

'Drawing' to learn Anatomy: Exploring the theoretical underpinning and conditions favouring drawing based learning

Alia Amin

Abstract

Medical educators are required to explore and introduce teaching and learning innovations to enhance students' cognitive growth and conceptual understanding. It is of particular importance in subjects of basic sciences which encompass basic principles of medical science and link the spheres of core knowledge and clinical application. There are multiple traditional approaches to teaching and learning of anatomy with varied preferences of use. Visualisation holds pivotal importance in learning anatomical knowledge. This review paper proposes use of drawing as a strategy to learn anatomy and describes some conditions for best use of drawing as a learning tool.

Keywords: Drawing, Teaching, Learning, Anatomy education

DOI: <https://doi.org/10.5455/JPMA.34788>

Introduction

Good knowledge of anatomy is essential to understand clinical sciences in medical education.¹ At a time when medical courses are delivered through diverse curricula in limited time span, implementing efficient learning approaches is a dire need.² Educational strategies for better retention, concept building and clinical application must be deployed rather than mere increase in cognitive load due to lots of theoretical information.³ In this context, visualisation is central to understanding life sciences⁴ and integral to scientific thinking.⁵ Visualisation is considered core skill to learn anatomy.⁶ Visualisations are of two types: internal visualisation like imagination or mental image formation, and external visualisation like learner-generated drawing.⁶ The use of art to elaborate anatomical structures is related to ancient times starting from the renaissance, and it continues to evolve.⁷ Early anatomists like Vesalius used drawing to record findings of dissection.⁸ In spite of its long history, learning anatomy by drawing has earned limited attention in medical education.^{9,10} This review was planned to explore the role of drawing-based learning (DBL) in anatomical sciences, to explain theoretical underpinning for DBL and devise conditions for its efficient use. In the first phase, Google Scholar database was

searched using title, 'use of drawing to learn anatomy'; and terms 'drawing', 'sketching', 'anatomy' and 'medical education'. Related articles in the database, and bibliography of selected articles were also searched to find relevant literature. In the second phase, another search was made to find literature explaining DBL as general phenomenon applicable to science education to get deeper understanding of theoretical underpinning of DBL and conditions for its efficient use.

Drawing as pedagogic tool in anatomy

Literature supports the efficacy of drawing as teaching and learning tool in anatomy.⁷⁻¹² Its efficacy for learning microanatomy is well documented.^{3,13,14} Drawing has been used as an in-class active learning strategy^{4,12,15} or as off-campus flexible learning strategy.¹¹ Clavert et al.¹² have endorsed the use of live drawing on black-board in amphitheatre to large group of students. They emphasised upon drawing construction in front of students which gives freeze frame of time to be utilized for clinical consideration. Nayak and Kodimajalu¹⁵ used progressive drawing during interactive windows in lecture at the start as lid-opener and later as monotony-breaker. Other than being interesting and effective, students called it a useful way to recall knowledge of anatomy, understand anatomical relations and test anatomical knowledge. The authors suggested that progressive drawings promote students' engagement, break monotony, and improve active learning. Progressive drawing is considered a good choice to make lectures inclusive for diverse population of students as it involves visual, auditory, read/write and kinaesthetic element of learning.¹⁵

Drawing helps improving both the ability to understand anatomy and test scores. Borelli et al.⁹ explored the effect of drawing workshops using pre-test/post-test format. They reported significant increase in knowledge of anatomy after drawing activity and post-intervention scores. Alhamdani et al.¹⁰ documented dental students' perception of drawing as learning aid in anatomy. Their drawings were used as assessment. Researchers found significant relationship between ability to understand anatomy and using drawing. Students did not find this intervention as adding to their work-load. In another study conducted by Noorafshan et al.¹⁶ majority of students agreed that

CEO Educational Research Foundation, Lahore, Pakistan.

Correspondence: Alia Amin. e-mail: dr.aaliaamin@gmail.com

sketching promoted understanding and deeper learning. Moreover, students found it enjoyable, easy and effective.

Researchers have also combined drawing with other strategies to learn anatomy. Naug et al.⁴ compared learning gains through drawing and plasticine modelling in one group and review questions in another group. Post-test score of students belonging to the drawing and modelling group was significantly higher. Combining haptics and observation with drawing is also thought to promote deeper understanding. Reid et al.⁸ reported utility of haptic-visual observation and drawing (HVOD) model to learn anatomy, which was found to be useful in building 3-dimensional (3D) mental model and improving retention. Backhouse et al.⁷ combined the elements of observation, reflection and repetition with drawing, in a cyclic method named 'ORDER' (Observe-Reflect-Draw-Edit-Repeat) as interactive online tutorial (IT). Students in ORDER-IT group outperformed the control group.

