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A Problem-based Multimedia Learning (PBML) Platform for Undergraduate Kinesiology Students

Chelsea Canlas, Natividad Chen, and Patricia Nguyen

Content Advisor:
Dr. Judi Laprade

BMC Supervisors:
Michael Corrin
Jodie Jenkinson
Derek Ng
Shelley Wall

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Keywords

undergraduate anatomy education, adaptive multimedia application, problem-based learning, computer-based learning, self-directed learning, e-learning, interactive learning, multimedia design principles, multimedia instruction, spiral curriculum, problem-based multimedia learning

Abstract

For our master's research project (MRP), we are designing a supplementary computer-based learning resource for an undergraduate anatomy course in kinesiology. As less time and fewer resources are allocated to anatomy courses, educators are increasingly relying on e-learning in addition to lectures and dissection. Computer-based resources have the potential to enhance learning due to their flexibility, accessibility, and low re-use costs. Problem-based learning (PBL) is a teaching modality that promotes deep learning because it requires students to be actively engaged and self-directed. Use of multimedia in e-learning can act as a guide for students, promoting active cognitive processing and enhancing the overall learning experience. Our MRP will be a Problem-based Multimedia Learning (PBML) application, which we define as an adaptive multimedia application that integrates PBL within a spiral curriculum framework. Ultimately, the goal of our collaborative project is to develop a learning resource founded on cognitive psychology, neurobiology, and principles of multimedia design.

Introduction

Anatomy is the cornerstone of all health and medical science education. Concepts and skills taught in undergraduate anatomy courses become essential foundational knowledge that is built upon in upper level courses and applied in professional settings (Miller, Perrotti, Silverthorn, Dalley, Rarey, 2002). In health and medical professions, accurate anatomy knowledge provides the basis for carrying out physical examinations, interpreting medical imaging, and performing clinical procedures (Davis, Bates, Ellis, Roberts, 2014).

Despite the importance of anatomy, there is widespread decline in anatomy education due to decreasing time and resources (Davis, et al., 2014; Hegarty, Keehner, Cohen, Montello, Lippa, 2007; Johnson, Charchanti, Troupis, 2012; Miller, et al., 2002; Sugand, Abrahams, Khurana, 2010). In addition to the allotment of fewer hours to anatomy courses, budget constraints have decreased the availability of cadavers for dissection labs (Anderton, Chiu, Aulfrey, 2016; Davis, et al., 2014; Hegarty, et al., 2007; Moxham & Moxham, 2007; Sugand, et al., 2010). Additionally, undergraduate anatomy educators are facing low student achievement and retention rates, as well as a growing academically diverse cohort of students (Miller, et al., 2002; Terrell, 2006).

With fewer classroom lectures and dissection labs, anatomy educators are increasingly relying on supplementary learning resources, including multimedia e-learning tools (Hegarty, et al., 2007; Johnson, et al., 2012; Sugand, et al., 2010). Development of broadband internet and wireless computing, coupled with innovations in video and audio technology, have produced higher quality simulations, models, and animations for anatomy education (Anderton, et al., 2016; Hegarty, et al., 2007; Qiao, et al., 2014). Simultaneously, students have rapidly become more technology-dependent (Green & Whitburn, 2016; Hegarty, et al., 2007; Terrell, 2006).

With a growing body of tech-savvy students, e-learning resources can enhance anatomy instruction (Johnson, et al., 2012; Mcnulty, Sonntag, Sinacore, 2009; Sugand, et al., 2010). E-learning resources can be reused with little cost, and can be modified to fit the needs of a particular course (Hegarty, et al., 2007). Moreover, students can use e-learning resources to learn and review materials at their own pace outside of the classroom (Johnson, et al., 2012).

Despite the increase in usage of e-learning resources in anatomy courses, there are conflicting studies on their efficacy and popularity. This may be because they are largely designed without consideration of theories of learning from cognitive psychology or neurobiology, nor do they follow empirically-derived multimedia design principles (Friedlander, et al., 2011; Hegarty, 2011; Terrell, 2006). Instead, many have been developed through trial and error in the classroom (Mcfarlin, Weintraub, Breslin, Carpenter, 2011; Richardson, Hazzard, Challman, Morgenstein, Brueckner, 2011; Terrell, 2006). Even though e-learning resources may have been created by experienced anatomy educators and multimedia artists, empirical studies demonstrate that 'expert' and intuitive opinions about multimedia design do not necessarily correlate to their actual effectiveness as teaching or learning tools (Hegarty, 2011).

Given the significant advancements in our understanding of learning and memory over the last several decades, there are considerable opportunities for improving anatomy e-learning resources by integrating cognitive psychology and neurobiology research with instructional design (Davis, et al., 2014; Friedlander, et al., 2011; Hegarty, 2011; Terrell, 2006). To take advantage of the unfulfilled potential of e-learning, we propose the development of a computer-based multimedia application founded on cognitive psychology, neurobiology and multimedia design principles. This application will serve as a supplementary resource in an undergraduate anatomy course.

Background

In our literature review, we synthesize concepts and skills students should gain from their anatomy education, summarize theories of learning from cognitive psychology and neurobiology, and outline instructional criteria relevant to successful anatomy learning. We then define and discuss the potential of problem-based learning. Lastly, we review how multimedia should be designed and implemented in an e-learning resource for anatomy education.

What concepts and skills should students gain from learning anatomy?

As a difficult subject to teach and learn, anatomy requires both substantial memorization and spatial cognition skills (Hegarty, et al., 2007; Miller, et al., 2002; Pandey & Zimitat, 2007; Qiao, et al., 2014; Wilhelmsson, et al., 2010). Memorizing is the first required step in learning anatomy as it forms the foundational knowledge of anatomical structures (Qiao, et al., 2014). In fact, there is a minimum of factual knowledge necessary for safe and effective clinical applications (McHanwell, et al., 2007; Wilhelmsson, et al., 2010). However, memorizing anatomy as only a collection of parts results in little understanding of how the system works as a whole (Miller, et al., 2002; Pandey & Zimitat, 2007; Hmelo-Silver & Azevedo, 2006). A comprehensive understanding of anatomy includes factual knowledge, but also, an ability to describe the shape of anatomical structures, locate structures relative to each other, and explain how structures are connected (Hegarty, et al., 2007; Wilhelmsson, et al., 2010).

