Hand drawing as a tool to facilitate understanding in undergraduate human biology: a critical review of the literature and future perspectives

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Science and drawing have been paired for hundreds of years, and this synergy is still prevalent in research investigating the role of drawing for developing and assessing understanding. However, despite research at the primary and secondary levels of education, there is limited research on whether drawing facilitates learning at the undergraduate level, particularly in human biology. This subject specifically is important to focus on as it can be a core subject on some multidisciplinary programmes that do not require a science background at entry. The literature reviewed in this paper highlights that drawing tasks are well received by students and that they perceive the tasks to be helpful for their understanding. There is also some evidence that it might improve learning. However, this cannot be concluded with confidence due to some limitations with respect to comparison groups, including such a group being absent, using retrospective cohorts as a control, and not controlling for instruction between groups. Furthermore, some of the reported improvements in tests are practically very small. More work is warranted in this area as there is a risk that misconceptions can be passed on to students and between students using this type of teaching activity.

Key words: Teaching; anatomy, physiology, draw, art

Introduction

There is a long held association between science and art when it comes to learning about the human body, developing largely during the renaissance period as a means to understand the human form and map out its internal structures (Mavrodi et al., 2013; Rifkin et al., 2006). An example familiar to most is Leonardo Da Vinci's Vitruvian Man, originally drawn in the late fifteenth century, but still used in some classrooms in the modern day (Babaian, 2009; da Silva et al., 2010). Developments in techniques and technologies mean that illustrations are no longer the sole medium by which knowledge of the human body can be shared, but drawing is still a widely used tool to teach science.

It is thought that drawing might aid memory and information recall (Heideman et al., 2017), encourage students to pay attention to the finer details (Dempsey & Betz, 2001), help understand the development of a structure as opposed to being presented with the completed image (Lysek & Gernot, 1981), identify misconceptions or promote deeper understanding of processes that written or verbal recall cannot (Murtonen et al., 2020), and encourage students to challenge and explore their representations of science to help them make meaning of the topic (Prain & Tytler, 2012). There is an abundance of examples of using drawings in primary and secondary science education such as to assess informal learning on field trips (Cainey et al., 2012), improve observation skills (Weekes, 2005), and to understand ideas about human biology (Granklint Enochson et al., 2015). Ainsworth et al (2011) offer a review of relevant research in this area and explore further ways in which drawing may help learning in science.

Despite the wealth of research at the lower levels of education, there is much less at the undergraduate level. This is perhaps because it is assumed that more mature students have already learned the fundamentals in preparation for more advanced study. This is not necessarily true though, particularly in the area of human biology. Some undergraduate programmes such as medicine, dentistry and physiotherapy require a suitable scientific background for entry to the programme. However, there are other programmes on which human biology is a core topic, but a science background is not required for entry, such as sport and exercise, health and social care, some allied health professions such as nursing and midwifery, and aesthetic professions such as health and beauty. In these latter subjects, other elements of biology such as cytology and genetics are often taught within physiology modules, so this paper uses the term human biology to reflect a broader scope than physiology alone. The majority of the research at Undergraduate level aims to use drawing to identify misconceptions in trainee science teachers (Bahar et al., 2008; Dikmenli, 2010; Kunt, 2016; Kurt et al., 2013; Pelaez et al., 2005), or to assess knowledge (Chang et al., 2020). There is very little in terms of implementing drawing as a strategy to improve understanding.

The aim of this paper is to critically review the existing literature on the use of drawing as a tool to improve understanding in undergraduate human biology, and to provide recommendations for future research.

Literature Search

Relevant literature was identified by searching ERIC (Education Resources Information Centre), British Education Index, Scopus and Web of Science with the following search term; (biology OR physiology) AND (“higher education” OR college* OR undergrad* OR “K-12” OR kindergarten* OR “primary school*” OR “middle school*” OR “high school*” OR “elementary school*” OR “vocational education” OR “adult education”) AND (Drawing or doodl* or sketch*).

Six inclusion criteria were applied to the retrieved studies:

1. The authors measured either the student perception of learning or took an objective measure of learning after the drawing intervention. Papers were excluded if the only provided a description of teaching practice or a lesson plan.
2. The student(s) participating in the study produced the drawing themselves.
3. The drawing was a still image with no dynamic element, either labelled or unlabelled.
4. The subject matter was related human biology.
5. The intervention used aimed to progress learning rather than assess current understanding or misconceptions.
6. Participating students are studying at the undergraduate level.