The biggest critique of in-class progressive drawings is that drawing in front of large classes may pose constraints of time, visual clarity or discerning illegible handwriting. More recently, it was thought to take the element of progressive drawing out of lecture theatre. Greene et al.¹¹ proposed the idea of online screen-cast, in form of pre-recorded progressive drawings made with simple lines and landmarks, to allow students to utilise them according to their own preference as opposed to single drawing in the classroom. The simple and stepwise progressive nature of drawing screen-casts and their usefulness to understand anatomical relationships was appreciated by the students. Pickering² also reported positive impact of drawing screen-casts provided to students through virtual learning media to be accessed at their convenience when they were off-campus.

Nonetheless, literature supports that drawing can help revealing inaccuracies in one's understanding of structure and function.¹⁷ Other than the teaching and learning purpose, It can also be an effective tool to assess the anatomical knowledge.¹⁷

Theoretical underpinning of DBL

Learner-generated drawings were defined by Van Meter and Garner¹⁸ as a constructive, goal-directed, strategic process to engage cognition in selecting, organising and integrating verbal and non-verbal representational modalities for better learning; wherein, the processes required for drawing rest entirely on the learner. As far as the theoretical foundation for DBL is concerned, there are multiple philosophical explanations described in literature. According to Naug et al.⁴ DBL is akin to Kolb's experiential learning, and offers active learning. Students, while

drawing, engage in experience, reflect upon it, respond to it and construct new knowledge. According to Slominski et al.,¹⁷ DBL entails assessment of existing knowledge structure or concept which appears in students' drawings. They quoted Ausubel's meaningful learning framework which articulates relation between prior knowledge and learning new material; wherein, meaningful learning occurs when students connect prior knowledge with new information to be learned.¹⁷

According to Meyer's cognitive theory of multimedia learning, drawing after reading text can foster deep learning, as words and pictures utilise two channels of information processing instead of overloading one channel.⁶ The use of drawing screen-casts conforms to the five principles of multimedia learning that aim at limiting the extraneous cognitive load in presentation which includes spatial contiguity, temporal contiguity, coherence, signalling and redundancy.² It is also argued that multimedia effect can be extended to include haptics. Involving multiple senses, like observation, haptics and drawing can improve integration of complex representations into schemata in the long-term memory.⁸

However, It is not just the multimedia effect that is responsible for DBL, rather it is generative learning.¹⁹ Drawing engages students with generative learning in translating text into diagram through three steps; first, as selection of information to be transformed into pictorial; second, as showing spatial organisation in diagram; and, third, as elaborating relationship between the text and diagram.²⁰

According to generative theory of drawing construction (GTDC),¹⁸ DBL involves selection and organisation of elements read in text to form internal verbal representation. Through referential links, internal non-verbal representation (visual) is activated which is integrated by mapping on to the elements present in the verbal representation in text book. This internal non-verbal representation is taken as a mental model which is copied by the learner as external verbal representation while drawing. In the process of integration between verbal and non-verbal representation, learners may activate prior knowledge to accomplish the task. This enable learners to detect inaccuracy in verbal representation before it is passed on to non-verbal representation, which otherwise may affect the accuracy of mental model and external non-verbal representation.¹⁸ Schmidgall et al.²¹ argue that benefits of drawing may be attributed to two processes; first, visualization, in which spatial features mentioned in the text are inferred to develop a coherent image; and second, externalization, in which visual representation is constructed externally on a paper.

According to Backhouse et al.⁷ DBL involves constructivism and experiential learning, and it is underpinned by picture theory which offers to observer more than just words. The theoretical basis for artistic gains of drawing differs from that of learning gains; wherein, the former elicits emotion, and the later elicits observation, thinking and creation of ideas. They argued that theoretical explanation of learning by drawing is rooted in three sets of relations; first, relation between observation and deep neural processing; second, relation between drawing and reflective thinking or meta-cognition; and third, relation between drawing, motor control and procedural skills.⁷

