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A case study: exploring the impact of 3D printed models on cognitive integration during clinical skills training

Étude de cas : explorer l'impact des modèles imprimés en 3D sur l'intégration cognitive durant la formation aux compétences cliniques

Kristina Lisk,[1,2] Jeffrey JH Cheung[3]

[1]Division of Anatomy, Temerty Faculty of Medicine, University of Toronto, Ontario, Canada; [2]The Wilson Centre, University of Toronto and The University Health Network, Ontario, Canada; [3]Department of Medical Education, University of Illinois College of Medicine, Illinois, USA

Correspondence to: Kristina Lisk, Division of Anatomy, University of Toronto, Medical Science Building, Room 1185. 1 King's College Circle, Toronto, Ontario, M5S 1A8, Canada; email: Kristina.lisk@utoronto.ca

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Abstract

Background: Cognitive integration occurs when trainees make conceptual connections between relevant knowledges and is known to improve learning. While several experimental studies have demonstrated how text and audio-visual instruction can be designed to enhance cognitive integration, clinical skills training in real-world contexts may require alternative educational strategies. Introducing three-dimensional (3D) printed models during clinical skills instruction may offer unique learning opportunities to support cognitive integration.

Methods: Using case study methodology, we explore how learners and an instructor used 3D printed bones to augment their learning interactions during a clinical skills laboratory on shoulder on palpation, and to describe the instructional strategies with 3D printed bones that may support learning. Students (n = 21) worked in small groups and were given access to a 3D printed clavicle, scapula, and humerus. Data were collected through observation, a student focus group, and a semi-structured interview with the instructor. Thematic analysis to review and code the data and to generate themes.

Results: We developed four themes that describe how 3D printed models were used in the classroom and how they may support cognitive integration: classroom interactivity, visualization of anatomy, integrating knowledge, and educational potential.

Conclusions: The findings demonstrate several ways 3D printed models can augment how learners, instructors, and educational materials interact with one another and how readily learners make connections between different sources and types of knowledge. This research extends previous work by demonstrating how social learning processes and interactions with physical models can offer unique affordances that may support cognitive integration.

Résumé

Contexte : L'intégration cognitive se produit lorsque les apprenants établissent des liens conceptuels entre des connaissances pertinentes et est connue pour améliorer l'apprentissage. Alors que plusieurs études expérimentales ont démontré comment le texte et l'enseignement audiovisuel peuvent être conçus pour améliorer l'intégration cognitive, la formation aux compétences cliniques dans des contextes réels peut nécessiter d'autres stratégies éducatives. L'introduction de modèles imprimés en trois dimensions (3D) dans l'enseignement des compétences cliniques peut offrir des occasions d'apprentissage uniques pour favoriser l'intégration cognitive.

Méthodes : En utilisant la méthodologie des études de cas, cette étude explore comment les apprenants et un instructeur ont utilisé des os imprimés en 3D pour augmenter leurs interactions d'apprentissage au cours d'un laboratoire de compétences cliniques sur la palpation de l'épaule, et pour caractériser les stratégies d'enseignement avec des os imprimés en 3D qui peuvent favoriser l'apprentissage. Les étudiants (n=21) ont travaillé en petits groupes et ont eu accès à une clavicule, une omoplate et un humérus imprimés en 3D. Les données ont été collectées par l'observation, un groupe de discussion d'étudiants et un entretien semi-structuré avec l'instructeur. Une analyse thématique a permis de passer en revue et de coder les données et de dégager des thèmes.

Résultats : Quatre thèmes ont été développés pour décrire comment les modèles imprimés en 3D ont été utilisés en classe et comment ils peuvent favoriser l'intégration cognitive : interactivité en classe, visualisation de l'anatomie, intégration des connaissances et potentiel éducatif.

Conclusions : Les résultats démontrent que les modèles imprimés en 3D peuvent améliorer la façon dont les apprenants, les instructeurs et le matériel pédagogique interagissent et la facilité avec laquelle les apprenants établissent des liens entre les différents types et sources de connaissances. Cette recherche s'ajoute à des travaux antérieurs en démontrant comment les processus d'apprentissage social et les interactions avec les modèles physiques peuvent offrir des potentialités uniques susceptibles de favoriser l'intégration cognitive.