In addition, sufficient understanding of anatomy involves critical thinking and problem-solving skills (Mille,r et al., 2002, Qiao, et al., 2014). Miller et al. (2002) assert that anatomy education should be taught as a “basis for logic and reasoning, deduction and problem-solving”. After all, in clinical applications, the purpose of understanding anatomy is to differentiate between normal and abnormal anatomy, and to realize how function is inextricably linked to anatomical structure (Miller, et al., 2002).

Miller et al. (2002) and McHanwell et al. (2007) summarize key concepts and skills students should gain from learning anatomy as listed in *Table 1*.

Table 1. *Key concepts & skills students should gain from learning anatomy (Miller, et al., 2002; McHanwell, et al., 2007)*

Key concepts	Key skills
● Integration of form and function ● Layered and segmental organization of bodies ● Group muscle dynamics ● Concept of "normal" anatomy (the most common variation) ● The effect of denervation on movement and normal resting position	● Ability to think across levels of organization (cells, organs, regions, whole body) ● Ability to visualize 3D form from word descriptions and 2D diagrams (spatial cognition and imaging) ● Ability to draw selectively on specific information and extrapolate from knowledge ● Awareness of word roots

In addition to teaching anatomy itself, Miller et al. (2002) argue that anatomy educators should instruct students how to best approach learning and studying anatomy. This perspective is also supported by studies in educational psychology (Terrell, 2006).

How do successful students approach learning anatomy?

Students who successfully learn anatomy strategically balance both surface and deep learning approaches (Choi-Lundberg, Williams, Zimitat, 2017; Johnson, et al., 2012; Pandey & Zimitat, 2007; Wilhelmsson, et al., 2010). A surface learning approach focuses on rote memorization, while a deep learning approach involves contextualization of information in relation to previous knowledge (Choi-Lundberg, et al., 2017; Pandey & Zimitat, 2007; Wilhelmsson, et al., 2010). The latter leads to an understanding of interrelationships between facts, which predicates an ability to abstract and generalize (Choi-Lundberg, et al., 2017; Pandey & Zimitat, 2007). In the context of anatomy, students using a deep learning approach employ visualizations to create a mental 3D map and contextualize their knowledge clinically (Johnson, et al., 2012; Pandey & Zimitat, 2007; Wilhelmsson, et al., 2010). This allows students to understand the spatial relationships between anatomical structures, and appreciate the relevance of anatomy to clinical practice (Johnson, et al., 2012; Pandey & Zimitat, 2007; Wilhelmsson, et al., 2010).

Although memorizing lists and using mnemonics may be part of the process of becoming familiar with anatomical jargon, using a surface approach alone never leads to sufficient understanding of the subject (Choi-Lundberg, et al., 2017; Johnson, et al., 2012; Miller, et al., 2002; Pandey & Zimitat, 2007). Choi-Lundberg et al. (2017) found undergraduate anatomy students who are uncertain about how to study anatomy, rely solely on a surface approach, and are motivated by fears of failure, perform more poorly on examinations. Conversely, students who are confident in their learning approach, strategically exploit surface and deep learning, and self-monitor their progress and time, perform more successfully on examinations (Choi-Lundberg, et al., 2017).

To encourage students to adopt a strategic approach to learning anatomy, anatomy should be presented as a basis for spatial reasoning and problem solving, as well as help students appreciate the relevance of anatomy to clinical practice (Choi-Lundberg, et al., 2017; Miller, et al., 2002; Terrell, 2006).

How can we effectively teach anatomy to undergraduate students?

Applying research from cognitive psychology and neurobiology

Currently, there is untapped potential for implementing evidence-based practices for anatomy education based on current knowledge of cognitive psychology and neurobiology of learning (Friedlander, et al., 2011; Leppink & Heuvel, 2015; Qiao, et al., 2014; Terrell, 2006). When designing our e-learning resource, we can incorporate the criteria outlined below to inform our instructional design.

Cognitive Load theory

Cognitive load theory revolves around the notion that students' working memories are limited in capacity and duration (Sweller, 1994). Extraneous cognitive load (ECL) refers to the way information and learning tasks are presented. When ECL is reduced, students' working memories can be more fully devoted to understanding and remembering new information (Sweller, 1994). Furthermore, intrinsic cognitive load (ICL) refers to the complexity of the learning task itself, based on the interactivity of elements in the learning material and the student's knowledge level (Qiao, et al., 2014; Sweller, 1994). ICL should be minimized for novice students, but as students become more proficient, ICL can be increased by raising task complexity and fidelity (Leppink & Heuvel, 2015; Qiao, et al., 2014). In our MRP design, we should minimize ECL while optimizing the ICL of the learning tasks to match the students' knowledge and proficiency levels (Sweller, 1994; Leppink & Heuvel, 2015; Qiao, et al., 2014).

Criteria based on Sweller's Cognitive Load theory and neurobiology of learning are outlined in *Table 2*.

Table 2. *Instructional Design Criteria based on Cognitive Load Theory and Neurobiology of Learning*

Instructional Implications	Applying strategies to our PBML
Worked Examples (Leppink & Heuvel, 2015; Qiao, et al., 2014; Terrell, 2006)	
● Provide detailed example of solved problem for student to study	● Present students with examples of solved case study questions before asking them to solve the problems themselves
Use completion tasks (Leppink & Heuvel, 2015)	
● Use partially worked out example problems to guide students through the solution	● Guide students through initial case study problems using simpler step-by-step questions before increasing the learning task complexity
Start with non-specific goals (Leppink & Heuvel, 2015)	
● Ask open-ended questions to encourage students to extend their knowledge base without encumbering them with a more strenuous task of finding definite solutions	● For example, start by asking students to list as many symptoms as they can from a case study, instead of immediately asking them to identify the cause of these symptoms
Avoid multitasking/split attention (Friedlander, et al., 2011; Leppink & Heuvel, 2015; Terrell, 2006)	
● Avoid dividing student attention between multiple sources split in either space or time by integrating multiple sources of information into a single coherent source	● When designing the user interface, present all the information required to solve each case study question on the same page
Respect modality boundaries (Leppink & Heuvel, 2015)	
● Present information through the modality that most appropriately and effectively communicates the learning task	● For each case study question, determine which media will be most effective (e.g. use sequential images to depict processes, use interactive 3D models to show spatial relationships).
Avoid redundancy (Leppink & Heuvel, 2015; Terrell, 2006)	
● Focus attention on important concepts and remove non-essential explanatory detail ● Explicitly indicate the important information to be learned	● When designing both the interface and visualizations, present the information in a direct and concise manner without any extraneous information.