According to Tyler and Likova,²² visual art learning entails interplay between perceptual, higher cognitive and motor functions, hence, showing potential for cross-cognitive transfer in learning and creativity. They argued that drawing may access semantic system in a way that improves cognitive access, and that the visual arts involve almost every subsystem of brain.²² According to some neuroimaging studies, drawing shares cortical substrates with writing, access to semantic system, memory-naming imagery and spatial understanding.²² Art seems to facilitate learning through 'emotional inspiration' an important aspect of art, which involves integration of cognitive, emotional and conative processes. Inspiration mediates the experience of emotional desires, motivational rewards and aesthetic value of visual stimuli which lends to goal-directed behaviours.²²

Seven conditions for learning by drawing

1. Simple but mindful visual productions

Drawing improves learning gain by visualisation.² The objective of drawings must be mindful production of illustration rather than aesthetically perfect diagrams.⁹ Anatomy drawing skills may follow a trajectory of imitation, manipulation, precision, articulation and naturalization.²³ However, for better learning gains, drawing must be clear with well-defined line work and vividly demonstrated anatomical layers with the help of shading or illustration.⁹ Drawing with clarity, simplification, explanations and comments is more important rather than for ornamental value of it.¹² Simplification is considered important which may be due to the fact that the recognition time for complex shapes is slower, hence, the learning is slower compared to simple shapes.²⁴ Moreover, drawings must be made mindfully. When students draw, they must pay attention to every minute detail of structure and function which is also helpful to assess students' concept and level of understanding.¹⁷

2. Self-generated drawings

Self-generated drawings engage learners more actively.⁶

Learner generate drawing is a cognitive learning strategy to foster learning; wherein, learner is not involved passively, rather actively selects, organises and integrates information to be learnt.¹⁹ Students can utilise drawing at their own ease of time and attempt in self-regulated way.⁷ Drawing involves the principle of constructivism and experiential learning.^{4,7} It is a complex activity which involves visual and spatial coordination linked to fine motor activity to form 3D structure on paper.⁸ Drawing demands investment of more mental effort and deep cognitive processing.¹⁹ Moreover, generating own representations is a strategy that allows students to organise their knowledge more effectively and integrate new and existing understanding.⁵

Drawing to understand text is considered self-regulated visualising.²⁵ While drawing, students convert textual information into pictorial information which engages them in a constructive and meta-cognitive process, and it also helps them make referential connections between words and pictures.⁶ It also requires them to make explicit their understanding in an inspectable form.⁵ According to Van Meter and Garner,¹⁸ learning by drawing is a constructive process and the main responsibility of learning lies with the learner. Learner-generated drawing facilitates integration of different cross-modality representations of information, and such challenges have valuable potential for improving student learning. When students are given active task to perform involving pictures like tracing, labelling, drawing etc., learning outcome increases as a result of improved picture processing.¹⁸ Active reconstruction of image through drawing or modelling can develop visual spatial thinking and robust memory of that image.⁴ It is considered to have a role in fostering deep learning and long term memory.²³

3. Seeing through mind's eye and drawing from memory

Third condition for DBL is very critical for learning gain, but is often missed. Learners must observe the object to be learned, see it through mind's eye, and then draw it from memory.²⁶ Seeing through mind's eye is creating image in mind which is based on prior observation.²⁶ Naug et al.⁴ used 'blank page technique' in which learners were required to draw from memory and rely on their own mental image. According to them, making images from mind without visual resources involves experiential learning, visual-spatial thinking and meta-cognition.⁴

4. Effective Support

Efficacy of drawing improves with instructional support.¹⁹ This support may be through activation of prior knowledge,¹⁸ illustrations with text,^{18,27} instructor-generated drawings, interactive live drawing,^{12,15} haptics,⁸

prompt and illustration comparison,^{19,27,28} drawing screen-casts¹¹ etc.

According to Van Meter and Garner's GTDC, integration step in drawing processing provides basis for the effect of provided support, which constrains drawing construction, checks accuracy and attracts learners to key elements and relationship in text.¹⁸ When illustration is provided as support with text, these two promote selection of elements from one another. Learner identifies elements of text in the illustration and finds more elements, hence, looks into text again to find that. This back and forth process goes on. The internal verbal representation makes foundation for internal non-verbal representation. Attempts at making non-verbal representation can send learner back to verbal representation or text when any difficulty is encountered in building internal image or mental model. Elements, in verbal and non-verbal representation, that most fit together are retained in the stored representation of information-to-be-learned.