Introduction

Within the health professions, various strategies have been used to support integration across curricula, programs, and teaching sessions.[1] However, the learning benefits of integration have been most pronounced when integration is conceptualized at the level of learner cognition.[2] *Cognitive integration* is defined as a process whereby a learner makes conceptual connections between two different types of knowledge.[2–5] Unlike curricular integration, which operates at the level of courses or entire curricula, cognitive integration is optimized during session-level teaching and learning activities.[1,2] For example, when teaching disease categories, novices develop superior diagnostic skills, over the long term, when their instructional materials explicitly connect the underlying basic science mechanisms with the clinical features associated with the disease.[4,6]

How best to design and implement integrated instruction for cognitive integration in real-world training contexts or procedural skills in unclear. Most evidence for cognitive integration comes from highly controlled experimental studies, which do not face real world constraints and, to maintain control, often preclude elements of peer-to-peer learning and instructor feedback.[4,7–15] These social interactions are common in classroom settings and could affect how different learning tools, such as simulators, are used,[15–19] and ultimately the effectiveness of learning. [20] Further, existing studies on cognitive integration predominately concentrate on teaching cognitive skills using text, image, lecture, and video-based learning modalities.[21] While informative, these studies neglect the potential for alternative instructional technologies that may be well suited to support procedural skills learning. For example, a recent study by Cheung et al., [15] has shown that integrated instruction in the medium of simulation may offer new avenues to enhance cognitive integration by more explicitly connecting the procedural actions of a skill on simulators (i.e., physical models) with its conceptual principles. Thus, while the literature has shown the value of designing audio-visual instruction to support cognitive integration for cognitive skills, procedural skills learning in real-world classroom settings, which introduces social and physical dimensions of learning, may require different instructional strategies for supporting cognitive integration.

Three-dimensional (3D) models may offer unique support for cognitive integration in procedural skills training. While physical models have long been used in anatomy and clinical teaching,[22–24] recent advancements in 3D printing technologies have improved educators' and students' accessibility to these learning resources.[25–27] Whereas access to bone models, cadaveric specimens, and virtual dissection technologies can be limited due to their relatively high cost,[28,29] improved access to low-cost, 3D printed anatomy models may create new opportunities to support student learning.[25] Using such models may provide learners additional practice and feedback,[30,31] and may help learners understand concepts through improved visualization compared to other media for learning (e.g., 2D images in textbooks).[32–35] In addition, providing opportunities to observe and manipulate 3D anatomical models while engaging in clinical skills training may assist students' cognitive integration of anatomical knowledge and clinical skills. However, the instructional strategies that best leverage the features of 3D printed models to support cognitive integration have not been described or evaluated.

The first step to bridging experimental findings on cognitive integration to inform the use of 3D models in real-world educational contexts is to explain the benefits of 3D models on the educational interactions of learners and instructors. To address this gap, this case study explores how students and their instructor use 3D printed models during a clinical skills laboratory on shoulder palpation. The goal of this study was to clarify how learners and the instructor leverage 3D printed models to augment their learning interactions, and to describe potential instructional strategies with 3D printed models that may support cognitive integration and deep learning.

Methods

To evaluate how 3D printed models might augment clinical skills learning in the real-world classroom context, this study used a single-case study methodology[36] to explore the impact of introducing 3D printed bone models into a shoulder palpation skills for Massage Therapy students. Case study methodology allows for in-depth exploration of complex issues in real-world settings and is ideally suited to evaluate the learning interactions made possible by 3D printed models and to examine how these interactions relate to cognitive integration and clinical skills learning.

We used a triangulation approach[37] to collect data using three qualitative methods: in-class observations, a student focus group, and a semi-structured interview with the instructor. The Humber Research Ethics Board determined that our study was exempt from research ethics review based on the provision of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans, article 2.5 (TL-0062).

