentioned exercises (see Figure 3). However several improvements were made. The learning path was reorganized into thematic modules (e.g., concentric muscle contraction; abdominals; ball throwing analysis; etc.). However those latter were not always organized from Exercise 1 to 4 in a linear way. Students could navigate by choice, that is they could postpone an exercise, pass to another one and come back later to complete it. A timer was inserted in the upper right corner. Several modifications were made to the User Interface: (i) buttons and textual information were positioned in the left part of the screen; (ii) font types, sizes and colors were better organized and unified across exercises; (iii) only the title of the exercise's step was shown along with a percentage of progression giving students more information on the remaining steps to complete the exercise.



Sélectionner un muscle à l'aide des flèches puis valider

Figure 3. Antepulsio® version 2-Exercise 1: Muscle understanding

6.2.2. UX

The Attrakdiff2 questionnaire was administered to compare scores to the original Baseline scores from version 1.

6.2.3. Spatial ability

Spatial Ability (SA) was measured using the Vandenberg and Kuse Mental Rotation Test (MRT: Vandenberg and Kuse, 1978). It is a paper-and-pencil test that consists of 24 items of 3D-objects. Each item consists of 5 figures, a 3D model on the left and 4 on the right among which participants must indicate those that are similar to the model. Participants have to mentally rotate the target figures to find the two correct items that match the reference. The score can range from 0 to 24. One point is given for an item only if both correct test figures were identified. The test was to be completed within a 6-minute period. This test was performed before training.

6.2.4. Motor imagery

Motor Imagery (MI) was measured using a laterality judgement test. It consists of a computer-based test that presents different hand stimuli on the screen: right or left hand, back or palm hand in various orientations (0°, 90°, 180°, 270°). Participants had to find the laterality of a stimulus without any hand or head movements by pressing on the keyboard's left or right arrow. The number of correct answers was collected. This test was carried out before training.

6.2.5. Anatomy Score (AS)

Like the pilot study, the correct answers of 20-items that were randomly selected from the same database were recorded. The anatomy test was run a second time at T2. The goal was to verify for any significant differences in anatomy knowledge after the one-week training using the tool, and if the knowledge change interacted significantly with UX.

7. Results

7.1. Descriptive results

Results at T1 and T2 indicate higher UX means than at B1 (Table 2). The normality assumptions for parametric tests were met for all constructs ($.127 < D_{K\text{-}S} < .897$; $p > .05$), except for MI ($D_{K\text{-}S} = .674$; $p < .05$). Moreover, UX means at T2 are higher than at T1. T-tests will be conducted to verify if these differences are significant.

Table 2. Attrakdiff dimensions, mental imagery abilities, Anatomy score results and Kolmogorov-Smirnov normality tests at T1 and T2

	T1 (*N* = 17)			T2 (*N* = 17)		
	M	*SD*	$D_{K\text{-}S}$	*M*	*SD*	$D_{K\text{-}S}$
PQ	1.32	.61	.158	1.39	.62	.154
HQ-S	1.73	.66	.184	1.85	.70	.225
HQ-I	1.64	.68	.127	1.85	.74	.182
UX	1.50	.38	.209	1.62	.45	.157
APP	1.79	.68	.216	1.94	.46	.198
Spatial Ability	5.47	2.67	.924			
Mental Imagery	61.47	3.67	$.674^{*}$			
Anatomy Score	12.47	2.76	.897	14.41	4.88	.935

Note. $^{*}p < .05$.

7.2. UX scores change between B1 and T1

We conducted independent *t*-tests between T1 and B1 for Attrakdiff evaluations (i.e., the delta - Δ) to verify significant differences, as samples are independent (see Table 3). Results display significant deltas between B1 and T1 for HQ-I only with a large effect size ($t = 4.17$; $p < .001$; $d = 1.18$); as well as for UX ($t = 2.51$; $p = .015$;

d = .71) for a medium to large effect size. Even if PQ change's *p* value is non-significant, it still yields a medium effect size. Attrakdiff dimensions' change yield an overall significant and large UX change (*Δ* = .36).