Instructional Implications	Applying strategies to our PBML
Organize information under hierarchy (Leppink & Heuvel, 2015; Terrell, 2006)	
• Show relationships among concepts, structures and finer details	• Employ visuals to show hierarchy of user experience (e.g. use progress bars, or present students with a user map) • Develop a style guide to depict structures in a consistent way across all media (e.g. always show muscles using the same hue of red)
Repetition (Friedlander, et al., 2011; Logan, et al., 2011; Terrell, 2006)	
• Before introducing new content, activate prior knowledge • Use repeated testing to enhance retention of anatomical material • Revisit information through multiple modalities and media	• Use a spiral curriculum to present the case study questions, so that students are repeatedly asked to address the same concepts and information in different contexts and media modalities
Spacing (Friedlander, et al., 2011; Terrell, 2006)	
• Break up didactic instruction with time for students to process information	• Present information in discrete 'digestible chunks' • When designing the user experience, ensure there is regular spacing between passive actions (reading) and active participation (interactive media, answering questions)
Rewards and reinforcement (Friedlander, et al., 2011)	
• Motivate students to achieve small, contiguous goals of learning to take advantage of brain's reward signaling on an ongoing basis	• When designing the user experience, rewards can be given for answering questions correctly (e.g. 'victory' animations and/or sounds) • Integrate metrics so students can visualize their own learning progress and successes
Visualization (Friedlander, et al., 2011; Terrell, 2006)	
• Encourage students to develop mental image representations	• Employ a range of anatomical visualizations (from 2D schematic diagrams to 3D animations)
Instill moderate levels of stress (Friedlander, et al., 2011)	
• Instill moderate amounts of stress in learning tasks to facilitate formation of memory	• For example, add a timer for certain case study questions, or integrate consequences for wrong answers (maybe in the application, they play the role of the clinician helping a patient)

Metacognitive theory

Metacognitive theory views students as active participants in their own learning (Friedlander, et al., 2011; Terrell, 2006). Strategies based on metacognitive theory are listed in *Table 3*.

Table 3. *Instructional Design Criteria based on Metacognitive Theory*

Instructional Implications	How these strategies can apply to learning anatomy in our adaptive multimedia application
Explain rationale behind teaching modality (Anderton, et al., 2016; Davis, et al., 2014; Friedlander, et al., 2011; Mitchell & Batty, 2009; Terrell, 2006)	
● Explain learning objectives and relevance of teaching material to profession	● Include an explanation of the rationale behind implementing a PBML modality
Promote awareness of metacognition (Friedlander, et al., 2011, Terrell, 2006)	
● Encourage students to identify personal goals and motivation for learning ● Provide ways for students to monitor their own learning progress ● Provide ways for students to evaluate their own learning and knowledge levels	● Include metrics so students can monitor their learning successes and knowledge gaps ● For each case study, provide a feature that allows students to reflect on their own learning and understanding of the material

Social Constructivist theory

According to social constructivist theory, learning should be a collaborative social process as knowledge arises through interaction with others (Friedlander, et al., 2011; Terrell, 2006). Criteria based on social constructivist theory are outlined in *Table 4*.

Table 4*. Instructional Design Criteria based on Social Constructivist Theory*

Instructional Implications	How these strategies can apply to learning anatomy in our adaptive multimedia application
● Provide opportunities for active engagement	● Problem-based learning is a student-directed learning modality that involves students actively learning collaboratively while working through inquiry-based clinical case studies (Sugand, et al., 2010)
● Develop contexts for learning	
● Design learning tasks to facilitate extrapolation	

More broadly speaking, research from cognitive psychology and neurobiology support three general instructional criteria for effective anatomy teaching: include clinical case studies, use visual display, and implement a multimodal approach (Friedlander, et al., 2011; Leppink & Heuvel, 2015; Qiao, et al., 2014; Terrell, 2006).

Teaching in context using clinical case studies

By requiring students to integrate anatomical knowledge, case studies can improve learning outcomes (Ikah, Finn, Swamy, White, Mclachlan, 2015; Johnson, et al., 2012). Additionally, when taught in clinical contexts, students report more positive attitudes and increased motivation towards learning anatomy (Bergman, Van Der Vleuten, Scherpbier, 2011; Ikah, et al., 2015; Johnson, et al., 2012; Wilhelmsson, et al., 2010). Clinical case studies strengthen understanding of anatomy and improve problem-solving skills by facilitating both knowledge retention and interdisciplinary knowledge transfer (Bergman, et al., 2011). Therefore, by including case studies, an anatomy e-learning resource has the potential to enhance student learning.

Including visual displays to reduce cognitive load

If designed and implemented appropriately, visual displays can reduce cognitive load and improve student learning of anatomy (Gross, Wright, Anderson, 2017; Hegarty, 2011; Peterson & Mlynarczyk, 2016). As external representations, visual displays can serve as external storages of information, freeing up working memory for other aspects of thinking (Gross, et al., 2017; Hegarty, 2011; Peterson & Mlynarczyk, 2016). For example, information graphics can enable complex mathematical computations to be replaced by simple visual pattern recognition processes (Hegarty, 2011). Moreover, interactive displays allow students to offload internal mental computations onto external manipulation of the display itself (Hegarty, 2011). Gross et al. (2017) found that students studying image-based exercises perform better on examinations and find them easier to understand in comparison to text-only exercises. Additionally, Peterson and Mlynarczyk (2016) concluded students perform better on examinations when 3D models were used in conjunction with lecture and dissection. By adhering to multimedia design principles, the visual displays in a learning resource could decrease student cognitive load and enhance their learning of anatomical concepts (Hegarty, 2011).

