An Assessment of Students' Perceptions of Learning Benefits Stemming from the Design and Instructional Use of a Web3D Atlas

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Abstract: This article has a dual purpose: it describes the development of *First Year Dental Anatomy (FYDA),* a web-based 3D interactive application used in the dental curriculum at a major Canadian university, and it reports on the results of a research study conducted to assess the perceptions of learning benefits students experienced through the use of FYDA in a dental anatomy course. Questionnaires administered upon the completion of three semesters during which FYDA was used reveal some benefits for learning, but also a few deterrents for use, primarily related to some aspects of design. Generally, the students received the application with interest and viewed it as a useful aiding tool in learning dental anatomy. The results suggest the overall 3D models met the students' learning objectives and expectations and, in their view, were conducive to their understanding of internal and external dental anatomy. Issues related to the over-sensitive controls, navigational flaws and manipulation difficulties caused some learners a certain level of frustration, but these were not severe enough to hinder the students' learning.

Keywords: higher education, first year dental anatomy, web-based atlas, web3D technologies, 3D graphics, 3D animations

1. Introduction

With the development of increasingly more sophisticated digital media for graphic design and visual spatial representation of objects in virtual environments, interactive 3D learning tools drawing on cognitive and constructivist learning theories have received much attention in recent years in terms of their instructional utility and pedagogical impact (Dalgarno & Lee, 2010; Huang, Rauch, & Liaw, 2010; Salajan et al., 2009; Wu & Chiang, 2013). This heightened interest in 3D learning tools, however, has not been accompanied at the same level by empirical research designed to test their impact on teaching and learning. Consequently, there is a persistent and perceived need expressed in the educational literature for more such research to illuminate the effects of 3D environments on learning outcomes (Dalgarno & Lee, 2010; Wu & Chiang, 2013).

The medical education field, broadly defined, has been at the forefront in the development of 3D atlases or 3D simulations intended to provide students and practitioners with virtual tools that enhance, supplement and, occasionally, supplant physical tactile environments when necessary (Brenton et al., 2007; Nigel, 2007). Published articles in the relatively early years of exploration and development espoused the 3D models' promise for the improvement of learning outcomes, but were primarily descriptive, rather than analytical in nature (Gehrmann et al., 2006; Sinav & Ambron, 2004; Trelease & Rosset, 2008). In this context, actual empirical studies have begun to emerge that attempt to support the incorporation of 3D materials in medical education and further afield. Thus, Wu and Chiang's (2013) study provided data suggesting that 3D animations improve visual comprehension of objects featuring complex structures. O'Byrne, Patry and Carnegie (2009) found that the use of digital interactive anatomy images are of special value for kinesthetic learners and are supportive of self-learning, a process which requires active and deliberate cognitive engagement on the learners' part (Zimmerman, 1995; Steffens, 2006). Schleich et al. (2009) showed that 3D computer graphics of atrial septation in the human heart led to a significant improvement in the teaching of complex notions and aided in the learning of the mechanics of atrial septation. Petersson, Sinkvist, Wang and Smedby (2009) reported that the *Educational Virtual Anatomy* program designed to teach anatomical dissection had

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potentially beneficial effects on students' knowledge testing and as an electronic resource in comparison with textbook material.

In dental education there is also mounting evidence pointing to benefits of web-based interactive models of instruction using three-dimensional objects. Such web-based tools are also known as Web3D technologies, described by Chittaro and Ranon (2007) as 3D content delivered to a user from a host server via a web browser. Gianquinto (2005) provided acknowledgment that 3D modeling and animation represent a rational progression in curriculum evolution via which students can expand their comprehension of "cavity design, discrimination learning, and procedural critique in a self-directed, self-paced learning environment" (p. 98). An example of early implementation of 3D models in dental education is the *Web-based 3D Online Crown Preparation Course*, designed to afford students with foundational knowledge in anticipation of preclinical skill development for full crown preparations (Spallek et al., 2000). Al-Rawi et al. (2007) suggested that their web-based application including interactive 2D and 3D elements designed for the anatomical interpretation of cone beam computed tomography was at least as effective in conveying the concepts taught as traditional instructional materials. Salajan and Mount (2008) provided examples from an early project which included an application using reconstructed 3D images for the representation of cavity preparations in restorative dentistry. In a follow-up study, Salajan et al. (2009) reported research data on the implementation of three separate web-based programs developed in-house and involving Web3D technologies: *Panoramic Radiography: Principles and Interpretation*, *Gross Human Anatomy 3D Atlas* and *Restorative Dentistry: Virtual and Interactive Cavity Preparations*. The post-implementation research indicated that the interactivity embedded in the applications were instrumental in reinforcing knowledge and in fostering students' learning of difficult concepts.

Given the increased research interest in Web3D technologies in medical and dental education, this article presents the design, development, implementation and evaluation of a 3D multimedia interactive web-based application, *First-Year Dental Anatomy* (FYDA), intended to introduce first year students in the Doctor of Dental Surgery (DDS) program at the Faculty of Dentistry of a major Canadian university to the fundamentals of dental anatomy. FYDA was created as a modular instructional program, combining high-end interactive 3D objects that can be manipulated by the user, 3D animations of anatomical processes and galleries of still images, all of which constitute a rich media environment for DDS students to explore in learning about dental anatomy. Placed within the context of previous research on Web3D technologies informed by cognitive and constructivist learning theories, this study seeks to answer the following questions:

1. What perceived learning benefits do students draw from their utilization of FYDA?
2. What multimedia and interactive design features included in FYDA correlate with students' perceived learning benefits?
3. How useful do the students consider FYDA as a learning aid in their exploration and study of dental anatomy?