The workflow of study retrieval is presented in Fig 1. The key information extracted from the remaining studies were (i) the students, (ii) the topic, (iii) the intervention, (iv) the findings. This key information is outlined in Table 1.

Drawing as a Tool for Learning the Representational Aspects of Human Biology

Musculoskeletal (MSK) anatomy is a classic example of where art and science have crossed over for learning, gaining particular ground during the renaissance years (Mavrodi et al., 2013; Rifkin et al., 2006). Phillips (2000) exploited this relationship literally, inviting medical students to partake in a three hour life drawing class. The objectives were to (i) help students learn the basics of life drawing, (ii) apply knowledge in a more holistic context and increase enjoyment of the anatomy course, (iii) consider the human body from an artistic rather than medical point of view, and (iv) provide an opportunity to observe a naked human body in detail. This is an interesting intervention that appeared to be well received by the students. Unfortunately, the author did not track the students after the course as it would have been beneficial to gain a deeper understanding about any impact that the class had on their subsequent studies. Also, as the objectives were relatively holistic the application to learning internal anatomy is limited.

Focusing more on the internal structures, and therefore the assessed content of most anatomy classes, Naug et al (2011) implemented drawing activities into a session for a multidisciplinary allied health cohort consisting of over 600 students. The class was delivered as a rotation of 10-15 minute activities, one of which was titled ‘blank page’. This activity required students to draw and label a component of the MSK system without access to other learning materials such as manuals or texts, and then revise their drawings after revision or discussion with a tutor. A survey was distributed after the session, and the 282 respondents overwhelmingly agreed that the activity assisted their learning and ranked the learning tool as good or very good. The authors concluded that the favourable responses were due to the active nature of the task and that it encouraged reflective observation of learning, conclusions supported by students identifying that the session was ‘fun’, ‘stimulating’, ‘challenging’ and it ‘made me think’. These are encouraging perceptions and identify the class as an example of good practice for student engagement. However, it is difficult to identify the direct effects of the activity on learning, as the pilot nature of the project meant that no outcome related to learning was measured. Furthermore it is not described how the students chose a topic to draw so they could have selected a topic they were more comfortable with, and less than half of the class responded to the survey, so those with a negative view of the activity may have chosen not to answer it. In the context of this review it should also be noted that some students opted to complete a clay modelling exercise instead, and the respondents are not separated in the results, so it is not clear how many of the respondents were referring directly to the drawing activity.

Borrelli et al (2018) also investigated the effects of drawing on learning MSK anatomy, but unlike Naug et al (2011) attempted to measure learning by implementing a test pre and post intervention. A group of 49 students from mixed scientific backgrounds were invited to take part in an extra-curricular anatomy drawing workshop. In the first half of the session students conducted a live drawing task imitating an instructor who was drawing on a whiteboard in front of the class. There was also some drawing instruction for aspects such as line formation and layering. The second part of the session consisted of copying structures from a cadaver specimen rather than from the instructor's drawing. The average test score increased significantly from 4.93 to 6.04 out of 20 after the session, but the practical relevance of this increase is questionable when considering that the upper confidence interval was an improvement of 1.7 marks. Moreover, there was no control group so the minor improvement in grade could have been down to any element of the class. The students perceived that their knowledge of anatomy improved as a result of the session, possibly due to learning how to simplify complex anatomy and how to recognize key features. However, it is difficult to affirm how true these perceptions are due to the underlying limitations of the study.

The need of a control group for comparison was partially addressed by Joewono et al (2018) by comparing the test results from three different undergraduate physiotherapy cohorts (2012, 2013, 2014; n = 147). The 2012 and 2013 cohort were taught by traditional methods incorporating group lectures and clinical practice, whereas the 2014 cohort also had added drawing activities. When analysed using inferential statistics the 2014 class scored significantly higher than the previous two cohorts. The average of the 2012 and 2013 class scores was 33.62 compared to 45.00 in the intervention group, meaning that the 2014 class demonstrated an approximately 34% increase. This appears to be a large increase, but this could have been put into better perspective if the authors had clarified the maximum score for the test. It would also have been beneficial if the authors had identified if any specific content was facilitated more by the drawing activity. Whilst the improved scores in this study are likely due to the intervention, the drawing intervention is not well described so the contribution of other factors to the improved score cannot be discounted. There is an example of one student's work in the paper, but it is unclear if it was done in class, out of class, with instruction, with notes, or what areas of the body were covered. Without this detail it is difficult to ascertain whether any effects would be due to the drawing activity *per se* or simply a case of extra instruction. The time difference between the drawing classes and the exam has not been described, so it is not known how well the students retained the information.