Study context

The shoulder palpation skills laboratory took place within the context of a 14-week clinical skills course within a 3-year accredited Massage Therapy advanced diploma program. The course focuses on fundamental massage techniques and in-depth palpation of the upper limb and consisted of three hours of theory instruction and three hours of hands-on practice each week. Within the clinical skills laboratory (where hands-on practice occurs) there are 11 hydro-electric massage tables, hydrotherapy, therapeutic exercise equipment, and one full-body skeleton. Students within this course also concurrently take a musculoskeletal anatomy course, taught by a different instructor, that focuses on the upper and lower limbs. Content between the two courses is aligned and approximately one week prior to the clinical skills laboratory on shoulder palpation (during week six of the course) students were taught shoulder anatomy. During a typical clinical skills laboratory, the instructor and students have access to a single full-body skeleton, their notes/textbooks, instructor lecture slides, a whiteboard, and their own bodies (and those of their consenting peers) to practice palpation. It was only in week 6 of the course, during the shoulder palpation laboratory, that students had access to the 3D printed bone models.

Selection of case

We selected the shoulder palpation skills laboratory as a representative case to explore the effects of 3D printed models on clinical skills acquisition and cognitive integration. This context includes multiple students learning a procedural skill that requires conceptual knowledge (e.g., anatomy), with the assistance of an instructor. Within this single-case study, two groups were identified and observed: 1) student pairs who had access to de-articulated 3D printed bones during a palpation skills laboratory; and 2) an instructor who facilitated a palpation skills laboratory with the 3D printed bone models accessible. A total of 21 students were present (nine pairs and one group that consisted of three students). A 3D printed clavicle, scapula, and humerus were placed beside each massage table before the laboratory started. All models were printed using acrylic-styrene-acrylonitrile (ASA) plastic and were produced using high resolution digitized files shared by the Parametric Human Project.[38] The course instructor was an experienced Massage Therapist and had taught the laboratory four times previously. The instructor knew that the 3D printed models would be present; however, neither the instructor nor students received training or instruction on their use, rendering them novel to all users.

Data collection

In-class observations. Four individuals were involved in observing the skills laboratory. Each observer was assigned different student pairs (4-6 students in total) and/or the instructor to observe. Three of the observers were hired research assistants (denoted RA1-3 in text) and one observer was a part of the research team (KL). KL was a colleague to the course instructor, but they did not have any influence on the instructor's professional evaluation.

At the beginning of the laboratory session, all students were informed of the four neutral observers in the learning space and were encouraged to participate as they normally do. Each observer took handwritten field notes throughout the session. Notes were focused on documenting how/if students and the instructor interacted with the 3D printed models. The handwritten field notes from each observer were typed up immediately following data collection and then provided to the research team for analysis.

Student focus group and instructor interview. Following the observed laboratory session, students who were present that day were invited by email to participate in a one-hour focus group session to elaborate on their experiences using the 3D printed models during their clinical skills laboratory. Students were excluded from participating in the focus group if they were not present during the shoulder palpation laboratory. Interview questions were designed by the research team to gain student perceptions of the utility of 3D bones and how they augmented their learning experience (e.g., Can you think of an instance where the 3D model changed your thinking or way you or your classmates approached the learning session?). Six students participated in the focus group that took place two weeks after the shoulder palpation laboratory. The focus group was facilitated by a research assistant with extensive experience moderating focus groups and no hierarchical relationship with students.[39] In addition, two-weeks following the laboratory session, KL completed a 30-minute semi-structured interview with the laboratory instructor to gain further insight on their experience of having access to the 3D printed models during the laboratory. Both the focus group and the instructor interview were audio-recorded. Table 1 shows the questions that were asked during the focus group and instructor interview.

Table 1. Focus group and instructor interview questions

Student focus group questions:
What did you think about using 3D printed bones during your clinical skill laboratory on the shoulder? How did the presence of the 3D printed bones impact how you participated in the laboratory that day? What did you like best about using the 3D printed bones during your clinical skills laboratory? How do you think your practice/preparation for palpation laboratory would change if you had access to your own set of 3D printed bones? Did you notice how other student groups were engaging in the session? Can you think of an instance where the 3D model changed your thinking or way you or your classmates approached the learning session? Have we missed anything regarding your experience with the 3D bones that you would like to add?
Instructor interview questions:
What did you think about using 3D printed bones during your clinical skill lab on the shoulder? How did the presence of the 3D printed bones impact how you participated in the lab that day? What did you like best about using the 3D printed bones during your clinical skills lab? Do you think that the students' understanding afterwards or throughout the lab was different compared to other regions of anatomy? Did you notice any changes or differences in terms of how [students] they were interacting with one another? How do you think your practice as an educator would change if you had access to a whole set of 3D printed bones during your clinical skills course?