A theoretical dyad linking together the cognitive theory of multimedia learning and constructivist learning constitute the epistemological background against which FYDA is explored and analyzed in this article.

2. Theoretical and conceptual framework

The design, structure and use of FYDA were informed by elements of the Cognitive Theory of Multimedia Learning (CTML) and constructivist learning. In this section, we describe these major theoretical strands and their contribution to the patterns of knowledge distribution in FYDA.

2.1 Cognitive theory of multimedia learning

It was just a matter of time before the use of Information and Communication Technologies (ICT) in education would lead to the emergence of theories in cognitive psychology that explicitly attempted to explain how multimedia technologies affect learning processes. Mayer (1997) was the first to propose a generative theory of multimedia learning. In later iterations of this theory, Mayer and Moreno (1999, 2002) re-conceptualized it as the Cognitive Theory of Multimedia Learning by incorporating concepts from dual coding theory, cognitive load theory and constructivist learning.

In Mayer and Moreno's CTML framework, the nonverbal and verbal coding systems proposed and developed by Paivio (1969, 1986) act as the main conduits through which learners process information. As a strand of cognitive psychology, dual coding theory postulates that human cognition is processed through two separate coding systems, one nonverbal and the other verbal. The first one, also called "the imagery system" by Paivio (1986, p. 53), is concerned with the analysis of mental representations, while the second one deals with the processing of language, whether in textual or verbal form. Paivio further contends that the two systems are independent of each other, in that they may both be active in parallel or one can be active without the other.

Cognitive load theory, as described by Chandler and Sweller (1991), regards the way in which cognitive resources are prioritized and allocated during learning or problem solving. It claims that redundant or irrelevant material that is assigned in instructional tasks generates a cognitive load that may interfere with learning. The selective allocation of cognitive resources has practical implications for Mayer and Moreno's CTML through the principles of multimedia design they proposed, which are described below.

Another theoretical element that informs Mayer and Moreno's CTML is constructivist learning, from which they borrow the notion that learners actively engage in their learning by selecting information, organizing it into coherent representations, followed by the integration of this information with existing knowledge (Mayer and Moreno, 2002). Figure 1 synthesizes the sequence of cognitive processing that operationalizes CTML and its cognitive and constructivist elements.

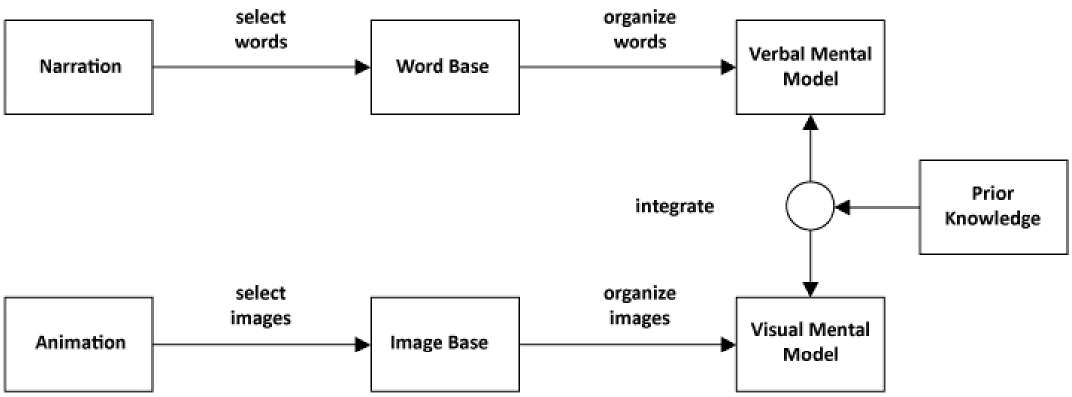

Figure 1: Conceptual map of the cognitive theory of multimedia learning (Mayer & Moreno, 2002, p. 111)

Based on this conceptual operationalization, Mayer (1999) developed five guiding principles for the design of multimedia instructional aides:

1. *Multiple Representation Principle.* This principle states that it is better to utilize two complementary modes of representation (e.g., text and images) for the delivery of learning material, rather than a single mode.

2. *Contiguity Principle.* According to this principle, the learner understands the corresponding textual and visual instructional materials better if these are presented at the same time, rather than separated by a time interval.

3. *Split-Attention Principle*. Under this principle, textual information in a multimedia presentation should be presented as an auditory narration, rather than on-screen text.

4. *Coherence Principle.* This principle recommends that the presentation of both text and images be concise and clear, and extraneous information be eliminated or kept to a minimum.

5. *Individual Differences Principle*. Acting as a corollary to the previous four principles, the last principle states that the consequences of these principles have a larger impact on low-prior-knowledge rather than high-prior-knowledge learners and on high-spatial rather than low-spatial learners (Mayer, 1999).

These principles have been applied and tested in the context of the development of multimedia learning systems, thus giving empirical support to CTML (Moreno & Mayer, 2000; Mayer & Moreno, 2002; Just et al., 2004; Underwood, 2008). Through the 3D objects, animations and the textual component attached to them, FYDA fits well in this model of cognition. Both the imagery and the verbal system are engaged simultaneously, alternatively or complementarily in relation to each other once the FYDA content is processed through the learner's cognitive functions.