Table 3. Independent *t*-tests between T1 and B1

	Δ	*t*	*p*	*d*
PQ	.30	1.72	.090	.49
HQ-S	.10	.46	.645	.13
HQ-I	.86	4.17	.001	1.18
UX	.36	2.51	.015	.71
APP	-.03	-.15	.879	-.04

7.3. UX scores change between B1 and T2

Independent *t*-tests were also conducted between B1 and T2, for the same reasons as mentioned above (table 4). In contrast with the T1-B1 comparison, all B1-T1 Attrakdiff dimensions deltas display significant changes except for HQ-S. In order of descending effect size: HQ-I (*Δ* = 1.07; *t* = 5.07; *p* < .001; *d* = 1.44); APP (*Δ* = .14; *t* = 3.88; *p* < .001; *d* = 1.10); PQ (*Δ* = .37; *t* = 2.12; *p* = .038; *d* = .60) and HQ-S (*Δ* = .22; *t* = 1; *p* = .318; *d* = .28). These results lead to a significant overall UX score change: *Δ* = .48; *t* = 3.25; *p* = .002; *d* = .92; with a large effect size.

Table 4. Independent *t*-tests between T2 and B1

	Δ	*t*	*p*	*d*
PQ	.37	2.12	.038	.60
HQ-S	.22	1.00	.318	.28
HQ-I	1.07	5.07	.001	1.44
UX	.48	3.25	.002	.92
APP	.14	3.88	.001	1.10

7.4. UX scores change between T1 and T2

We ran paired-samples *t*-tests between T2 and T1 for our test-posttest sample (table 5). The results indicate no significant change between T1 and T2 for any of the Attrakdiff dimensions, nor for the overall UX dimension (all p-values are above the .05 confidence interval). Despite a non-significant *p* value, we can still observe – small – effect sizes for HQ-I and UX's deltas (respectively: *Δ*M = .20; *d* = .23 and *Δ*M = .11: *d* = .17).

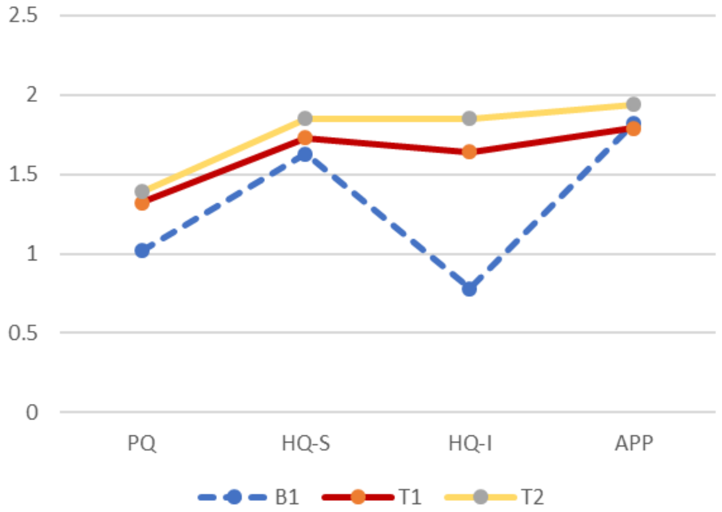


Figure 4. UX assessments at B1, T1 and T2

Table 5. Paired *t*-tests between T2 and T1

	ΔM	*t*	*p*	*d*
PQ	.07	.55	.589	.09
HQ-S	.11	.55	.587	.13
HQ-I	.20	1.44	.168	.23
UX	.11	1.24	.230	.17
APP	.14	1.00	.332	.19