Analysis

We analysed the study data from a cognitive-constructivist paradigm, meaning we assumed the observations of our research team and the actions and words of the study participants were subjective and context-specific representations of how the phenomena of cognitive integration and procedural skills learning occurs in the presence of 3D printed models.[40] Both authors co-led the analysis. KL and JC are both education scientists with PhDs in health professions education and both have conducted experimental studies on cognitive integration. KL is also an anatomist and anatomy instructor with experience with 3D printing and JC brings additional expertise in procedural skills learning and simulation-based training.

Using thematic analysis,[41,42] all field notes and audio recordings from the focus group and interview were analyzed.[43] Both authors independently read, re-read, and listened through all data and took descriptive notes. Initial coding was also completed independently. Each author generated codes using their own informed perspectives on cognitive integration and learning, while being attentive to the possibility of unexpected or disconfirming codes. Subsequently, over the course of three research meetings, the authors met to clarify their initial codes and to generate a refined code structure, returning to the data independently between subsequent meetings to ensure their revisions were comprehensive and that no additional insights needed to be considered. Following the third meeting, the authors applied the final coding structure to all data and then together generated themes that comprehensively explained the data. Data were organized and analyzed using Microsoft Word and Excel. Data from specific students could not be linked across the field notes and focus groups; however, instructor data captured in the field notes was linked to the instructor interview as there was only one instructor.

Results

We generated four themes from the analysis of the laboratory observations, student focus group, and instructor interview: classroom interactivity, visualization of anatomy, connecting knowledge, and educational potential. The themes represent the observed and perceived influence of incorporating 3D printed anatomy bones during the shoulder palpation laboratory.

Classroom interactivity

Introducing 3D printed models had several impacts on the classroom interactions that occurred between students and their peers, students and the instructor, and individual interactions with the educational materials. We developed three subthemes that clarify these effects on classroom interactivity: *peer teaching*, *modeling*, and *self-discovery*.

The availability of the 3D printed models created several opportunities for *peer teaching*. Students intuitively leveraged the models to address questions and clarify how to identify anatomical landmarks. As an example, before two students began practicing their palpation skills, one student asked their peer "*where is it?*" (in reference to the lesser tubercle) and their peer then picked up the model and pointed to the lesser tubercle and responded, "*…lesser tubercle is more lateral. Oh wait, no it's more medial. Okay, can you feel it?*" [field note, RA1]. In another instance, when one student was actively exploring for the superior border of the scapula on their partner they asked, "*do I feel for a notch?*" [field note, RA1] before proceeding to pick up the 3D model to show their peer the bony marking; running their fingers along the 3D model before trying to locate the structure on the body of their partner. Focus group data also indicated that students acknowledged enhanced opportunities for peer-teaching and improved access to relevant learning materials.

> *…always went back to it, got me and my partner involved in it, having a set by your side is more time efficient, instead of waiting for the instructor to come by to help you or instead of just seeing it one time.* [focus group]

The 3D models also created *modeling* opportunities between students and the instructor. As the instructor demonstrated the process of the identifying bony structures on the full body skeleton, students followed along using their own set of bony models. The instructor and students also used the models for questioning and demonstrating proper technique. For example, while at one table of students, the instructor asked, "*where do we find the infraglenoid tubercle?*" In response to the students' uncertainty, the instructor asked the students to review their scapular model, and then probed, "*(now) where are you going to go?*" [field note, KL].