5. Drawing Accuracy

Making drawing with accuracy is thought to increase learning gain and that, the integration of internal verbal and non-verbal representation makes drawing more advantageous over just provision of illustrations with text.¹⁸ In case of any contradiction found while mapping verbal and non-verbal representations, both the text and illustration are available to resolve the contradiction, a process that provides basis of relationship between drawing accuracy and learning gains.¹⁸ Evidence supports that drawing is useful learning strategy provided it is not poorly done.²⁹ Schmeck et al.¹⁹ and Schwamborn et al.²⁸ found positive correlation between drawing accuracy score and comprehension post-test score. They called it prognostic drawing effect in which quality of drawing predicts performance in subsequent test. Drawing construction improves learners' ability to detect comprehension errors which, in turn, would increase fix-up attempts.²⁷ It is considered to improve metacognitive skills like self-monitoring through error detection and rectification which, in turn, leads to deeper learning and long term memory.²³ For the accuracy of non-verbal representation, verbal representation needs to be accurate which can be increased when drawing support is provided; one representation can be used to resolve queries about the accuracy of the other representation.¹⁸ In a study, Van-Meter documented that groups of students who were provided external support in the form of illustration and prompted questioning constructed drawing more accurately than the illustration group or the reading group.²⁷ Moreover, drawing accuracy is not correlated with spatial ability and motivation.¹⁹

6. Use for testing higher order cognition

Drawing is useful in assessing students' thinking¹⁷ and understanding of spatial aspects.³⁰ The benefits of drawing are revealed in assessments of connected and organised knowledge (high order thinking) rather than recognition of factual text information through multiple choice questions.^{21,27} Van Meter et al.³¹ reported that students in drawing group performed significantly better on problem-solving test, but found no effect on MCQ test. Likewise, Leopold and Leutner³² also endorsed that the learning benefit of drawing is evident in assessments that test deeper understanding and that are sensitive to higher level of comprehension. This positive effect of using drawing strategy to understand science text is attributed to role of drawing in helping students construct mental model of content to-be-learned.³²

7. Haptics, Observation and Repetition

Learning processes like observation, visualisation, haptic reasoning and visuo-spatial understanding are closely related to artistic approaches.³³ According to Keenan et al.,³³ observation, repetition and visualisation should be incorporated within any artistic learning approaches. According to haptic-visual observation and drawing model (HVOD) proposed by Reid et al.⁸ use of haptics, 'the sense of touch', helps in understanding 3D structure and in making mental model of an object prior to drawing, and that, the haptics gives additional mean of gathering data required for drawing from the object (humerus or skull) being observed. Students also perceived utility of HVOD model of learning in improving retention of knowledge. Moreover, Reid et al.⁸ discussed that when students observe any anatomical part using their haptic sense, draw it and refer to atlas to annotate, their psychomotor and cognitive domains are activated, resulting in deeper cognitive understanding. Dempsey and Betz²⁶ have suggested a model of using biological drawing as scientific tool to learn. According to their model, first two steps include critical observation and drawing from memory. Artistic methods such as drawing develop skills like critical observation.^{7,26}

Discussion

Drawing is a visualisation strategy that helps in text comprehension in an engaging and motivating way.⁶ Drawing is a pedagogic tool that improves observational processes, content area knowledge, text comprehension, writing among students.¹⁸ Drawing is considered to be useful for activities like explaining, reasoning, communicating,⁵ self-monitoring of comprehension,²⁷ and metacognition.⁷ Representational work has the potential to promote self-regulated learning.⁷

It is considered a cost-effective method which is fun and more engaging and improves anatomical knowledge understanding and retention.⁹ The efficacy of drawing is established not only in gross anatomy, but also in micro-anatomy. In some parts of world, there is some organisational noise about utility and relevance of histology drawing manual in undergraduate medical courses. However, research has validated its efficacy and suggested its continual use.³

For better outcome, learners must generate simple conceptual drawing, seeing through the mind's eye, including every detail with maximum accuracy. Van Meter and Garner have emphasised three conditions to make best use of the drawing: drawing accuracy, effective support, and higher order assessment.¹⁸

However, it is argued that, owing to difference in age and content to be learnt, it is difficult to generalise the efficacy of external supports.²⁷

For incorporating DBL, some challenges may be encountered. First, learner-generated drawings may increase cognitive load. Leutner et al.²⁵ have argued that visualisation strategies induced by reading text without picture, transform verbal information to pictorial information which induce extraneous cognitive load (ECL). On the other hand, it may induce germane cognitive load (GCL) and activate meta-cognitive processes of mental model quality control, leading to deeper understanding and learning. Schmidgall et al.²¹ says that drawing increases cognitive demand, however, once externalized, drawing can offload cognition. However, the relationship between cognitive load and learning gain through drawing can be an interesting area to be explored further.