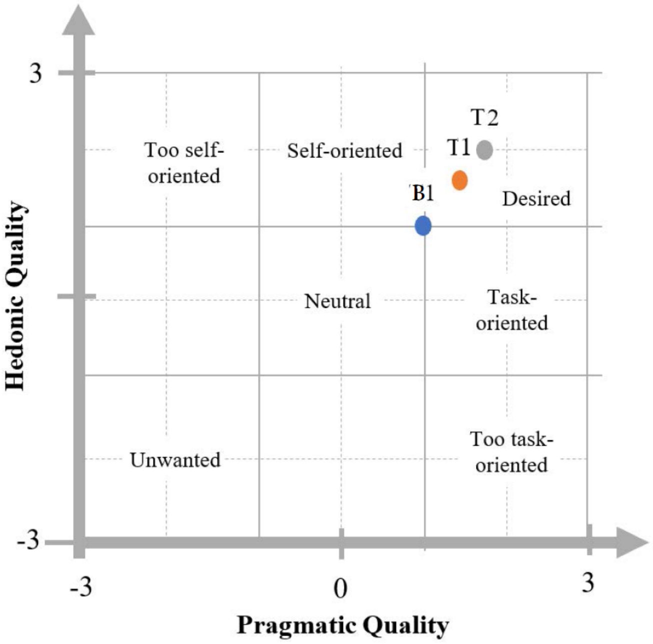


Figure 5. UX change between B1 and T23

Using the UX framework based on Attrakdiff, as proposed by Lallemand et al. (2015) and inspired by Hassenzahl (2003, p. 37), Figures 4 and 5 show a qualitative enhancement of Antepulsio®'s UX during our experimental protocol. The most significant enhancement was between pilot study and experiment 1, especially for the HQ-I dimension. At B1, UX was positioned at the intersection between four zones: The Neutral, the Self-Oriented, the Task-Oriented and the Desired zones. Then, at T1 and T2, Antepulsio®'s UX assessments yielded a complete entry into the Desired zone, which indicates a balance between the tool's hedonic qualities and pragmatic qualities. In other words, the system provides strong enjoyment qualities, as well as strong effectiveness.

7.5. Anatomy score change between T1 and T2

The anatomy score's delta between T1 and T2 (Δ_{AS}) score yielding a normal distribution (D_{K-S} = .139; *p* = .200), we ran a paired-sample *t*-test with our test-posttest population to verify if the one-week training significantly improved the anatomy score (AS) . The result indicates a significant and positive change: Δ_{AS}M = 1.94; Δ_{AS}SD = 3.03; *t* = 2.64; *p* = .018; *d* = .77.

7.6. Anatomy score and UX

To run tests on Anatomy Score (AS), we used Δ_{AS} to verify if the training-post-training AS difference significantly interacted with any of the Attrakdiff dimensions. We found that the general Hedonic Quality mean (HQ) at T2 is negatively correlated with Δ_{AS}: *r* = -.500; *p* = .042. Whereas the pragmatic perception (PQ) yields no interaction with performance.

7.7. Motor imagery, spatial ability, UX and performance

Embodiment-linked processes were also verified. Mental Imagery at T1 was found to predict PQ at T2 (i.e. by the end of the experiment), explaining 20% of PQ's variance: $\beta = .491$; $p < .05$; $R^2 = .200$. Consequently, MI was also found to predict the overall UX score at T2, explaining 23.50% of UX's variance: $\beta = .532$; $p < .05$; $R^2 = .235$

On the other hand, Spatial Ability was found to predict Δ_{AS}, explaining 33% of Δ_{AS}'s variance: $\beta = .575$; $p < .05$; $R^2 = .330$. Consequently, we ran regression analyses with Δ_{AS} as a predicted variable, to investigate predictive models. We executed Model 1, which comprises only PQ and HQ as UX dimensions predictors at T2. We also executed Model 2, with PQ and HQ, to which we added SA, as predictors. Results of regression models with ΔAS as a predicted variable are shown in Table 6.