2.2 Constructivist learning

In the educational realm, constructivism is generally seen as a deliberate process by which the learner constructs his own knowledge by virtue of analyzing and internalizing information he or she absorbs through independent thinking (Jonassen, 1994; Conceição-Runlee & Daley, 1998; Huang, Rauch, & Liaw, 2010). Resnick (1981), for instance, stated that "these constructions respond to information and stimuli in the environment, but they do not copy or mirror them" and this process has implications for the learning environment in that "instruction must be designed not to put knowledge into learners' heads, but to put learners in positions that allow them to construct well-structured knowledge" (p. 660). A similar position is adopted by Shuell (1986) who supports the idea that "cognitive approaches to learning stress that learning is an active, constructive, and goal-oriented process that is dependent upon the mental activities of the learner" (p. 415).

FYDA's facilitation of constructivist learning through its multimedia environment is theoretically and empirically substantiated by Mayer's (1997), Mayer and Moreno's (2002) and Moreno's (2008) unambiguous interpretation of constructivism in the context of multimedia learning. Through the evidence yielded by their research into the multiple effects of multimedia on cognitive processes, they support the view that construction of knowledge occurs through the visual and verbal representations described in CTML. In this sense, FYDA is appropriately suited to facilitate constructivist learning. It observes Mayer and Moreno's (2002) cautionary note that "the challenge for designers of multimedia instructional messages is to foster constructivist learning even when no hands-on activity or social activity is possible" (p. 110).

FYDA's interface permits the learner to conduct a critical analysis and comparison of the different content elements contained in a certain learning module. The textual component that augments the visual demonstration serves as a means for in-depth probing of the subject at hand, allowing the student to corroborate information between the two modes of content delivery. Thus, the learner can draw his or her own judgment through a dual analysis of the interrelations between the 2D and 3D visual media and the written document. Consequently, through the content provided in FYDA, the learner proceeds to construct his/her mental representation of the objects or elements presented in the 3D atlas and the other modules of the application. He/she can reinforce this mental representation by manipulating the 3D objects as frequently as needed in order to consolidate the knowledge he/she has constructed (Chittaro & Ranon, 2007).

3. Design process and features of FYDA

Consistent with previous courseware development projects at the Faculty of Dentistry, (Salajan & Mount, 2008; Salajan et al., 2009), FYDA is the result of the collaborative work of a team of developers. This team included the faculty member who taught the dental anatomy course, an academic technology specialist who coordinated the overall direction of the project's instructional design, a web developer who programed the application's functionality, and a biomedical animator who produced the 3D objects and media incorporated in the application.

The content of FYDA includes interactive 3D representations of dental anatomy, as well as animated 3D representations of dental evolution and development. FYDA has twelve modules that can be accessed from the application's main entry page shown in Figure 2. Without minimizing the importance of other modules, the *3D Atlas* is described in more detail in the following subsection.

Figure 2: Splash screen in FYDA

3.1 The 3D Atlas module

The *3D Atlas* module was the most complex and advanced addition to FYDA, both in terms of its graphic design and in its potential pedagogical impact. It was meant to provide a visually rich environment in which three-dimensional versions of individual teeth could be manipulated in various ways by students in meeting a required expectation of the course, that is, knowledge of the internal and external anatomy of permanent dentition.

In order to assist students, particularly those with no prior knowledge of anatomy, in acquiring a solid understanding of dental anatomy, the *3D Atlas* conveys the content in several ways, in accordance with the principles of multimedia learning discussed earlier. The entry point into the *3D Atlas* consists of a screen containing a partial 3D image of the human lower maxilla and mandible with selectable teeth that become highlighted in red once the mouse cursor is placed over them (see Figure 3). From this image, the user may select any of the teeth for viewing, at which point the selected tooth is displayed on the atlas's examination field (see Figure 4).

The atlas is comprised of the following elements: *3D Teeth Models* – represented by 3D images of natural specimens obtained with permission from the university's anatomy lab, and rendered in 3D via a micro CT scanner; *Transparency Panel* – provides the user with the possibility to modify the transparency levels for the external and internal anatomical features; *Orientation Helper* – indicates the anatomical facet shown on the tooth model (e.g., buccal, lingual, distal, mesial, etc.); *Text Panel* – contains a description of the characteristics of the displayed tooth (e.g., definition, function, notation, etc.); *Control Strip* – contains command buttons located at the bottom of the examination field; *Dropdown Menu* – for the selection of tooth models to be viewed (Figures 4 and 5).

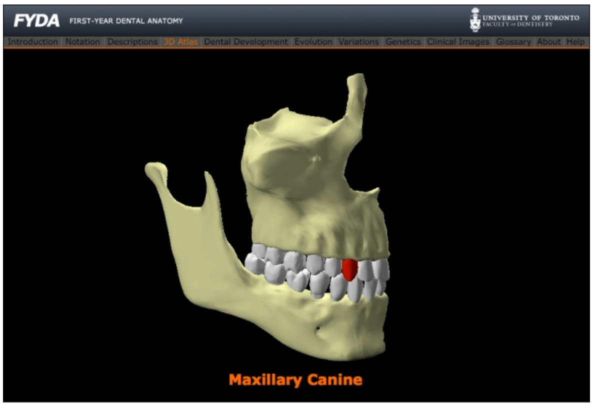

Figure 3: Entry screen of the *3D Atlas,* with selectable teeth

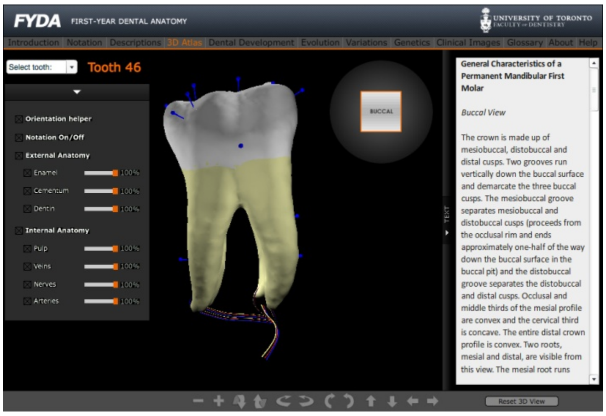

Figure 4: Screenshot of the *3D Atlas* with all navigational and functional features displayed

