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Visual Literacy Skills of Students in College-Level Biology: Learning Outcomes following Digital or Hand-Drawing Activities

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Visual Literacy Skills of Students in College-Level Biology: Learning Outcomes following Digital or Hand-Drawing Activities

Abstract
To test the claim that digital learning tools enhance the acquisition of visual literacy in this generation of biology students, a learning intervention was carried out with 33 students enrolled in an introductory college biology course. This study compared learning outcomes following two types of learning tools: a traditional drawing activity, or a learning activity on a computer. The sample was divided into two random groups. In the first intervention students learned how to draw and label a cell. Group 1 learned the material by computer and Group 2 learned the material by hand drawing. In the second intervention, students learned how to draw the phases of mitosis, and the two groups were inverted. After each learning activity, students were given a quiz, and were also asked to self-evaluate their performance in an attempt to measure their level of metacognition. At the end of the study, participants were asked to fill out a questionnaire that was used to measure the level of task engagement the students felt towards the two types of learning activities. The students who learned the material by drawing had a significantly higher average grade on the associated quiz compared to that of those who learned the material by computer. There were no other significant differences in learning outcomes between the two groups. This study provides evidence that drawing by hand is beneficial for learning biological images compared to learning the same material on a computer.

Afin de vérifier le bien-fondé de l'assertion voulant que les outils d'apprentissage numériques renforcent l'acquisition de la littératie visuelle parmi la génération présente d'étudiants en biologie, une intervention d'apprentissage a été effectuée auprès de 33 étudiants inscrits dans un cours collégial d'introduction à la biologie. Cette étude compare les résultats d'apprentissage suite à l'utilisation de deux types d'outils d'apprentissage : une activité de dessin traditionnel ou une activité d'apprentissage par ordinateur. L'échantillon a été divisé en deux groupes formés au hasard. Au cours de la première intervention, les étudiants ont appris à dessiner et à caractériser une cellule. Le groupe 1 a appris la matière par ordinateur et le groupe 2 l'a apprise en faisant les dessins à la main. Au cours de la seconde intervention, les étudiants ont appris à dessiner les phases de la division cellulaire (mitose) et la manière dont les deux groupes ont appris cette matière a été inversée. Après chaque activité d'apprentissage, les étudiants ont subi un test de contrôle et on leur a également demandé d'auto-évaluer leurs résultats pour tenter de mesurer leur niveau de métacognition. À la conclusion de l'étude, on a demandé aux participants de remplir un questionnaire qui a été utilisé pour mesurer le niveau de participation à la tâche perçu par les étudiants par rapport aux deux types d'activités d'apprentissage. Les étudiants qui avaient appris la matière en dessinant ont obtenu une note moyenne considérablement plus élevée à leur test de contrôle que ceux qui avaient appris la matière par ordinateur. Il n'y a eu aucune autre différence significative dans les résultats d'apprentissage entre les deux groupes. Cette étude fournit la preuve que le fait de dessiner à la main est bénéfique pour apprendre des images de biologie par rapport à l'apprentissage par ordinateur de la même matière.

Keywords
biology, college, visual literacy, digital, drawing

Cover Page Footnote
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Visual literacy is the ability to communicate knowledge through imagery. Biology is the most visual of the sciences and has a long history of the use of imagery for defining and linking concepts in living systems. In the digital age, bioinformatics has radically expanded the importance of imagery in biology because the massive amounts of data can only be conceptualized using a visual format. For example, 3D protein imaging has changed our way of learning about protein structure because students can now easily interact with the image (White, Kahriman, Luberice, & Idleh, 2010). Something that was very abstract can now be seen to have a shape that can be more easily related to its function. It is thus very important for biology students to be able to interpret, use and create images using conventional and 21st century media. In other words, students must become visually literate (Santas & Eaker, 2009). Seely Brown (2002) defines visual literacy in the current generation as “a screen language”; that is, to be a literate member of society in the digital age, one has to be able to access and interpret visual media.

Different learning styles and different media exposure define the form of visual literacy, which in turn affects the social construction of knowledge (Prensky, 2001a). Since the cognitive structures of teachers and students have generally developed within different media, it is possible that there is a mismatch between the teacher’s expectations for learning outcomes, and the students’ understanding of what learning is expected from them. This problem is outlined by Prensky (2001) who coined the term, “Digital Natives” to refer to people who were brought up immersed in digital media, which has a high emphasis on visual representations of information, and “Digital Immigrants” to refer to people who have had to adapt to using digital media, and have learned to acquire information through text.

However, an empirical study by Brumberger (2011) examining student interpretation of visual material refutes the argument that Digital Natives have any particular skill in visual literacy. Her study demonstrates that so called Digital Natives are, in fact, not particularly adept at visual communication, and that they need to be taught how to interpret visual images. There seems to be some controversy as to the degree to which students should be taught using the newer digital tools versus the more traditional instruction of drawing and writing. Kozma (1991) expressed the concern that the computer makes short cuts in the route to cognition, whereas with traditional drawing methods the transformational operations are the responsibility of the learner.