Table 6. Regression models with Δ_{AS} as a predicted variable at T2

	Model 1		Model 2	
Predictors	β	p	β	p
Constant	6.08	.035	7.83	.005
PQ	.220	.356	.236	.253
HQ	-.547	.033	-.432	.049
Spatial Ability			.491	.028
F	2.90	.088	4.68	.012
R^2	19.20%		41%	

In Model 1, HQ at T2 significantly predicts Δ_{AS}: $\beta = -.547$; $p = .033$. Whereas PQ (T2) do not yield a significant effect within the model ($p = .356$). Total explained variance for Model 1 is $R^2 = 19.20\%$. In Model 2, HQ at T2 significantly predicts Δ_{AS}: $\beta = -.432$; $p = .049$. SA improves the model's variance by a $\Delta R^2 = 21.80\%$, and significantly predicts Δ_{AS}: $\beta =.491$; $p = .028$. Consequently, Model 2 explains $R^2 = 41\%$ of Δ_{AS}' variance. Hence, results indicate that both HQ and SA predict the change of the anatomy score between T1 and T2.

8. Discussion

The test-posttest design of Experiment I provided a more complete overview of Antepulsio®'s UX. First, our results provided evidence of a significant and large UX improvement especially for the HQ-I dimension between the second version of the application (T1 & T2) and the first prototype (B1). Thus, the enhancement made following Experiment I had a positive impact on students' experience (UX) and appreciation (RQ1). The increase of HQ-I may be explained by the guidelines enhancements and the additional legends associated with colors explaining the type of muscle contraction. This increase might also be explained by the fact that HQ-I had the lowest score at B1 ($M = .78$) giving a large space for improvement. These enhancements may have led students to better identify themselves to the application in general and to the 3D avatar in particular. We assume that the legends and visual cues have helped students in their 3D visualization of anatomical structures. This is in line with Roach et al. (2018) study who provided evidence that guiding students where to look improves their spatial reasoning. The authors suggested that visual guidance may be applied in anatomy to improve student's interpretation of visual content such as anatomical structures.

We did not find any significant change for any of the Attrakdiff dimensions between T2 and T1. This result is mainly explained by the fact that the same application was tested two times by the same students within the same week. Furthermore, this result suggests that there is no effect of three training sessions on UX. In other words, learning about the content conveyed by the application and learning how to use the application itself did not significantly improve Antepulsio®'s UX scores. This result is at odds with previous studies (Bhattacherjee et al., 2004; Venkatesh et al., 2011; Martin et al., 2016) where interaction with an application significantly decreases UX after use. The fact that Antepulsio®'s UX did not decrease after use gives more value of its acceptance by students.

The fact that the HQ-I dimension has been found to evolve in comparison with the other Attrakdiff dimensions says something about the evoked cognitive processes when using Antepulsio®. We assume that interactions with a human avatar enables user's identification. Several cognitive sub-processes may have been called upon in this very complex self-identification. For instance, individuals express their self through physical objects (Prentice, 1987; Hassenzahl, 2003). We assume that interacting with a human avatar calls upon empathy (Hamilton-Giachritsis et al., 2018). Mental and motor imagery, action observation and embodiment are part of empathy components (Decety & Jackson 2004). One sees others through one's own embodied cognition (Decety and Jackson 2004). When using Antepulsio®, students are turning the avatar in 3D, imagining the movement to study and observing the avatar's movement, making several clicks to interact with the avatar. All these processes share similar underlying neurocognitive processes (Decety & Jackson 2004; Vogt et al., 2013) and may be behind this significant increase of HQ-I.