Second, DBL can pose time constraint,⁹ issues of visual clarity or discerning illegible handwriting.¹¹ These issues are particularly related to progressive in-class drawings. Instructions including progressive or live drawings are useful^{12,15} and engage diverse population of students who may have visual, auditory, read/write and kinaesthetic preferences of learning.¹⁵ However, time constraint may limit its use as pedagogic tool. Sufficient time on task is essential in optimal achievement in any learning activity.³³ Moreover, selection of content and complexity of drawing may influence time on task and students' engagement. Greene et al.¹¹ proposed the idea of online screen-cast to allow students to utilise them according to their own knowledge and preference as opposed to single drawing in classroom. Off-campus drawing can be useful for self-study and revision purposes.⁷

Third, varied spatial ability or drawing skills of lecturers or

students is considered as having an influence on learning gain.¹⁰ However, accuracy of drawing is more important than aesthetics. Backhouse et al.⁷ have documented that prior experience of arts did not affect learning gain in drawing-based pedagogy. Likewise, according to Schmeck et al.,¹⁹ there is no correlation between spatial ability and drawing accuracy. The skills or experience required to use artistic learning approaches must not be prohibitive.³³ The issue of variability in spatial ability can be addressed by encouraging the students to use drawing for learning rather than producing an artwork.³³

Nonetheless, students' affective systems including attitude, value, self-efficacy and interest in drawing to learn is another challenge in adopting DBL.³⁴ In order to foster DBL, instructors must work on developing students' positive affect, visual literacy and model based reasoning skills including creation, use, evaluation and revision.³⁴

Conclusion

Drawing-based learning involves active and experiential learning. It is not only engaging, but also helpful in understanding anatomical planes and improves retention of knowledge. For the best use of DBL in anatomy, one must ensure learner partnership in simple and mindful productions of high drawing accuracy using mind's eye and critical observation. Moreover, external support may facilitate the learning gain. This review provides basis for further in-depth exploration of learning anatomy through drawing by way of more comprehensive or systematic approaches.

Disclaimer: None.

Conflict of Interest: None.

Source of Funding: None.

References

1. Amin A, Iqbal J. Effective ways to learn and retain gross anatomy Pak Armed Forces Med J 2019; 69: 708-14.
2. Pickering JD. Measuring learning gain: Comparing anatomy drawing screencasts and paper-based resources. Anat Sci Educ 2017; 10: 307-16.
3. Rafi A, Rauf A, Anwar MI. Significance of Actually Drawing Microscopic Images and Its Impact on Students' Understanding of Histology. J Dow Uni Health Sci 2017; 11: 77-81
4. Naug HL, Colson NJ, Donner D. Experiential Learning, Spatial Visualization and Metacognition: An Exercise with the "Blank Page" Technique for Learning Anatomy. Health Prof Educ 2016; 2: 51-7.
5. Ainsworth S, Prain V, Tytler R. Drawing to learn in science. Science 2011; 333: 1096-7.
6. Lin L, Lee CH, Kalyuga S, Wang Y, Guan S, Wu H. The effect of learner-generated drawing and imagination in comprehending a science text. J Exp Educ 2017; 85: 142-54.
7. Backhouse M, Fitzpatrick M, Hutchinson J, Thandi CS, Keenan ID. Improvements in anatomy knowledge when utilizing a novel cyclical "Observe-Reflect-Draw-Edit-Repeat" learning process. Anat Sci Educ 2017; 10: 7-22.