Figure 5: Tooth model displayed with adjusted transparency levels and hidden panels

3.2 Implementation of FYDA in the dental anatomy course

FYDA represented a significant addition to the Dental Anatomy and Occlusion course as interactive instructional material. The course is offered once a year during the fall semester, thus FYDA can only be employed during that time. FYDA was implemented by the course instructor, following a specific protocol tailored to the goals of the course.

First, students were instructed to use FYDA as a review tool after each lecture. Subsequently, students were asked to review all lecture material by consulting the content included in FYDA. For instance, after a class lecture on incisors using PowerPoint slides, students were asked to review the incisors content in FYDA (Descriptions and 3D Atlas Sections). Closer to their mid-term exam, students had one whole morning reserved to, again, review FYDA in preparation for the exam. Students' use of FYDA, however, was not limited to the protocol outlined above. Therefore, some of them might have explored FYDA's content for multiple purposes that went beyond the review of lecture material or exam preparation.

4. Research methodology and design

4.1 Research method

A survey method was used in the evaluation of students' perceptions of learning benefits resulting from their interaction with FYDA. Since FYDA was included as supplemental material (see section 3.2), the research relied on gathering indirect evidence via two opinion-based surveys measuring student perceptions of learning benefits.

The *First-Year Student Technology-Proficiency Profile* (FYST) questionnaire was derived from an instrument developed in a previous study (Salajan, Schönwetter & Cleghorn, 2010) and was intended to gauge the level of familiarity and proficiency the students considered they had in using digital technologies for educational purposes. The FYST questionnaire contained 35 items, combining demographic information items, five-point bipolar symmetrical Likert-scale items and an open field for additional responses. The second instrument, *First-Year Dental Anatomy Evaluation* (FYDA) questionnaire, was specifically designed to evaluate the use of FYDA by the DDS students. It consisted of 18 items, combining an identifier field, 14 five-point bipolar symmetrical Likert-scale items and a final open response field. The items specifically used in the statistical analysis are presented in Table 3.

Cronbach's alpha coefficient value for the items on the FYST instrument was 0.94, while for the items on the FYDA instrument this was 0.90. Both values were above the 0.70 reliability threshold considered adequate in survey research (DeVellis, 2011; Nunnally & Bernstein, 1994).

4.2 Data collection and response rates

Since the FYST instrument was distributed to students at the beginning of the semester and the FYDA questionnaire was deployed at the end of the semester, the two instruments contained a unique identifier field, for questionnaire matching purposes. Only completed, matched questionnaires were retained for analysis.

A convenience sampling technique was used to survey a target population limited to the first-year cohort, which typically enrolls approximately 65 students every academic year. Therefore, from a target population of 194 students, we received 107 complete matched responses, representing a 54.9% overall response rate for the three semesters combined. While no consensus exists regarding acceptable response rates in survey research (Fowler, 2009), the combined response rate obtained in this study may be considered adequate as a representative sample of the target population (Nulty, 2008).

In terms of the respondents' demographic characteristics, of the 107 students, 45 were male and 62 were female. The ages of the respondents ranged from 20 to 35, with a median of 23 years and a mean of 23.5 years. A two-way ANOVA test with age entered as independent variable and cohort years entered as the dependent variables revealed no significant differences between the three groups of respondents.

5. Analysis and results

Descriptive statistics from the FYST questionnaire revealed that students were fairly reserved in their self-assessment of computer proficiency, as measured by a five-point Likert-scale item with the lowest level labeled as *Novice* and the highest level as *Expert*. In turn, the students were somewhat comfortable in trying new technologies on a scale from *Very Anxious* to *Very Comfortable* at the extreme low and high ends, respectively. In terms of the purpose of computer usage, the students reported communication and information retrieval as the most important, followed by educational purpose. Gaming was a far less important purpose of computer use for the respondents (see Table 1).

Table 1: Student self-assessed proficiency with technology and types of computer use

FYST self-assessment of proficiency and main purposes of computer use					
Proficiency	*M*	*SD*	*Purposes*	*M*	*SD*
Expertise	3.06	1.06	Education	4.03	1.15
Comfort	3.58	1.24	Information	4.44	0.90
			Communication	4.46	0.98
			Gaming	2.47	1.39

Regarding the purposes for which FYDA was used by the DDS students, Table 2 shows the distribution of frequencies reported for each type of use, displayed in its corresponding sequence as an answer selection on item Q2X on the FYDA questionnaire. These results evidently suggest that students found FYDA as applicable in a variety of learning scenarios that addressed some of their most immediate needs in assimilating course content.