Unlike the pilot study, we found an interaction between students' UX and their anatomy scores (RQ2). More precisely, the hedonic quality mean at T2 was negatively correlated with the anatomy scores. This result indicates that anatomy scores interact with a decrease of the tool's hedonic perception, whereas the pragmatic perception yields no interaction with performance. Learning Antepulsio®'s conveyed content decreased the general pleasure using the tool. We can speculate that when the learning goal is reached, the hedonic perceived quality wears out. In other words, the instrumental interest and the enjoyment decreases, whereas the tool's pragmatic qualities are equally perceived as it helped participants reach their learning goals. Indeed, as stated by Hassenzahl (2003, p. 34), "a pragmatic product is primarily instrumental. It is used to fulfil externally given or internally generated behavioral goals." Hedonic quality, however, focuses on "the Self, i.e., the question of why does someone (...) use a particular product" (Hassenzahl, 2010, p. 50). This is in line with two of students feedbacks. First, they stated that Antepulsio® is a good tool for revision. This gives us clear indication regarding its future implementation in our curricular design in order to keep the hedonic stimulation as high as possible. Secondly, students stated that some exercises required a lot of time to be completed. Even though we shortened the exercise length, perhaps more of the exercises could be shorter and more pleasant.

Finally, motor imagery predicts PQ and overall UX score at T2 (RQ3). To our knowledge, this is the first time that motor imagery ability is linked to UX in general and to its pragmatic dimension. It is thus difficult to discuss such a novel finding with regards to previous studies. We can however speculate that good motor imagery ability is needed to positively estimate the pragmatic dimension of Antepulsio®. Therefore, our learning tool may be more adequate for high motor imagery students and confirms thus the enhancer hypothesis (Hegarty and Sims, 1994; Hegarty, 2005). This interpretation remains speculative and more research is needed before drawing final conclusions. On the other hand, mental rotation ability predicts anatomy score improvement (RQ4). These results are in line with a huge amount of previous studies ascertaining the importance of good spatial abilities in anatomy knowledge acquisition (e.g. Guillot et al., 2007).

9. Conclusion and implications for design

Fostering embodied learning in functional anatomy is simple because the main knowledge to acquire is the movement itself and its analysis. It can occur through real movement execution, motor imagery or action observation. These latter share similar processes and similar neural substrates (Vogt et al., 2013).

An additional way to foster embodied learning in anatomy passes through real movement execution (exercises 2 and 3) and interactions with the avatar. The clicks and manipulations of the avatar, the perspective changes, the zoom in and out actions are made to better visualize the human body and its movements. According to Wiedenbauer and Jansen-Osmann (2008) manual rotation training enhances mental rotation performance. We thus assume that giving the students the ability to interact with the avatar would enhance their spatial ability and reduce their cognitive load.

Nevertheless, even with such interactions, our results provided evidence that good motor imagery ability is needed to positively estimate the pragmatic dimension of Antepulsio®. The conception of an anatomy digital tool should consider such individual differences as well as students' cognitive load and visual strategies (Mayer, 2002; Hegarty & Kriz, 2008; Hegarty & Sims, 1994; Hegarty, 2005). This would help developers and educators choose the best visual cues to add into their applications to foster empathy and consequently embodied cognition during the learning process.

Another notable result of our study is the importance of students UX during tool development. Our user-centered design method allowed us to improve the app's interface and the exercises gameplay. The enhancement of the Attrakdiff2 scores across our study was noteworthy. Studying in detail the change of its dimensions gave us insight into some of our students' cognitive and psychological learning processes. The overall hedonic dimension can give us insight into the enjoyment perceived by the students. Our students' enjoyment decreased as soon as the pedagogical goals were attained. This will help us enhance our gameplay in the future for a better learning motivation. It will also help us better implement our tool into the curriculum. The hedonic identification dimension may be linked to students' empathy with the 3D avatar and could therefore give insight into the embodied learning process.

Finally, in the absence of a control group, the impact of Antepulsio® on learning outcomes was not studied. The implementation of the tool within our curriculum followed by a randomized controlled study will thus be conducted in the future. Furthermore a quantification of embodiment will be conducted. This will help us better understand the impact of Antepulsio® on complex anatomy concepts understanding.

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