Drawing as a Tool for Learning Biological Processes

Understanding the anatomy of the MSK system is an important fundamental of many professions, but student understanding is limited without the ability to apply the knowledge. Murtonen et al (2020) argue that some knowledge can be memorised without the need of a deeper understanding of the content, but drawing can help to identify misconceptions and learn processes beyond static anatomy. Such research is limited in an MSK context. One paper looked to use an eight-week art observation class called 'Training the Eye' to improve the medical observation skills of medical students (Naghshineh et al., 2008), however the students did not actively take part in the drawing, so it is beyond the scope of this review. To examine the effects of drawing on applying knowledge then we must look wider than the MSK literature to the more abstract concepts of physiology.

Strand and Boes (2019) and Ylostalo (2019) describe some example interventions including drawing tasks for teaching biological processes, but do not evaluate their effectiveness. Rotbain et al (2005), on the other hand, implemented a drawing intervention with the aim of improving student understanding of DNA structure and replication. Biology majors (n = 187) were separated into a control and intervention group. The control group undertook traditional classroom teaching, whereas the experimental group also completed a drawing task that consisted of activities such as completing and labelling figures. Both groups sat a multiple-choice question (MCQ) exam at the end of the scheme of work (20 hours), with the experimental group scoring higher than the control group on all aspects of the test. It is difficult for an MCQ exam to test the application of knowledge to processes, however the students reported to find the task particularly beneficial for understanding the process of DNA translation. The study suffers from some limitations, the main one being that the improved scores may have been the result of extra instruction rather than the drawing task *per se,* as the authors themselves state that, ''*... and also enabled teachers to pay attention to the individual progress of each student, which is especially important in heterogeneous classes''*. Moreover, the absence of a retention test means that it is unclear if the task helped the students to recall the information later in the course, and an MCQ test does not necessarily challenge misconceptions. Nevertheless this study did successfully implement a controlled trial in the same cohort of students, marking an improved research design from the MSK research described in the previous section and making the paper more informative than the example classes from other authors (Strand & Boes, 2019; Ylostalo, 2019).

Research has also been conducted on the use of drawing interventions to facilitate learning of cell structure and division (Bell, 2014; Murtonen et al., 2020). Bell (2014) taught the fundamentals of cell structure and mitosis to 33 students enrolled on an introductory college biology course. The class was split into two groups after the taught session, with one group undertaking a more passive drag and drop set of activities on an interactive PowerPoint, and the other group a more active drawing task requiring them to copy and label from stock images. The groups were inverted, so one group did the drawing task for cell structure and the other one for mitosis so that both groups took part in the intervention. This allowed a crossover design, and to partially account for the absence of a control for prior knowledge and therefore the risk of one group performing better than the other group irrespective of an intervention. Learning was assessed at the end of each task using a quiz. The results demonstrated an improved average grade in the hand drawing group for the cell structure quiz, but there were no differences between groups for the mitosis quiz. However, whilst statistically significant, the difference between the groups in quiz one translated to an average improvement of only 1.6 marks out of 20. Therefore, in practice the hand drawing intervention could be argued to be of no greater value than the PowerPoint exercise. However, an alternative form of assessment may have helped better identify the effects of the drawing activity. For example the mitosis quiz asked students to *'draw a cell in a particular phase of mitosis, labelling specified structures'*, so in the absence of any further detail this appears to be as fundamental a question as the cell structure quiz, without asking the students to apply their knowledge to a process. The quizzes were also completed only immediately after the class, so any instruction is likely to have been of acute benefit, and the real interest is in whether the interventions help student retain the knowledge for future application. Despite the criticisms of this study the design is an advancement on Rotbain et al (2005) in terms of matching the level of instruction so any changes are more likely to be directly due to the intervention.

Similar to Bell (2014), Murtonen et al. (2020) was interested in the use of drawing to help the understanding of cell division, this time meiosis. An intervention group completed a drawing task to act as a prompt for comparison against a model answer and to discuss misconceptions. This task took place pre-session and acted as an extra activity compared to the control group, so the fact any findings may be due to extra instruction, and that the drawing task was more to initiate a future exercise, means that this study falls outside of the scope of this review.