Table 2: Frequency of purposes of use for FYDA as reported by students

FYDA Purpose of Use	**Frequency**	**Percentage**
(1) To study before exam	27	25.2
(2) To study before class	2	1.9
(3) As a supplement to lecture material during class	8	7.5
(4) To review after class	3	2.8
(5) As a reference tool throughout the semester	22	20.6
Multiple/combined*	45	42.0
Total	*107*	*100.0*

*Multiple or combined use denotes the selection of two or more types of uses from the five possible responses to question Q2X: *"For what purpose(s) did you use FYDA?"*

The mean values reported by the respondents on some of the more relevant Likert-scale items on each instrument are presented in Table 3. For ease of presentation, the items are coded with the number of their position in each particular instrument, joined by a suffix indicating to which instrument they belong. Thus, an item coded Q1E is part of the FYST questionnaire, while an item coded Q1X is part of the FYDA questionnaire, where the suffixes *E* stand for *Entry* and *X* stand for *Exit* questionnaires, respectively. A unique descriptor for each item is also provided for ease of identification and reference in further explanations of the results in this article.

As indicated by their rating of item Q31E on the FYST questionnaire, the students expected online materials to improve their academic productivity. However, the students were somewhat more reserved in their ratings of multimedia (Q32E) and simulations (Q33E) as factors contributing to the improvement of their academic productivity. In responding to the FYDA questionnaire, the students rated fairly highly the helpfulness of the annotations, the transparency settings and the teeth models, generally in learning about various anatomical features of teeth (Q5X, Q6X and Q7X), but appeared to rate the models slightly lower as contributors to their understanding of the internal and external dental anatomy. In addition, the students provided high ratings regarding FYDA's coverage and explanations of dental anatomy concepts which met their learning objectives (Q14X), and were particularly positive in their rating of the accuracy of FYDA's graphic design elements (Q16X). Finally, the ratings on items Q15X and Q17X suggest the students considered that FYDA's interface was easy to use and that FYDA had a high level of interactivity.

Table 3: Reported mean values for items used in the statistical analysis

First-Year Student Technology-Proficiency Profile				
Item	*Stem*	*Descriptor*	*M*	*SD*
Q7E	I use the computer for education	Education	4.03	1.15
Q8E	I use the computer for information retrieval	Information	4.44	0.90
Q9E	I use the computer for communication	Communication	4.46	0.98
Q10E	I use the computer for gaming (i.e., educational, entertainment, etc.)	Gaming	2.47	1.39
Q12E	How confident do you feel using a computer?	Computer	3.96	1.09
Q13E	How confident do you feel using a laptop?	Laptop	3.99	1.12
Q16E	How confident do you feel using the internet?	Internet	4.62	0.76
Q17E	How confident do you feel using a web browser (e.g., Internet Explorer, Firefox, etc.)?	Browser	4.46	0.85
Q21E	How confident do you feel using computer-based simulations?	Computer Simulations	3.49	1.11
Q31E	To what extent do you expect the online course materials (e.g., lecture notes, presentations, etc.) to improve your academic productivity?	Online Materials	4.30	0.97
Q32E	To what extent do you expect the multimedia components (e.g., audio/video clips, etc.) to improve your academic productivity?	Multimedia	3.45	1.08
Q33E	To what extent do you expect the interactive simulations (e.g., 3D atlas, virtual microscope, etc.) to improve your academic productivity?	Interactive Simulations	3.48	1.07

First-Year Dental Anatomy Evaluation				
Item	*Stem*	*Descriptor*	*M*	*SD*
Q5X	In learning to identify structures of the external anatomy of the tooth, the annotations (e.g., blue pins, red highlightable areas) on the models in the 3D Atlas were:	Annotations	3.87	0.70
Q6X	In learning about the internal anatomy of the teeth, the transparency settings (e.g., making parts of the tooth appear "see through") in the 3D Atlas were:	Transparency	4.05	0.80
Q7X	Overall, to what extent do you think that the models in the 3D Atlas were helpful in learning about teeth?	Overall Models	3.87	0.77
Q8X	The models in the 3D Atlas had a major contribution to your understanding of the external and internal anatomy of the teeth.	Anatomy	3.36	0.93
Q9X	The models in the 3D Atlas helped you achieve your learning objectives for the dental anatomy section of the course.	Learning Objectives	3.50	0.79
Q10X	The models in the 3D Atlas helped you in your preparation for the course assignments.	Assignments	3.17	0.88
Q11X	The models in the 3D Atlas helped you in your preparation for the exam(s).	Exams	3.64	0.76
Q12X	In general, the manipulation of the models in the 3D Atlas was:	Manipulation	3.29	1.04
Q13X	To what extent do you think that FYDA as a whole was useful in helping you reinforce your knowledge of the course material covered in class?	Reinforce Knowledge	3.69	0.74
Q14X	The choice of concepts and topics included in FYDA as a whole met your learning expectations.	Learning Expectation	3.80	0.51
Q15X	How would you rate FYDA's user interface?	Interface	3.65	0.72
Q16X	How would you rate FYDA's graphic depictions (3D and 2D) of the concepts you learned in class?	Graphics	4.02	0.52
Q17X	What level of interactivity would you attribute to the content of FYDA as a whole?	Interactivity	3.66	0.58
N = 107				

These findings partially respond to the study's research questions and represent the first level of data analysis that provide information on the self-reported benefits the students derived from their use of FYDA. In order to further substantiate the analysis conducted and, in addition, reveal the relationships between students' technological competencies and their use of FYDA, a series of non-parametric correlation tests were conducted among the variables within each questionnaire, as well as among selected variables between questionnaires.