The third way we observed 3D printed models influencing classroom interactivity was by creating opportunities for learning through *self-discovery*, that is, without direct instruction from the instructor. For instance, when given time to review the anatomical structures, without instruction to use the models, one student tried connecting the humerus and scapula together to recreate an articulating shoulder joint [field note, RA1]. During the focus group, students also expressed a desire to have the models as self-study materials that could be taken home. The utility of self-discovery through the 3D models was also recognized by the instructor, who shared that if the models were available in the future, they would offer "students to lead things a bit and explore" on their own [instructor interview].

Visualization of anatomy

Throughout the laboratory, students manipulated the 3D printed models in various ways to visualize and understand the anatomical structures of the shoulder. Frequently, students were observed to be placing the individual bones on either themselves or on their partner in effort to confirm the location of structures or to better understand the positioning of the bones in their own bodies. During the focus group, one student described the 3D printed scapula a "*good reference*" as they could easily place the bone directly on their partner to help visualize the location of various bony landmarks. Further, another student shared that when they had difficulty visualizing the location of a certain muscle relative to the scapula, and that having the bone model *"made it easy, easy to look at*" and contributed to their overall understanding.

During several peer interactions, we observed students referring to the models to better visualize the location of the structures that they were trying to palpate. In an illustrative example, while being palpated by their partner, one student told their partner, "*Remember the structure from what it looks like on the model.*" After which both students picked up the model to review the location of the bony marking [field note, KL].

Students in the focus group noted that in contrast to having the single skeleton at the front of the room, the de-articulated 3D printed bones at each learning station added "*practicality*" [focus group] to these learning tools. Several students also emphasized that they liked how the 3D printed models were "*mobile*" and that their mobility optimized their value as they could easily manipulate the bones to match the positioning of their partner. Students believed that this ultimately helped them to conceptualize the location of the anatomical structures of the shoulder as they were trying to palpate them on their partner.

> *No matter what position they are [student partner], you could rotate it and envision it way more efficiently… it was really good, especially for palpating so you can understand, okay that's where that is. Envisioning enhanced a lot more.* [focus group]

As described by the instructor, the presence of de-articulated 3D printed models also challenged learners to really understand how the bones would articulate with one another and their positioning within the body relative to other soft tissues.

> *It was good to get a better idea of the actual shape of the bones because we didn't have the bones attach…… forced them [students] to look at the bones and orient them properly.* [instructor interview]

Connecting knowledge

The 3D printed models provided an additional modality that helped learners connect knowledge across different sources of information and different knowledge types. Students freely shifted their attention between notes and textbook materials, lecture slides, instructor demonstration, manipulating the 3D printed models, and palpating their own bodies.

> *…just having that there [bone model] and being able to see it in front of you and thinking in your head, okay this is this, and this is this and that, and I think that was a lot better, it definitely helped with understanding a lot better.*

This created a variety of use patterns and sequences for each of the modalities. In one instance, while the instructor was explaining the scapula to the class, one pair of students immediately attempted the palpation on a student, a second pair positioned the 3D printed scapula beside their partner as they performed the same technique, and a third pair reviewed the 3D printed scapula first (~30 seconds) and put it away before attempting the techniques on one another [field note, RA2]. Students in the focus group recognized the challenges associated with "*connecting studies (of) anatomy to (the) body*" but one participant in the focus group shared that the 3D printed models helped them "*map*" their learning during the session and another described how the models helped them to apply "*where the bone would be, where certain insertions would be, or where things would protrude out….*"

Educational potential

Students and the instructor both recognized several potential educational opportunities that could be afforded by the availability and use of de-articulated, 3D printed bones in the clinical skills laboratory. These opportunities were characterized into two subthemes: *improved accessibility and deep learning*.

Overall, students perceived the 3D printed models as "*better*" in comparison to only using the 2D images or referencing the one skeleton at the front of the room as a learning adjunct during their skills laboratory.

> *It supplemented my learning… I left more confident. As opposed to just looking at the skeleton at the front of the room and her describing it and palpating on somebody, I could orient myself with the bone in front of me.*

There was also excitement around the potential of having these models available in all sessions as students recognized the potential value of having access to relevant bony models during clinical instruction. As noted by one student, having access to 3D bone models would allow them to view the bony structures from all orientations, in addition to the typical orthogonal views presented in their textbook, arguing it would help them to better conceptualize the location of structures in a real body.