Progressing from cellular biology, there is very little research examining the effects of drawing activities on understanding of more complex systems physiology. One study did implement such a task to teach an element of renal physiology, specifically the function of a nephron (Robinson et al., 2018). A class of medical students were issued with a large poster of a nephron developed by staff and refined by students in a previous cohort. The self-directed problem-based learning pedagogy employed by the course required students to work in groups to research a particular section of the diagram and to peer educate others in the group. The effectiveness of the task was evaluated by comparing the test scores of the cohort with previous classes who did not have access to the drawing task. Statistical analysis identified an overall significant F value for the ANOVA, but post hoc tests were absent so significantly different pairings were not elucidated. In context, whilst statistically significant, the overall average score for the intervention group was less than two marks higher than the control cohort with the lowest score. This is possibly because the students appeared to do well on the test before the intervention, with the control years scoring 89.3 and 88.4%. Therefore, either the test employed (retired medical exam questions) was not sensitive enough to identify a gap in learning, or the topic in question was not sufficiently challenging enough to require an intervention. In addition, despite the task being associated with a drawing the students could complete the task without drawing themselves. Thus, meaning that the application of the findings to understanding the benefits of drawing for systems physiology is limited. Of interest though is that the students did perceive the drawing to be helpful in the initial stages of learning as it gave them an immediate framework of understanding and was copied and posted in rooms to serve as a reference and became more useful as the degree went on. This raises a consideration for knowledge retention, which was unfortunately not measured in his study.

Summary and Recommendations for Future Research

This review identifies that there is a relatively small body of literature investigating the benefit of drawing activities for learning human biology at undergraduate level. It is difficult to conclude from the existing literature that drawing activities facilitate learning at this level due to limitations including in some cases an absence of outcome measures related to learning, no student follow up to identify retention, and inappropriate comparison groups. Some of the issues with the comparison groups included not having comparable levels of instruction so any changes may not be due to drawing *per se*, and using previous cohorts as a comparison where it cannot be guaranteed that previous experiences or instruction on other parts of the course were comparable to the intervention group. Admittedly it is difficult to include a genuine control group as for ethical reasons no student group can be purposely disadvantaged if it is believed an intervention group will have greater achievement. However, based on current literature this greater level of achievement cannot be assumed, and if it was true then a comparison group could be exposed to the intervention post study to ensure an equitable learning experience on the course. Taber (2019) offers recommendations for selecting control groups in a recent review.

These limitations are important to address as one could argue that drawing activities could be detrimental to learning when considering that drawings have been shown to unearth misconceptions in students and trainee teachers. Such misconceptions could inadvertently be passed on through such teaching activities (Bahar et al., 2008; Dikmenli, 2010; Kunt, 2016; Kurt et al., 2013; Pelaez et al., 2005).

Below are some suggestions for future directions to help address some unanswered questions and control for some of the discussed limitations.

(1) Prospective studies should be designed whereby a cohort is split into relevant experimental groups at the start, controlled for academic ability and experience. This will prevent the need for retrospective comparison to previous cohorts.

(2) Students should be tracked prospectively to measure knowledge recall later to help identify false positives and negatives. For studies attributing an improved score to drawing activities it cannot be ruled out that any benefit was only acute. Conversely studies reporting no benefit of the activities cannot be certain that the same level knowledge was not retained for longer in the intervention group. Student perceptions should also be collected at a later date to ensure that any perceived benefit of learning was not a result of the novelty of the task.

(3) Current research tends to focus on static elements on human biology such as MSK anatomy or components of a cell. Future research should apply drawing tasks to processes that require an understanding of location in space such as integrative systems physiology.

(4) Several studies in this review are ran with medical students who would be expected to already have a level of understanding of fundamental human biology. As a generalisation, this population is arguably not where this research should be targeted as they may learn irrespective of intervention, as witnessed by Robinson et al (2018). Future work should be applied to undergraduate students on courses that may not have required a fundamental level of science knowledge for entry, but for which human biology is an important element e.g. sport and exercise, health and

social care, some allied health professions such as nursing and midwifery, and aesthetic professions such as health and beauty.

(5) It is the author’s opinion that future research should first aim to identify if drawing is an effective learning tool at the undergraduate level before more detailed research. A proposed research design is outlined in Table 2. If drawing activities are found to be beneficial to learning then further research is needed into styles of delivery from the teacher, or drawing competence of the student, in order to prevent inadvertent passing of misconceptions. It could also lend from existing work that aims to set conditions under which the learning technique may be most efficacious (Tytler et al., 2020).