Implementing multimodal anatomy education

Current anatomy courses widely employ multiple teaching modalities to complement lectures and dissection, including peer-group problem-based learning, body painting and a variety of computer-based learning resources (Anderton, et al., 2016; Davis, et al., 2014; Sugand, et al., 2010). Not only do students find benefit in multimodal anatomy curriculum, but also, multimodal teaching can accommodate a range of learning styles (Anderton, et al., 2016; Friedlander, et al., 2011; Johnson, et al., 2012). Specifically, there is an ever-increasing support for integration of active learning modalities to supplement traditional didactic lectures (Anderton, et al., 2016, Davis, et al., 2014).

As an active learning resource, our multimedia application will use problem-based learning (PBL) to complement traditional teaching methods. PBL is a student-directed learning modality that facilitates active engagement and deep learning (Sugand, et al., 2010). The following section discusses PBL in further detail and how it can be used in an e-learning context.

What is problem-based learning and how is it currently implemented in anatomy curricula?

What is Problem-based Learning?

Problem-based learning (PBL) is an educational modality in which students collaborate in a common environment to solve problems. PBL is founded on four principles: 1) constructive, 2) collaborative, 3) contextual, and 4) self-directed (Bergman, et al., 2013).

In the context of anatomy education, PBL uses clinical case studies to promote both integration and extrapolation of anatomical knowledge in critical thinking scenarios (Bergman, et al., 2013). PBL engages students in active learning as opposed to passive learning and rote memorization common in traditional teaching modalities (Dahle, et al., 2002). By requiring students to make decisions deciphering problems and developing solutions, PBL enables student to identify and address their knowledge gaps (Poulton, Conradi, Kavia, Round, Hilton, 2009). Ultimately, PBL aims to improve both understanding and knowledge retention in students studying anatomy.

In addition, PBL promotes invaluable skills such as critical thinking, problem-solving, and effective communication (Crawford, 2011; Mandeville & Stoner, 2015; Wang, et al., 2010). Mandeville & Stoner (2015) attribute the development of these skills to the inquiry-based analysis, peer collaboration and reimagined roles of students as teachers within PBL. Furthermore, Ma et al. (2008) suggest that PBL's collaboration, student-centered learning, and use of case studies are key to developing students as independent, deep learners.

Despite these potential benefits, the successful implementation of PBL depends on robust lesson plans and trained facilitators (Bergman, et al., 2013; Wang, et al., 2010). With all this in mind, a well-designed PBL curriculum can provide a rich learning experience by anchoring student knowledge within clinical examples, and allowing a self-directed learning pace.

<u>What is e-Problem-based Learning?</u>

Due to the instructor-facilitated group format and interdisciplinary nature of PBL, traditional PBL is labour and time intensive (Mandeville & Stoner, 2015; Wang, et al., 2010). However, PBL in an online format (ePBL) can reduce the resource demand. Many studies have already implemented ePBL to take advantage of the flexibility, cost-effectiveness and accessibility of computer-based learning (Backhouse, Fitzpatrick, Hutchinson, Thandi, Keenan, 2016; Crawford, 2011; Kim & Kee, 2013). Unfortunately, current ePBL resources often follow a simple framework without exploiting e-learning features like interactive media (University of British Columbia, 2010; McMaster University, 2013).

ePBL is able to incorporate most of the outlined principles of PBL (contextual, self-directed, and constructive), but struggles at integrating the collaborative component. Crawford (2011) and Dennis (2003) tested the effectiveness of various forms of online communication such as an asynchronous forum or instant chat. However, the results were inconclusive because of technical issues such as download speed, software bugs, and long loading times. The technical difficulties did not prevent learning, but proved frustrating for students adapting to the e-PBL modality (Crawford, 2011; Dennis, 2003). Ultimately, current ePBL resources are hindered by interface and software limitations, but ePBL modality has the potential to embody all the features of PBL with the added benefits of a digital application.

How is PBL and e-PBL currently implemented in anatomy education?

Since its creation in the 1980s, PBL has been widely used to teach introductory anatomy (Backhouse, et al., 2016; Bergman, et al., 2013; Crawford, 2011; Findlater, Kristmundsdottir, Parson, Gillingwater, 2012). Many studies found PBL improves academic performance, demonstrating that it is an effective teaching strategy in anatomy education (Backhouse, et al., 2016; Wang, et al., 2010; Findlater, et al., 2012; Mandeville & Stoner, 2015).

Traditionally, PBL is implemented in the classroom, in which the instructor presents open-ended clinical case study problems for students to solve. More recently, there has been increasing incorporation of ePBL in anatomy curricula. During in-class PBL, facilitators guide students as they collaborate to solve the problem, and as student proficiency increases, their role is minimized (Mandeville & Stoner, 2015). Analogous to the facilitators, Kim & Kee (2015) embeded prompting questions within their ePBL program to provide guidance to students through the clinical case study problems.

How should PBL be implemented to enhance anatomy learning?

The benefits of PBL rely on its implementation in the anatomy curriculum. Learning outcomes must be clearly defined so that students know how to direct their learning (Wang, et al., 2010). Furthermore, the questions presented in the PBL exercises must guide students to understand increasingly complex concepts and new information (Wang, et al., 2010). Building on the constructive principle of PBL, incorporation of a spiral curriculum, an iterative revisiting of topics with increasing complexity, may help students develop an ability to review and retain anatomical knowledge (Harden & Stamper, 1999).

Furthermore, the goals and premise of PBL must be clearly explained to students to reduce the frustrations associated with self-directed learning regardless of platform (Chakravarthi & Haleagrahara, 2010; Crawford, 2011; Findlater, et al., 2012; Mandeville & Stoner, 2015). This can be resolved by adding introductory tutorials to either in-class or online PBL. This is also supported by Anderton et al. (2016), Davis et al. (2014), and Mitchell and Batty (2009) who concluded that adults learn more effectively when learning goals are communicated to them.