Thus, a bivariate analysis using Spearman's test for non-parametric correlation yielded statistically significant medium to strong effect sizes among several variables in the FYST questionnaire, in accordance with Cohen's (1992) determination of effect size values. As shown in Table 4, some of the more notable statistically significant correlations are those among the students' declared purposes of computer use and their expectations regarding the use of online materials, multimedia and simulations to improve academic productivity. Thus, it can be observed that the use of computers for educational and information retrieval purposes (Q7E and Q8E, respectively) are strongly correlated with the students' expectation that multimedia elements (Q32E) and simulations (Q33E) would contribute to an improvement in their academic productivity.

Table 4: Correlations for selected FYST items

Items		Q7E	Q8E	Q9E	Q10E	Q31E	Q32E	Q33E
Q7E	*Education*	-						
Q8E	*Information*	.665**	-					
Q9E	*Communication*	.392**	.368**	-				
Q10E	*Gaming*	.192*	.200*	.054	-			
Q31E	*Online Materials*	.152	.000	.039	.184	-		
Q32E	*Multimedia*	.447**	.319**	.163	.278**	.475**	-	
Q33E	*Simulations*	.432**	.349**	.134	.191*	.453**	.826**	-
*$p < .05$; **$p < .01$								

Correlations between items on the FYST and FYDA questionnaire items were also conducted in order to ascertain the way in which connections between students' various self-reported competencies in using computer technology and their rating of FYDA's multiple features assisted students in consolidating their knowledge of dental anatomy. These aspects are directly addressing the study's research questions, and further discussion and interpretation is offered in section 6.

Consequently, correlations between, on the one had, a number of items on the FYST questionnaire dealing with student confidence levels regarding the use of computers (Q12E), laptops (Q13E), the Internet (Q16E), browsers (Q17E) and computer-based simulations (Q21E), and, on the other hand, items related to students' use of FYDA, resulted in low effect sizes (see Table 5). Thus, it appears that the high confidence ratings students reported in using the aforementioned computer technologies were of little or no consequence on students' perceptions as to whether: a) the 3D models were useful in their learning about dental anatomy; b) the 3D models assisted them in learning for course assignments and exams; c) the overall FYDA application reinforced their understanding of course material.

However, individual pairs of correlations between students' expectations of interactive simulations to improve their academic productivity (Q33E) and several items on the FYDA questionnaire were of particular interest (Table 5). Thus, low to medium, statistically significant effect sizes were observed between Q33E and the students' reported impression that the 3D models in FYDA were helpful in learning about teeth (Q7X), that the models contributed to their understanding of internal and external dental anatomy (Q8X) and that the models helped them attain their learning objectives (Q9X), respectively. A further statistically significant positive correlation was recorded between Q33E and the students' medium rating of FYDA as a helpful tool in the preparation of course assignments (Q10X). In addition, positive correlations were observed between Q33E and items related to FYDA as a useful tool in the students' preparation for exams (Q11X) and in the reinforcement of their course material knowledge (Q13X), but only the latter was statistically significant.

Table 5: Correlations between self-reported FYST computer competencies and student perceptions of FYDA learning benefits

Items		Q7X	Q8X	Q9X	Q10X	Q11X	Q13X
Q7E	*Education*	.140	.250*	.114	.221*	.093	.161
Q12E	*Computer*	-.032	.047	-.061	-.096	.005	-.016
Q13E	*Laptop*	.024	.145	-.002	-.018	.033	-.023
Q16E	*Internet*	-.052	.006	-.134	-.079	.072	-.114
Q17E	*Browser*	-.034	.028	-.077	-.059	.099	-.073
Q21E	*Simulations (C)*	.140	.218*	.106	.219*	.099	.137
Q33E	*Simulations (I)*	.336**	.321**	.280**	.298**	.148	.300**
*$p < .05$; **$p < .01$							

In a similar fashion, correlations between the same items related to student confidence levels in using computer technologies and items measuring student perceptions regarding the various FYDA design features, such as helpfulness of annotations (Q5X), helpfulness of transparency settings (Q6X), ease of model manipulation (Q12X), usability of user interface (Q15X), accuracy of graphic depictions (Q16X) and level of interactivity (Q17X), yielded low, but not statistically significant effect sizes (Table 6). These results suggest, again, that the high levels of confidence reported by students in using various relevant computer technologies were not related to their ability to use FYDA's interactive content.

Table 6: Correlations between self-reported FYST computer competencies and FYDA design features

Items		Q5X	Q6X	Q12X	Q15X	Q16X	Q17X
Q7E	*Education*	-.020	.295**	.256**	.150	-.016	.065
Q12E	*Computer*	-.034	-.042	.097	.004	-.079	.014
Q13E	*Laptop*	-.026	.011	.145	.104	-.012	.024
Q16E	*Internet*	-.082	.060	.085	.037	.116	.032
Q17E	*Browser*	-.060	.022	.089	.005	.089	-.101
Q21E	*Simulations (C)*	.158	.169	.198*	.171	.111	.227*
*$p < .05$; **$p < .01$							

A third set of correlational analysis using Spearman's test was conducted on FYDA items, specifically between reported mean values related to design and functional features of the application, and values recorded on items measuring perceptions of learning outcomes. As the correlation matrix in Table 7 shows, with very few exceptions, all effect sizes among items were statistically significant and specifically address the first two, inter-related research questions. Thus, statistically significant correlations on the helpfulness of the 3D models' annotations (Q5X), transparency settings (Q6X) and overall design (Q7X), on the one hand, and reported learning results, on the other hand, yielded medium to very strong effect sizes. The overall helpfulness of the 3D models in learning about teeth (Q7X) was both positively and strongly correlated with the students' reported ratings on achieving their learning objectives in dental anatomy (Q9X), as well as with their understanding of the internal and external tooth anatomy (Q8X). Furthermore, Q7X yielded similar strong effect sizes in its correlations with items that measured the students' impression that FYDA reinforced their understanding of course material (Q13X) and that the range of topics and concepts covered in FYDA had met their learning expectations (Q14X).