8. Reid S, Shapiro L, Louw G. How Haptics and Drawing Enhance the Learning of Anatomy. *Anat Sci Educ* 2019; 12: 164-72.
9. Borrelli MR, Leung B, Morgan MC, Saxena S, Hunter A. Should drawing be incorporated into the teaching of anatomy? *J Contemp Med Edu* 2018; 6: 34-48.
10. Alhamdani FY, Hatem HA. Drawings as learning aid for the human anatomy students' based evaluation. *J Oral Health Craniofac Sci* 2017; 2: 090-095.
11. Greene SJ. The use and effectiveness of interactive progressive drawing in anatomy education. *Anat Sci Educ* 2018; 11: 445-60.
12. Clavert P, Bouchaïb J, Duparc F, Kahn J. A plea for the use of drawing in human anatomy teaching. *Surg Radiol Anat* 2012; 34: 787-9.
13. Cracolici V, Judd R, Golden D, Cipriani NA. Art as a Learning Tool: Medical Student Perspectives on Implementing Visual Art into Histology Education. *Cureus* 2019; 11: e5207.
14. Balemans MC, Kooloos JG, Donders ART, Van der Zee CE. Actual drawing of histological images improves knowledge retention. *Anat Sci Educ* 2016; 9: 60-70.
15. Nayak SB, Kodimajalu S. Progressive drawing: A novel "lid-opener" and "monotony-breaker". *Anat Sci Educ* 2010; 3: 326-9.
16. Noorafshan A, Hoseini L, Amini M, Dehghani MR, Kojuri J, Bazrafkan L. Simultaneous anatomical sketching as learning by doing method of teaching human anatomy. *J Educ Health Promot* 2014; 3: 50.
17. Slominski TN, Momsen JL, Montplaisir LM. Drawing on student knowledge of neuroanatomy and neurophysiology. *Adv Physiol Educ* 2017; 41: 212-21.
18. Van Meter P, Garner J. The promise and practice of learner-generated drawing: Literature review and synthesis. *Educ Psychol Rev* 2005; 17: 285-325.
19. Schmeck A, Mayer RE, Opfermann M, Pfeiffer V, Leutner D. Drawing pictures during learning from scientific text: Testing the generative drawing effect and the prognostic drawing effect. *Contemporary Educ Psychol* 2014; 39: 275-86.
20. Fiorella L, Mayer RE. Eight ways to promote generative learning. *Educ Psychol Rev* 2016; 28: 717-41.
21. Schmidgall SP, Eitel A, Scheiter K. Why do learners who draw perform well? Investigating the role of visualization, generation and externalization in learner-generated drawing. *Learning and Instruction* 2019; 60: 138-53.
22. Tyler CW, Likova LT. The role of the visual arts in enhancing the learning process. *Front Hum Neurosci* 2012; 6: 8.
23. Kumar D, Rajprasath R. Drawing skills in anatomy education and the millennial learner: A cognitive and metacognitive viewpoint. *Res Dev Med Educ* 2019; 8: 58-60.
24. Miller R. Approaches to learning spatial relationships in gross anatomy: perspective from wider principles of learning. *Clin Anat* 2000; 13: 439-43.
25. Leutner D, Leopold C, Sumfleth E. Cognitive load and science text comprehension: Effects of drawing and mentally imagining text content. *Computers Human Behavior* 2009; 25: 284-9.
26. Dempsey BC, Betz B. Biological drawing: A scientific tool for learning. *Am Biol Teach* 2001; 63: 271-9.
27. Van Meter P. Drawing construction as a strategy for learning from text. *J Educ Psychol* 2001; 93: 129-40.
28. Schwamborn A, Thillmann H, Opfermann M, Leutner D. Cognitive load and instructionally supported learning with provided and learner-generated visualizations. *Computers Human Behavior* 2011; 27: 89-93.
29. Scheiter K, Schleinschok K, Ainsworth S. Why sketching may aid learning from science texts: Contrasting sketching with written explanations. *Top Cogn Sci* 2017; 9: 866-82.
30. Ainsworth S, Stieff M, DeSutter D, Tytler R, Prain V, Panagiotopoulos D, et al. Exploring the value of drawing in learning and assessment. Singapore: International Society of the Learning Sciences; 2016.
31. Van Meter P, Aleksic M, Schwartz A, Garner J. Learner-generated drawing as a strategy for learning from content area text. *Contemporary Educ Psychol* 2006; 31: 142-66.
32. Leopold C, Leutner D. Science text comprehension: Drawing, main idea selection, and summarizing as learning strategies. *Learning and Instruction* 2012; 22: 16-26.
33. Keenan ID, Hutchinson J, Bell K. Twelve tips for implementing artistic learning approaches in anatomy education. [Online] [Cited 2020 Jan 20]. Available from: URL: <https://doi.org/10.15694/mep.2017.000106>.
34. Quillin K, Thomas S. Drawing-to-learn: a framework for using drawings to promote model-based reasoning in biology. *CBE—Life Sci Educ* 2015; 14: es2.