To successfully implement PBL in a learning resource, there are several potential limitations to the modality that needs to be addressed. Kirschner, Sweller and Clark, (2006) criticize the misuse of long-term and working memory required by PBL. To minimize cognitive load from PBL, instructional strategies such as repeating concepts, gradually increasing the complexity of learning tasks, and using worked examples of solved case study problems can be incorporated into the instructional design. Additionally, a multimodal approach can minimize the intensive resource use associated with traditional PBL by introducing key concepts in class to be later reviewed in ePBL modules (Bergman, et al., 2013; Dahle, et al., 2002; Johnson, Charchanti, Troupis, 2012; Wang, et al., 2010). As a supplement to lectures, ePBL can minimize the time instructors teach in-person and provide students the benefits of self-directed, contextual learning. Lastly, some studies have found similar performance between students exposed to traditional learning and students who underwent PBL (Kirschner, et al., 2006; Prince, et al., 2003; Sanson-Fisher & Lynagh, 2005). However, this may be because traditional examination formats limit students' abilities to demonstrate their PBL-acquired knowledge and skill-sets (Chakravarthi & Haleagrahara, 2010; Kirschner, et al., 2006). Moreover, as a supplement to lectures and dissection, ePBL applications can enhance student learning without removing benefits from traditional teaching methods.

How should we design multimedia for problem-based learning?

Multimedia can be incorporated into PBL to create a rich multi-layered learning environment. When designed for a purpose, multimedia integrated into clinical scenarios have the potential to direct students in a specific direction, or omit visual information to prompt further inquiry (Johnson, et al., 2012; Persson, Fyrenius, Bergdahl, 2010). *Table 5* highlights important criteria to apply multimedia design to our e-PBL application.

Table 5: *Summary of multimedia use in PBL*

Literature	Applying strategies to our PBML
(Persson, et al., 2010)	
Images	• Use concise number of images • Images may be blurred to increase complexity of problem or to focus student attention • Avoid obvious cues that may give away solution
Videos and animations	• Use both verbal (oral), and nonverbal (emotions and body language) cues to promote critical thinking in student • Videos enable presentation of scenarios that students cannot otherwise experience due to ethical constraints such as botched procedures
(Kim & Kee, 2013)	
Interactive media	• Use interactive media to increase authenticity, realism and engagement of posed clinical problem

Ultimately, by designing an e-PBL resource as a supplementary learning tool, we can combine both the features of traditional PBL with the added advantages of a digital application. By incorporating instructional strategies based on cognitive psychology and neurobiology of learning, and well-designed multimedia, our PBL e-learning resource has the potential to foster active, deep and contextual learning in anatomy students.

Why should we design a digital application?

For students learning anatomy, digital platforms and online videos are a popular, ubiquitous resource. Barry et al. (2016) and Jaffar (2012) found the majority of the students employ web-based platforms to source information, either by using internet search engines and/or social media websites. In helping their understanding of anatomy, 78% of students rated these videos as “useful,” “very useful,” or “extremely useful,” while 50% of students indicated they used video clips at least once per week (Barry, et al., 2016; Jaffar, 2012).

There are conflicting studies on student satisfaction with current computer-based resources in anatomy courses (Choi-Lundberg, et al. 2017; Davis, et al., 2014; Green & Whitburn, 2016; Mcnulty, et al., 2009; Salajan, Mount, Prakki, 2015). Mcnulty et al. (2009) concluded that students find computer-based resources useful for learning anatomy, and that students who use them most frequently score higher on exams than students who never access online resources. In contrast, a survey by Davis et al. (2014) concluded only a third to a half of students find computer-based tutorials useful for learning anatomy. Another survey by Choi-Lundberg et al. (2017) found students rate online resources as least useful when compared to other learning modalities. In this study, students who prefer online resources perform poorer on examinations compared to students who prefer other learning modalities (Choi-Lundberg, et al., 2017).

The range of student feedback on computer-based learning in anatomy courses may be due to the inconsistency with which they are implemented. Most current learning resources are not designed based on educational psychology or neurobiology, and do not adhere to empirical multimedia design principles (Friedlander, et al., 2011; Hegarty, 2011; Terrell, 2006). For example, Salajan et al. (2015) found students felt that the web-based 3D application was useful in learning dental anatomy, but their learning process was hindered by problems with the interface design. Additionally, Barry et al. (2016) found that 22% of students indicated that YouTube videos’ usefulness for anatomy learning varied depending on its content.

By designing a computer-based learning resource to aid anatomy learning, we capitalize on the preference of the current student population for communicating and accessing information digitally (Green & Whitburn, 2016). However, the effectiveness of our MRP as a learning tool will largely depend on the quality of the instructional and user interface design.

What is a multimedia learning environment?

A multimedia learning environment, as defined in the Cambridge Handbook of Multimedia Learning, uses both words and visuals to help students construct mental models (Mayer, 2017; Schnotz, 2017). Instead of passively presenting information, which often is the case when a learning resource is purely text-based, a well-designed use of text and visuals engages the student to become an active "sense maker" (Mayer, 2017). In the context of anatomy education, both traditional resources such as blackboards and printed books, and digital resources such as e-courses and 3D models are considered multimedia learning environments (Clark, 2017; Mayer, 2017; Nye & Graesser, 2017; Schnotz, 2017).

It is important to note that design choices should not be based on what technological capabilities a medium has to offer, but instead on how students can process information from the modality to foster their learning. Designing for multimedia learning should be student-centered as opposed to technology-centered (Mayer, 2017). Choosing the appropriate medium to communicate information can initiate the cognitive processing required for a deeper understanding of the material.

Although we will be designing a multimedia application, the type of active learning we hope to promote is not measured by behavioral activity or how 'hands-on' the application is. Multimedia messages can be designed to promote active cognitive processing, even when the student is behaviorally inactive (Mayer, 2017). Therefore, the degree of interactivity doesn't necessarily promote learning. The ultimate goal of multimedia instruction is meaningful, deep learning, which leads to better knowledge retention and learning outcomes (Mayer, 2017).

According to Mayer's cognitive theory of multimedia learning, the challenge when designing instructional material is guiding the appropriate cognitive processing without overloading the student's working memory capacity. Because learning anatomy requires substantial memorization, spatial cognition and problem-solving skills, these cognitive demands are important to keep in mind when designing instructional multimedia. Principles for designing multimedia learning environments aim to minimize extraneous processing (avoid elements that do not contribute to learning), manage essential processing (provide visual cues to highlight relevant information), and foster generative processing (guide the reorganization of information to form a coherent mental model) (Mayer, 2017; Schnotz, 2017; Sweller, 1994).