Although ranging from medium to high, lower statistically significant effect sizes were reported for items inquiring about FYDA's 2D and 3D graphic design (Q16X) and FYDA's interactivity levels (Q17X) when correlated with the abovementioned items measuring students' reported learning outcomes. It is important to note that correlations between the ease of manipulation of 3D models (Q12X) and the interface's user friendliness (Q15X), on the one hand, and FYDA's helpfulness in reinforcing knowledge (Q13X) or contributing in the students' learning expectations (Q14X), on the other hand, yielded statistically significant medium effect sizes. However, although manipulation and interface items correlated positively with items related to the 3D models' contribution to the students' understanding of internal and external anatomy (Q8X), and to achieving student learning objectives in the dental anatomy part of the course (Q9X), the low effect sizes were not statistically significant.

Table 7: Correlations between design features of FYDA and student learning outcomes

Items		**Q8X**	**Q9X**	**Q10X**	**Q11X**	**Q13X**	**Q14X**
Q5X	*Annotations*	$.446^{**}$	$.528^{**}$	$.383^{**}$	$.446^{**}$	$.511^{**}$	$.412^{**}$
Q6X	*Transparency*	$.511^{**}$	$.398^{**}$	$.436^{**}$	$.286^{**}$	$.332^{**}$	$.305^{**}$
Q7X	*Overall Models*	$.615^{**}$	$.671^{**}$	$.581^{**}$	$.548^{**}$	$.682^{**}$	$.555^{**}$
Q12X	*Manipulation*	$.282^{**}$	$.292^{**}$	.187	$.276^{**}$	$.379^{**}$	$.260^{**}$
Q15X	*Interface*	$.270^{**}$	$.214^{*}$	.143	$.253^{*}$	$.263^{**}$	$.345^{**}$
Q16X	*Graphics*	$.301^{**}$	$.312^{**}$	$.271^{**}$	$.335^{**}$	$.270^{**}$	$.426^{**}$
Q17X	*Interactivity*	$.351^{**}$	$.312^{**}$	$.234^{*}$	$.397^{**}$	$.347^{**}$	$.400^{**}$
$^{*}p < .05$; $^{**}p < .01$							

In order to test whether FYDA's graphic design accuracy and level of interactivity could be considered predictors of perceived positive learning outcomes, a series of linear regressions was conducted on particular items of interest. Thus, as Table 8 shows, graphic design (Q16X) and interactivity levels (Q17X) are statistically significant predictors for a perceived acquisition of an understanding of internal and external dental anatomy (Q8X) and attainment of dental anatomy learning objectives (Q9X). The rest of the functionality features listed in Table 7 could not be considered predictors for Q8X and Q9X, as the regression tests among these items were not statistically significant.

Table 8: Linear regressions results for key FYDA features impacting on understanding of external and internal anatomy and on reported learning objectives

Dependent Variables								
	Q8X (Internal/External Anatomy)				Q9X (Learning Objectives)			
Variables	*β*	*SE*	*t*	*p*	*β*	*SE*	*t*	*p*
Q16X	.420	.173	2.43	.017	.381	.147	2.60	.011
Q17X	.425	.154	2.76	.007	.315	.131	2.41	.018

Apart from the ratings recorded on the Likert-scale items on the two questionnaires, 29 subjects volunteered open responses, representing a 27.1% response rate given the sample of 107 subjects available for the study. Although very few comments suggested that the 3D models or FYDA in general were not conducive or useful to learning, the majority of the statements revolved around the ease of 3D model manipulation of the models and navigation related to the 3D atlas.

Table 9: Types of open responses on the FYDA questionnaire

Open responses to item Q18X		
Concern	*Respondent*	*Response text*
Navigation	R#3	I enjoyed the 3D models and the effects however I feel it was too cumbersome to navigate through the website and it was too text heavy for something to read on the internet.
Usability	R#5	The glossary is not user-friendly (to have to highlight one word and read its definition one at a time is inefficient) - it would be better if the 3D atlas were of different teeth (other than the artificial teeth we already have been given. Since we have the models of the artificial teeth which we can hold in our hands the digital version is useless.) - The evolution of teeth is really well done and easy to understand, however the radiographs are difficult to read.
Manipulation	R#6	The 3-D Atlas was difficult to manipulate. It was hard to get it to the angle you wanted. Furthermore, the images of teeth shown on FYDA of teeth that were depicted in our lecture notes were very difficult to see. And we were not able to zoom in. You also need a variety of pictures and in colour to help us the variations. Many times I would go google the images to understand the concept. In terms of general concepts, it was helpful I guess. The best way to learn in general for this course is through the teeth models that were given to us. This is because you are able to not only visualize, but touch and rotate things to your own needs. FYDA may be used as a supplement if needed.
Annotations	R#29	The graphics and rendering look really good and high class. It can be hard to rotate the tooth, since it seems the point of the axis of rotation changes (axis of rotation seems to be relative to the screen, not the tooth). Maybe when the mouse goes over a pin, the area that it refers to lights up. This would especially be useful for the pins locating grooves and such, since these are regions and not single points. Very clean though, so definitely shows that lots of work went into it, and that's awesome.
Purpose	R#55	I didn't use the FYDA system very often. I feel that identification of teeth is not something that can be electronically learned. Every tooth is different. It is rare that the idealized depictions of teeth in the program will ever present to you in real life.