> *It's just better than seeing or drawing two halves (anterior and posterior views) - whereas having just one you can hold in your hand.* [focus group]

Students also believed "*deeper learning*" was achieved as they were able to integrate the use of the bony models while simultaneously learning to palpate the structures on their peers. Access and manipulation of the models also supported independent problem-solving which some students recognized as a benefit in contrast to referencing images in their textbook when trying to palpate different landmarks.

Discussion

This case study explored the impact of introducing 3D printed bone models in a real-world clinical skills palpation laboratory. The findings of this research demonstrate several ways 3D printed models can augment how learners, instructors, and educational materials interact with one another, how learners visualize anatomy, and how readily learners make connections between different sources and types of knowledge. Our findings suggest that 3D printed models serve a similar role as "integrated instruction" described in previous studies on clinical reasoning,[4,9,21] namely, encouraging learners' cognitive integration of relevant anatomical (i.e., shoulder anatomy) and procedural skills knowledge (i.e., shoulder palpation technique), and ultimately their learning.

Previous studies have applied experimental methods to demonstrate how explicit cause-and-effect relationships can affect student's clinical reasoning ability by encouraging or discouraging cognitive integration of basic science and clinical knowledge.[3,7,11,44] Our findings extend this research by demonstrating how cognitive integration may be supported by physical instructional materials, and through social interactions in an authentic learning environment. This suggests that cognitive integration may be supported through careful design of physical instructional materials, social interactions between learners, and between learners and their instructor(s).

This case study uncovered several strategies for supporting the development of learners' cognitive integration that rely on interactions between learners and their environment, which can be described by the concept of affordances. Affordances are the possibilities for action that an environment provides an individual.[45] For example, an individual learner in the palpation skills laboratory, the specifics of their own body, their peers and the instructor, and physical resources (projector screen, 3D printed bones etc.) all represent aspects of the environment that *afford* particular behaviours. Learners' cognitive integration then, is determined not only by the text, images, and words in a lecture, but also who and what physical resources are present in the learning environment. As such, cognition is a situated activity that is dependent on the learning environment and actions performed in that environment.[46,47]

Introducing physical affordances into classroom learning creates unique opportunities to support learning and cognitive integration through embodied cognition. Embodied cognition relates to the notion that cognition is contextual,[48] suggesting that the physical actions of the body have a direct effect on mental processes like learning and perception.[49-52] Thus, when learning to perform clinical skills, it may be that providing additional external representations that encourage physical actions can support embodied cognition and serve as a form of cognitive integration of visual, motor, and spatial information. These processes and affordances may be particularly relevant for the kinds of clinical skills that require anatomical knowledge, manipulations of one's own body, and procedural motor actions that affect 'invisible' features (e.g., palpating bony landmarks).

Limitations

The findings on the impacts of 3D printed models in our study are limited. Firstly, the effects of 3D models were likely dampened by the lack of orientation and preparation the instructor had prior to the session. Though the 3D printed models were well received, they could be improved through explicit guidance and instructions on how to optimize their use.[53] For example, students and faculty were reticent to use the models at the beginning of session (or even forgot about them at one point as noted by the instructor). Additional preparation and examples of how these learning tools may be used may help educators and learners better leverage them to their full potential. This single-case study also only presents the experiences of select students from one cohort and one instructor and therefore are not intended for generalization to other settings. Further, it is important to recognize that the authors subjective expertise on cognitive integration and instructional design influenced several aspects of this study, including the analysis and reported findings.[54]

Conclusions

Our findings demonstrate how cognitive integration can operate within real-world clinical skills training and the potential for 3D printed models to facilitate cognitive integration. Our results describe several strategies that students and a clinical instructor discovered through their own use of 3D printed models that can inform how these models may be optimized during clinical skills instruction. We suggest that the instructional strategies afforded by 3D printed models may support cognitive integration and learning of clinical skills that require learners to interact with 3D representations of anatomy. Future work should explore how to best leverage models to support learning via creating educational settings with the appropriate material and social contexts that enrich learners' cognitive integration.

Conflicts of Interest: All authors have nothing to disclose.

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