Schnotz (2017) presents a model of integrative text and picture comprehension (ITPC model), which shares concepts with both Sweller's cognitive load theory (1994) and Mayer's cognitive theory of multimedia learning (2017). These principles are based on empirical research, and are heavily grounded in cognitive theory. Generally, these guidelines encourage designers of instructional media to avoid contributing to extraneous processing. As Schnotz (2017) summarizes it: "less can be more." Some of the guidelines used for instructional design are listed in *Table 6*.

Table 6. *Guidelines for instructional multimedia design (Schnotz, 2017)*

Guidelines for instructional design	Applying strategies to our PBML
Conditional use of media (similar to Mayer's multimedia principle)	● Use text with content-related images when students have low prior knowledge (applicable to our project's target audience)
Spatial and temporal contiguity (similar to Mayer and Fiorella's coherence, signaling, spatial contiguity, temporal contiguity, and redundancy principles)	● If written text is used, present it in close spatial proximity to the picture ● if spoken text is used, present it in close temporal proximity to the picture ● multimedia messages should be presented in manageable segments

Guidelines for instructional design	Applying strategies to our PBML
Text modality for animations (similar to Lowe and Sweller's modality principle, and explored in Lowe and Schnotz' animation principles in multimedia learning)	● When animations are combined with text, use narration instead of written text due to the fluent nature of the animation. (When animations are presented with written text, visual processing systems are divided between two tasks, resulting in split attention)
Text modality for static images (similar to Ayres and Sweller's split-attention principle, and Lowe and Sweller's modality principle)	● If the content is difficult to understand, provide ample learning time, use low complexity visuals, and use written text rather than spoken text
Verbal redundancy across modalities (similar to Ainsworth's multiple representation principle)	● Written text that duplicates spoken text is not necessary when combined with pictures

With the growing use of e-learning technologies, user interface design has also become an integral factor to the success of a multimedia application (Hegarty, et al., 2007; Van Nuland, 2016). When we design user interfaces for specific modes of learning, it is important that we design for easy use. Constant usability testing must be done throughout the development process.

Additionally, integrating instructional support in the user interface is important in multimedia learning environments (Scheiter, 2017). Integrating support structures such as progress bars, prompts or menus will not only orient students within the application framework, but also notify students of their progress and performance throughout their learning experience allowing for opportunities for self-directed learning. Moreover, the level of instructional support should accommodate the level of student proficiency (Hmelo-Silver & Azevedo, 2006; Leppink & Heuvel, 2015). Because case study exercises often require more complex problem-solving, guided prompts can help students draw selectively from the information presented to answer the exercises (Leppink & Heuvel, 2015). As students become more proficient, they are increasingly capable to process more complex information and therefore, less instructional support is required to support learning and understanding (Leppink & Heuvel, 2015; Qiao, et al., 2014).

<u>*Instructional multimedia*</u>

Static visuals:

Pervasive in anatomy learning resources, static visuals have been used for centuries to enhance anatomy learning. According to Mayer's multimedia principle, students learn best from text that include visual content than from text alone (Butcher, 2017; Gross, et al., 2017; Mayer, 2017). For example, Gross et al. (2017) demonstrated that students learning musculoskeletal anatomy find exercises using both images and text less cognitively demanding than purely text-based exercises. Visual information can reduce cognitive load and facilitate development of mental anatomical models (Gross, et al., 2017; Mayer, 2017; Schnotz, 2017).

Increasing the consistency or fidelity of images does not necessarily result in improved learning outcomes. Fenesi, Mackinnon, Cheng, Kim and Wainman (2017) found that students exposed to high quality images perform better that students exposed to low quality images when immediately tested. However, when students were exposed repeatedly to low quality images, their performance improved significantly (Fenesi, et al., 2017). These findings suggest that use of high-fidelity images is not necessarily more effective that low-fidelity images and instead, providing multiple learning opportunities may have a greater impact on long-term performance. Benefits of repetition for learning can involve incorporating different styles of static visual representations. Moren, Ozogul and Reisslein (2011) determined that students who employed both realistic visualizations and abstract diagrams perform better in tests than if they used only one type of visualization (Moreno, et al., 2011).

For a visually complex subject like anatomy, low-fidelity schematic visuals may be more effective than realistic visuals for communicating spatial relationships or multi-layered concepts. Although realistic visualizations can be useful for identifying structures and depicting spatial relationships, schematic visualizations guide students' attention towards the most relevant aspects by removing all irrelevant information (Butcher, 2017; Scheiter, Gerjets, Huk, Imhof, Kammerer, 2009).

The delivery method of visualizations also has different impacts on student learning. Fiorella and Mayer (2015) compared the efficacy of instructor-drawn diagrams and already-drawn diagrams presented during a lecture, and concluded that watching instructors draw diagrams as they orally explain a topic results in deeper learning than giving the same oral explanation for already-drawn diagrams. The act of drawing is comparable to animations wherein the visualizations become a series of dynamic representations that display spatial and temporal change (Fiorella & Mayer, 2015; Lowe & Schnotz, 2017).

Animations:

When the design and implementation are based on cognitive theory , animations can make complex material easier to comprehend (Mayer & Moreno, 2002). Well-designed 3D animations can effectively communicate spatial relationships between elements while avoiding extraneous processing (Hegarty, 2007; Hoyek, Collet, Rienzo, De Almeida, Guillot, 2014). Animations have potential advantage over videos because animators can be selective about presenting essential information. For example, animations can use visual cues to help direct students to the relevant elements (Butcher, 2017; Lowe & Schnotz, 2017). A review paper by Hoffler and Leutner (2007) identifies consistent benefits of animation for learning which are most prevalent when depicting problem-solving knowledge. Moreover, animations may be the optimal media for communicating concepts such as joint function, group muscle dynamics, and motion because of their ability to depict nonlinear movement and processes over time (Brucker, Scheiter, Gerjets, 2014).

However, the effectiveness of animations as a learning tool for anatomy is not always positive. In animations, information is communicated transiently thereby forcing students to continuously integrate previously and newly delivered content, which may overwhelm students (Brucker, et al, 2014; Mayer, 2017; Schnotz, 2017; Sweller, Ayres, Kalyuga, 2011). Some studies have found that animations are either equally or less effective than static visuals (Hoffler & Leutner, 2007; Mayer, Hegarty, Mayer, Campbell, 2005). In fact, passively watching animations can create a superficial illusion of understanding in students (Hoyek, et al., 2014; Lowe & Schnotz, 2017). Although animations can effectively communicate concepts that show change over time, it is important to consider the limitations of dynamic visuals when designing a learning resource.