Disclosure statement

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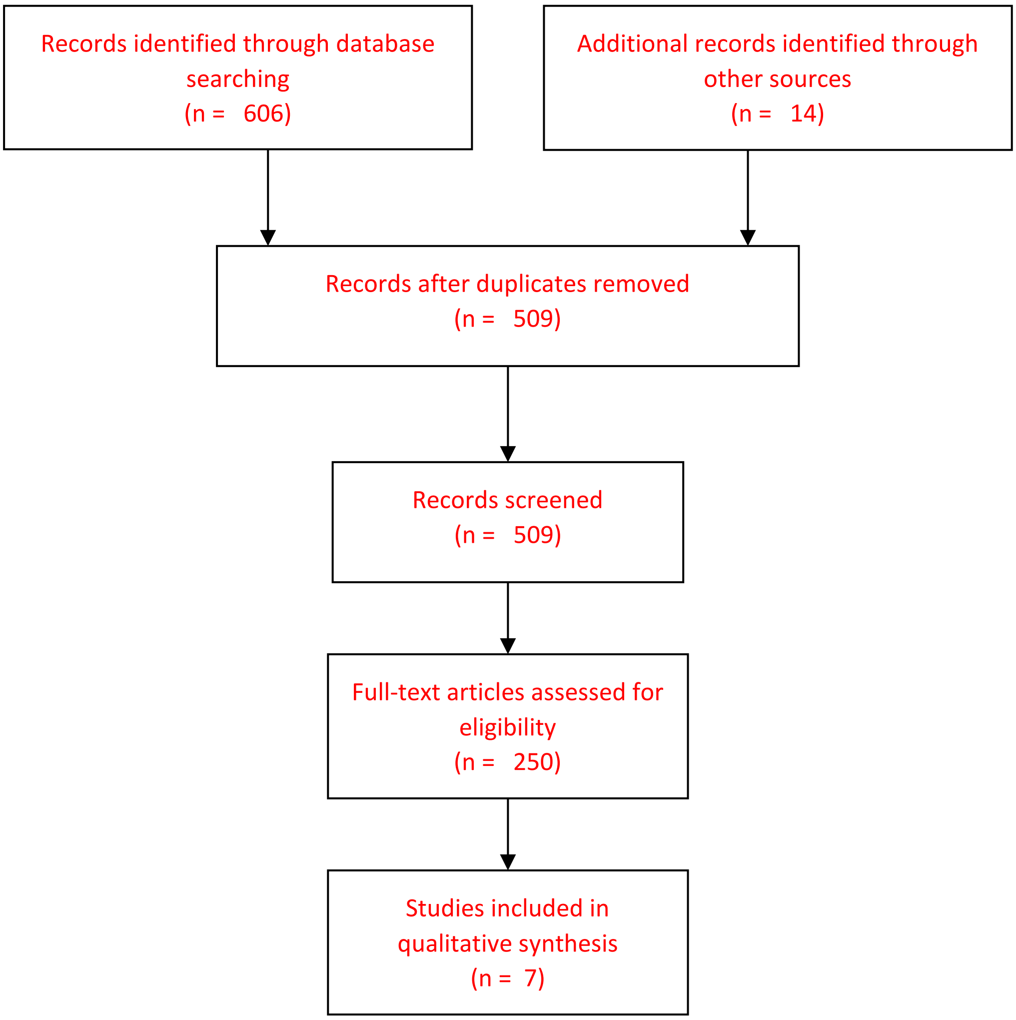

Fig 1. Workflow diagram of study selection

Table 1. Retrieved studies that matched the inclusion criteria for the review

Study	Level	Topic(s)	Intervention	Findings
Bell (2014)	33 students from a pre-university science programme	Cell structure Cell division	All students attended the same taught session and were then assigned to one of two intervention, (i) interactive drag and drop images on PowerPoint, (ii) traditional drawing copying from stock images. The groups were inverted so they were in a different intervention group for the cell structure and cell division topics. Learning was assessed via a quiz following the intervention.	The hand drawing group scored better in the structure quiz (statistically significant), but there was no difference in results for the cell division quiz.
Borrelli et al. (2018)	49 undergraduate students enrolled on medicine, dentistry or allied health science degrees	Musculoskeletal anatomy	In the first half of the session students followed live instruction and imitated the image created by an instructor. This included some instruction on drawing e.g. line formation, layering. In the second half of the session students created drawings from observing cadaver specimens. All students sat a test before and after the session.	Test scores were significantly improved after the intervention. The students perceived an increased knowledge of anatomy, attributed to learning how to simplify complex anatomy and how to recognize key features.
Joewono et al. (2018)	147 undergraduate physiotherapy students over three different cohorts	Musculoskeletal anatomy	Cohorts from 2012 and 2013 were taught via traditional means including lecture classes and clinical practice. The 2014 class had an additional drawing class where they were encouraged to hand draw the relevant region of the body on an A3 page. The first semester module mark was used as the main study outcome measure.	There was a statistically significant increase in the average test score in 2014 which was not observed between 2012 and 2013.
Naug et al. (2011)	282 undergraduate students from mixed allied health programmes	Musculoskeletal anatomy	Students took part in a class rotation of activities which included a task named 'blank page', where they were instructed to draw or model an element without notes. They then worked with tutor to identify errors.	There was no objective measure of learning, but students were found to perceive the activity as having helped their learning. Positive comments included that it was 'fun', 'stimulating', 'challenging' and it 'made me think'.
Phillips (2000)	Undergraduate medical students	Musculoskeletal anatomy	Students attended a 3-hour life drawing class with a life drawing tutor and an anatomist.	Student perspectives are not described in detail, though the author's commentary suggested that feedback was generally