6. Discussion and interpretation

In direct response to the first two research questions, the correlational analysis revealed some strong relationships between elements of FYDA's design and perceived learning outcomes in relation to the 3D components of the atlas. Consequently, it is interesting to note that while the students considered the overall models in the *3D Atlas* useful in learning about dental anatomy, they seemed to derive fewer learning benefits from particular features of the atlas. It is possible to infer here that, when asked to think about unique details or features of the application, students were slightly more discriminative in assessing those specific elements than in ascertaining the general functionality and content coverage of the atlas as a whole. A logical implication, therefore, is that in the students' view, individual features of the *3D Atlas* served specific functions as, for instance, the transparency levels controlled the overlapping graphic layers of the tooth models or the annotations supplied precise textual input about unique aspects of tooth anatomy. In turn, a 3D model in its entirety may be less subjected to distinct deconstructive analysis, since the entire object acts as instructional material with complex functionality and multiple learning purposes. Thus, it may be stated that the 3D models, as a whole, provided the students with a range and array of concepts that satisfied their overall learning expectations.

In response to the third research question, the students appear to have considered FYDA a useful application in their study of dental anatomy concepts. The ratings recorded for several items on the FYDA questionnaire appear to support this finding (see Table 3). Thus, the students particularly rated the 3D models included in the atlas as very helpful in learning about dental anatomy. However, when asked about specific purposes for which they used the 3D models, the students offered higher ratings for the use of the models in conjunction with their preparation for exams, a finding that supports the course implementation protocol described in this article, which allocates students time to explore FYDA ahead of their exams. Slightly lower ratings were offered by the students when asked about the usefulness of the 3D models for course assignments. However, it appears that the students were highly satisfied with FYDA in its entirety, when it came to their perceptions of how the application met their individual learning objectives and in helping them reinforce their understanding of course material.

While the above results may be considered positive outcomes of FYDA's implementation in the course, some limiting factors that may have prevented a more successful experience on part of the students need to be examined at this point. Thus, in terms of functionality, it appears that students encountered some difficulties in manipulating the 3D models as well as in using the application's interface. This aspect was evidenced partly through the statistical analysis above (see Table 7), which yielded non-significant low effect sizes on correlations between these particular design features and perceived learning outcomes. Moreover, this apparent deficiency in functionality may also be explained by the finding that students may have expected the 3D objects to have a limited influence on their learning, as suggested in part by the correlations presented in Table 4. An additional explanation may also be derived from the relatively low level of confidence reported by the students in using computer simulations, which presented a statistically significant correlation with the learning outcomes as a consequence of using FYDA's 3D features and interactive functionality.

Yet another plausible reason for this shortcoming may rest in the learning curve the students may have experienced in order to get familiar with the 3D models and FYDA's interface, as well as in some of the technical design inconsistencies identified by students while using FYDA and reported in their open responses (see Table 9). While the students reported no substantial objections regarding the scope and utility of the instructional content presented in the application, some fine-tuning of a number of graphic design elements that impact on the delivery of such content would be beneficial. Thus, some of the textual components of the applications could be either reconfigured as shorter modules or excluded where appropriate. Consequently, superfluous or irrelevant information would be eliminated, so that unnecessary textual information would not distract from the visual exploration of the 3D models and other graphic elements.

7. Conclusion

This article presented the development of FYDA, an interactive web-based application in dental anatomy employing Web3D technologies, and the post-implementation evaluation on the students' perception of learning benefits conducted via survey research. The stages of development were informed by and took into consideration the principles of design proposed by the multimedia learning theory, combining textual and 3D visual inputs of learning material for multiple avenues to deliver content to first-year dental students. The results of the study indicate that the students considered they generally benefitted from the use of FYDA. The application augmented the kinesthetic learning the students undergo via tactile manipulation of synthetic teeth replica with the high-resolution spatial representation of fine anatomical features and details on the internal and external surfaces of the 3D teeth models.

By and large, the students viewed FYDA as a useful tool in meeting their learning of dental anatomy concepts. However, the analysis of results indicate that the students were hindered to a certain extent in, but not necessarily prevented from, achieving their learning objectives because of what could be thought of as superficial, correctable concerns related to design, interface usability and 3D object manipulation. FYDA exhibited a number of graphic design and functional inconsistencies, which may explain why some students may have felt frustrated in attaining full mastery of the product's many interactive features. FYDA appears to have provided the students with a rich visual environment, through which they could explore facets of dental anatomy otherwise difficult to visualize in flat or 2D imagery common to print-based atlases or textbooks, despite some minor technical flaws, inaccuracies and inconsistencies.

In congruence with current research on the use of 3D graphics and animations in the health sciences education, FYDA can be seen as instrumental in providing students with interactive three-dimensional spatial configurations of anatomical structures, which may facilitate learning about human anatomy. As immersive visual technologies evolve, reconsiderations of three-dimensional designs may be required, at which time research on new digital approaches to 3D visual representation could build on the work conducted in this and other studies related to interactive Web3D technologies. Based on the research we conducted in this study, we may state that the principles of design, derived from theories of cognitive and constructivist learning, on which FYDA was built, can extend to and enhance the exploration and learning of other highly visual fields of knowledge.

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