3D models:

3D models have the potential to support student understanding of anatomical spatial relationships, but their efficacy for learning depends on the interface usability. Brenton et al. (2007) and Salajan et al. (2015), designed computer-based resources for undergraduate students that include 3D models on the brachial plexus and dental anatomy, respectively. In both studies, students found the user interface and 3D models difficult to manipulate, thereby interfering with their learning process.

Garg et al. (2002) suggests an optimal strategy for implementing 3D models is one that includes pre-programmed key views. Constrained views provide the essential information needed for spatial learning, whereas unconstrained control results in multiple orientations that result in cognitive overload, especially for students with low spatial ability. The authors concluded that the option to slightly rotate the model “without distracting from the canonical view” allowed for further spatial learning.

Interactive design:

Interactivity should be designed to allow for easy navigation and use (Hegarty, 2011). The interface design must ensure that the student has the necessary knowledge to interpret and manipulate the information on display. Excessive user control such as zooming in/out, panning and rotating may disorient the student. Ultimately, interactive displays should be designed for the task to be performed to achieve the specific learning objective of the module.

McFarlin et al. (2011) described an approach to designing computer-based learning modules for an undergraduate health science curriculum that uses a structurally linear gaming format. In their e-learning application, students must score 70% or higher on games and quizzes to 'unlock' subsequent material and move forward in the learning module. If students score less than 70%, they are redirected to a series of remedial slides. The author's incorporation of a spiral curriculum and embedded assessments adhere to the principles of repetition, rewards and reinforcement based on educational psychology. Even though the authors do not formally evaluate the e-learning resource on student performance, aspects of their design approach can be applied to our MRP to enhance anatomy learning.

Importance of multimedia design

Despite clear benefits to incorporating visuals to decrease cognitive load and enhance learning, each medium of visual display has different advantages and disadvantages depending on the information to be communicated (Hegarty, 2011; Mayer, 2017). Moreover, the efficacy of the medium for learning depends heavily on the usability of the display interface (Brenton, et al., 2007; Garg, et al., 2002; Hegarty, 2011; Salajan, et al., 2015). As we design multimedia for our MRP, it is imperative to consider principles of multimedia design based on cognitive science (Hegarty, 2011). All considered, we should design each visual display to meet student needs and serve specific learning objectives.

Goal and Objectives

Goal:

The goal of our MRP is to engage undergraduate students in deep and active learning of lower limb anatomy.

Primary objective:

We strive to develop an adaptive multimedia application that 1) uses a PBL approach within a spiral curriculum framework, and 2) incorporates multimedia such as 2D illustrations, 3D models, animations and interactive components. Our design will be guided by educational psychology, and principles of multimedia design.

Sub-objectives:

To achieve our primary objective, we will 1) design a decision-making tree that promotes inquiry-based analysis, 2) contextualize lower limb anatomy by presenting clinical case studies, and 3) incorporate multimedia visuals to facilitate cognitive processing of key concepts.

Methods

Audience:

We will design our MRP for first-year kinesiology students in Dr. Judi Laprade's anatomy course to use as a supplementary learning resource. The MRP can also serve as a teaching tool for Dr. Laprade and her teaching assistants to use during lectures and/or tutorial sessions.

Visual Treatment:

Our MRP will be the first example of a Problem-based Multimedia Learning (PBML) application, which we define as an adaptive multimedia application that integrates problem-based learning within a spiral curriculum framework. As described by Merri (2017), an adaptive multimedia application monitors learner progress and modifies learning tasks so that "their difficulty, level of support and guidance, and available [...] features are optimized to meet needs of individual learners". Specifically, our PBML project will incorporate interactive multimedia that assess and adapt to each student's input. As a student-directed learning resource in which students solve open-ended clinical case studies, our MRP adheres to PBL principles. Even though our MRP is largely self-directed, we will support student learning by providing embedded scaffolds that guide the inquiry process. Lastly, to promote knowledge retention, we will integrate PBL within a spiral curriculum, defined as a constant revisiting of the same concepts and skills with increasing complexity at each iteration (Harden & Stamper, 1999).

The PBML application will include case studies focusing on the three joints of the lower limb (hip, knee, and ankle), each of which will include a series of problem-solving modules. Each module exercise will incorporate multimedia (2D illustrations, 3D models, 2D/3D animations) and interactivity. Students are guided through these PBL modules with increasing complexity and fidelity.