				positive, and offered that it may be good for students to see things from a new point of view.
Robinson et al. (2018)	Undergraduate medical students	Renal physiology	The class was issued with a large poster of a nephron to learn about renal physiology and histology. Students worked in groups to study a section of the diagram in detail and peer educate each other. The students did not necessarily have to conduct any drawing themselves. The efficacy of the intervention was evaluated by asking students to sit a test consisting of retired questions from the medical examination.	Test scores were significantly improved in the second year of utilizing the intervention (following some edits suggested by the first cohort). The students perceived the drawing as being beneficial as it (i) gave them an immediate framework for understanding the histology, pharmacology, and physiology of the nephron, (ii) it did not allow them to neglect the learning of renal physiology, (iii) was always present in the study rooms and it served as a reference that became more useful as the course went on.
Rotbain et al. (2005)	187 biology major students	DNA structure and replication	Students were separated into a control or intervention group. The control group undertook traditional classroom teaching, whereas the experimental group also completed a drawing task that consisted of activities such as completing and labelling figures. Both groups sat a multiple-choice question (MCQ) exam at the end of the scheme of work (20 hours),	The intervention group scored higher than the control group on all aspects of the test.

Table 2. Proposed research design to investigate the effects of drawing on learning at the undergraduate level

Element	Recommendation
Participants	Students enrolled onto undergraduate programmes that may not have a pre-entry science requirement, but for which human biology is a key element. See recommendation 4 in the text.
Subject matter	A topic with a spatial and temporal element and which requires interaction of different systems to allow the assessment of both information recall and application of knowledge. See recommendation 3 in the text. For clarity, the digestive system will be used as an example here, focusing on the path of food and water through the system, and the interaction with other systems for absorption and excretion.
Study groups	Study group 1 (control): Taught the digestive system content using traditional means. The taught content should include images like those that group 2 will draw to ensure that any differences can be attributed to the drawing, and not the use of images. Study group 2 (intervention): Taught the same digestive system content as group 1 by the same teacher, but they are required to add to a drawing as they move to a new aspect. For example, they may start with a large outline of the human body and then add the internal structures with some additional representations of biological processes such as amylase activity in the buccal cavity. This design would control for the level of instruction, ensuring that differences between the groups is not a result of extra instruction in the drawing group. It also ensured that the drawing task is complementing rather than replacing other forms of instruction to promote student accessibility. In follow up work study group 2 could be adapted as per recommendation 5 in the text, or additional groups may be added whereby the drawing task is completed under different conditions or following some basic drawing instruction.
Group allocation	Rank assign students to each group based upon either (i) their performance in a recent summative assessment, (ii) a pre-test on the topic of question, or (iii) a combination to account for academic ability (using (i) as a proxy measure) and prior understanding of the topic. See recommendation 1 in the text.
Outcomes	Objective measurement: A summative exam with questions aimed at assessing both information recall (e.g. name one portion of the small intestine) and application of knowledge (e.g. imagine somebody has eaten a bowl of cereal with milk, explain how, when and where the respective nutrients are absorbed by the body). Subjective measurement: Collect student perceptions of whether they found the drawing task beneficial for their learning using qualitative methods. Study groups 1 and 2 could be inverted at the end of the study to allow perceptions from both groups. Retention of knowledge and changes in perceptions: The test should be repeated at a later date to understand if any differences are acute or continue after a period of time, and allow students to reflect on the drawing task (see recommendation 2 in the text).