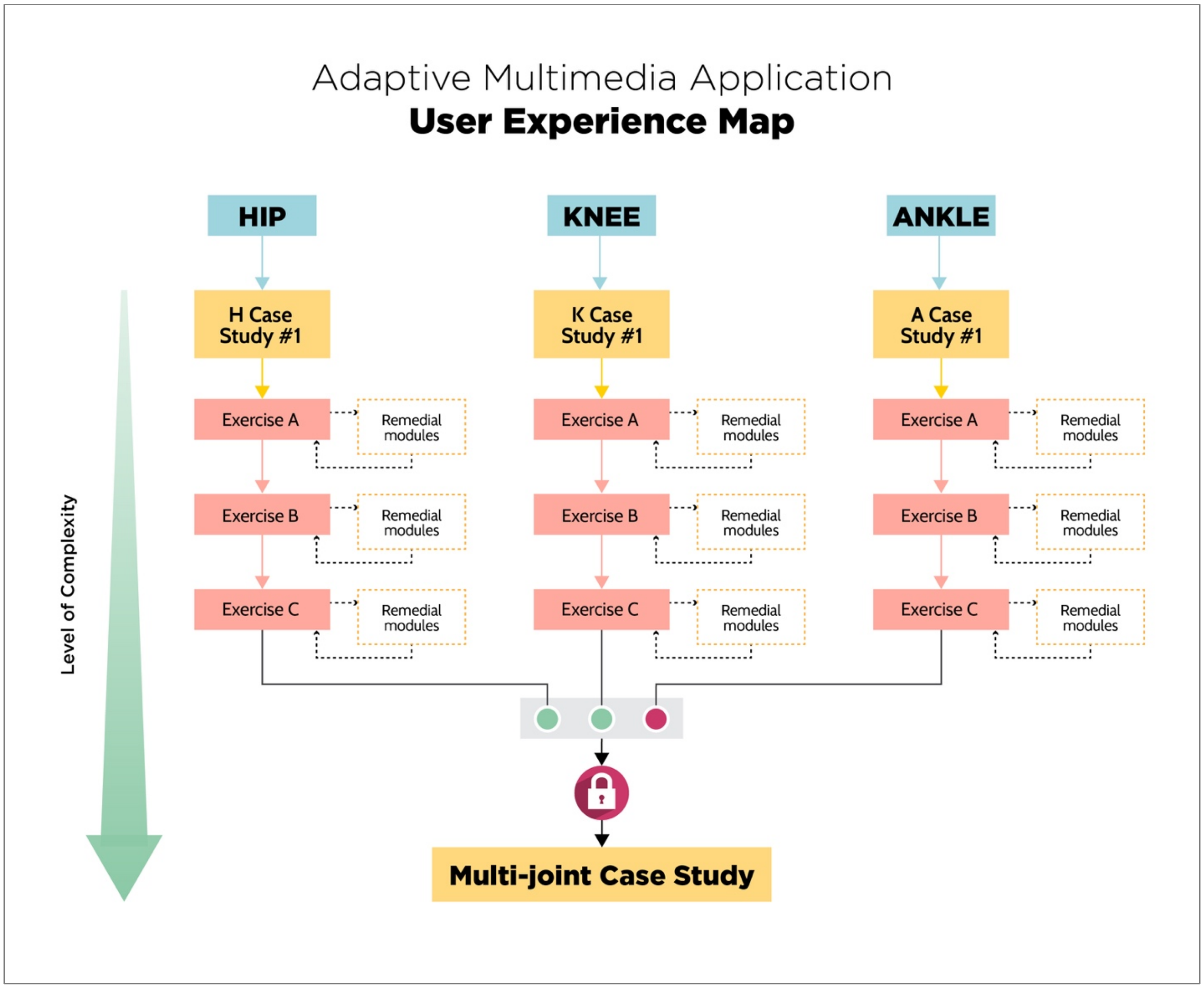
Figure 1 summarizes the proposed user experience map. For each case study exercise, there are two user scenarios: 1) students correctly solve the problem, and move forward to the next problem; or 2) students incorrectly solve the problem, and are directed to a remedial module. At this level, there are also two possible scenarios based on performance. If students correctly complete the remedial module, they will return to the original case study exercise. Conversely, if they incorrectly solve the remedial module, they will be directed to an additional remedial module to review foundational anatomical knowledge.

Once all case studies have been completed for all three joints, the student will ‘unlock’ the final level which will be the most complex and involve a multi-jointed movement (e.g. gait cycle). At this level, students will need to extrapolate from concepts and knowledge presented in previous case studies, and apply them in the final case study.

Overall, the design of our adaptive multimedia application is structurally linear and uses a gaming format of ‘unlocking’ levels to move forward to more challenging questions. However, the user journey itself is variable depending on performance. Students with an incomplete understanding of the concepts will be ‘taking steps back’ in order to solve a problem. Each remedial learning module will cover foundational anatomical concepts, but it is ultimately up to the student to take what they have learned from these modules to solve the case study.

Design of user interface will depend on the modality presented. However, a cohesive overall interface aesthetic will be established in the form of a style guide. A more comprehensive framework of the application will be determined once content and decision trees have been established. When completed, our PBML application will be downloadable software accessible via a website.

Figure 1. *Mock flow chart demonstrating application framework*



Procedure:

To guide our application's instructional and user interface design, we will hold informal focus groups with students and teaching assistants in Dr. Laprade's anatomy course. For the students, we will ask their opinions on the usefulness and efficacy of current resources they use. Furthermore, we are interested in their experiences with Dr. Laprade's tutorial sessions, small group PBL case study exercises currently implemented in the course. Specifically, we are interested in 1) how the sessions were helpful/unhelpful for learning anatomy, and 2) how they collaborated and problem-solved to complete the exercises. For the teaching assistants, we will primarily focus on Dr. Laprade's tutorial sessions. We would like to know 1) what problem-solving methods students employ, 2) what concepts students excel at or struggle to understand, 3) when and how they prompt students, and 4) what type of learning tools they find useful during these sessions.

Using case studies constructed by Dr. Laprade, we will collaborate to construct decision trees. These decision trees map out the user journey based on student performance. Each branch of the decision tree represents a specific module within a case study in which the student answers a PBL question. For each module, we will need to determine the media and instruction modality most appropriate and effective for communicating the key concepts and learning task. For example, a 3D model would better communicate how the femur head fits within the acetabulum than a 2D diagram. However, a rotatable component should be added to the 3D hip model if the purpose is to communicate how ligaments restrict the range of motion of the hip joint.

After completing the decision trees and determining a style guide, we will then design and create the multimedia visualizations and program the e-learning application. Programs that we may use include: *Photoshop* and *Illustrator* for the 2D static visuals; *Toon Boom Harmony* and *After Effects* for 2D animations; *Zbrush*, *Cinema 4D*, and *Autodesk Maya* for the 3D models and 3D animations.

Anticipated Significance

Primarily, we are developing a learning tool that integrates case studies of the lower limb joints in order to support a comprehensive understanding of lower limb anatomy. Our MRP aims to promote active, deep learning in first-year kinesiology students, and enhance their knowledge retention and understanding of leg anatomy. By fostering critical thinking at an early stage in their undergraduate education, our MRP has the potential to not only improve their learning outcomes in the anatomy course, but also, to impart effective learning skills that these undergraduate students can apply in their upper-level courses, and eventually, in their careers.

More broadly speaking, this MRP is a collaborative endeavor that introduces a novel teaching modality we have termed Problem-based Multimedia Learning (PBML). If successfully implemented as a learning tool, our MRP can serve as a foundation on which to build additional case studies on other anatomical structures. Our PBML framework could also serve as a design template that other courses in kinesiology or other health science disciplines can emulate. Ultimately, the design and implementation of this MRP have the potential to contribute to our collective understanding of how multimedia integration within ePBL can enhance learning.

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