The emerging field of embodied cognition posits that haptic (exploratory movement) information is involved in shaping the brain’s cognitive structures; that is, the way in which one moves his/her body shapes the way one thinks (Lakoff & Johnson, 1999). For example, Mangen & Velay (2011) propose that writing by hand promotes learning because there is direct interaction between the hand movements and the visual information received by the brain, whereas typing hinders cognitive links because it splits attention between the hand movements with the keyboard or mouse and the visual information from the screen. One of the earliest papers in this field, by Hulme (1979), demonstrated that children learn abstract figures better when tracing them by hand. In simple terms, the eye has to see what the hand is doing in order to properly integrate the two sources of information. Based on this theory, there is a growing movement to promote explicit teaching of visual literacy to science students through drawing (Ainsworth, Prain & Tytler, 2011).

In spite of the growing acknowledgment of the importance of linking movement with cognition, there are now many software-imaging applications available for learning about biological structures and concepts. Some are open source software, and many are only available commercially, associated with the marketing of textbooks, and protected by copyright. Many educators assume that these digital tools will enhance student engagement and improve comprehension.

We know of no study that directly compared how learning using digital tools versus learning the same material through the traditional means of guided drawing can affect visual literacy learning outcomes. In a biology taxonomy class, Strain & Chmielewski (2010) compared traditional versus computer-assisted visual learning on measures of student satisfaction only. In that study students classified trees using traditional classification methods or using a computer application called Conifer ID. This study was different from the present study as it was not applying haptic communication. White, Kahriman, Luberice, and Idleh (2010) compared learning outcomes for the topic of protein structure using a lecture-only and a lecture plus protein imaging activity platform, but again, this study did not examine the effect of haptic communication. Our study seeks to address this deficit by comparing visual literacy learning outcomes between two instructional tools used for a learning activity that develops visual literacy in biology. The question being addressed is whether, for students enrolled in a college level biology course, the use of digital technology as a learning activity improves the learning outcomes for drawing and labelling biological structures, when compared to traditional drawing activities for learning biological structures. In our study, one group used digital technology to learn how to label and assign functions to biological structures within the cell. The other group used guided drawing to learn about those same biological structures. The learning outcomes evaluated included content knowledge, the ability to self-evaluate [an aspect of metacognition (Taylor, 1999)], and task engagement [an aspect of motivation (Pintrich & Schunk, 1996)].

Methods

This study used a randomized, cross-over, comparative research design in an attempt to determine if there were any significant differences in the visual literacy learning outcomes of students enrolled in a college level biology course who used digital activities on a computer for learning, when compared to the outcomes of students who used traditional drawing activities for learning.

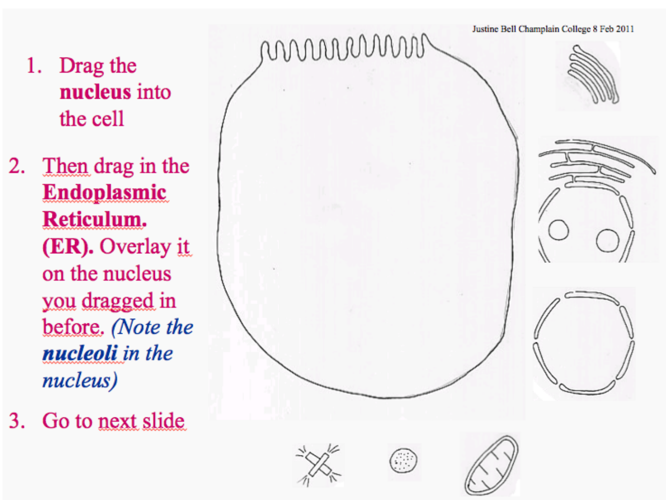

Figure 1. Digital activity for Topic 1: Learning to draw a cell. This slide (slide 2 of 14) shows the first 3 actions of 17-action sequence. (The hand-drawing activity is identical except that students have to re-draw the structure themselves.)

The digital activity consisted of a PowerPoint that students worked with in editing mode. The PowerPoint was interactive and provided feedback to the students because as the students worked in editing mode following step-by-step instructions, they were able to label structures or identify and drag structures into their correct position (see Figure 1). A corrected slide would follow the slide that the students had edited for themselves. On the last slide, students were instructed to play the slide show. The slide show was animated, such that structures would appear one by one, in the positions to which they had been dragged, followed by the slide with the correct version. Students could either self-correct while in editing mode, or wait until they had played the slide show to compare their attempt with the correct version. The students could carry out this exercise as many times as they pleased. The images in the PowerPoint were scanned hand drawings in order to teach the students the correct stylistic conventions for drawing biological structures. PowerPoint was chosen as the vehicle of instruction, as most students were very familiar with this software and they were able to use it easily.

The digital activity was interactive in the sense that the students could follow instructions and put their responses into the activity, and then receive instant feedback by comparing their responses to the correct answer. This process is different from copying a drawing as in a traditional learning approach, because, with this digital exercise, the students created the image first, and then compared it to the correct image, where the salient features were animated in order to bring attention to them. In a traditional drawing exercise, the student copies a drawing but may not be shown how their drawing differs from the original.

The traditional drawing activity consisted of exactly the same sequence of images as the digital activity, but presented on paper, with spaces for students to copy drawings and label structures. The students followed the same step-by-step sequence of images as used in the digital activity. Although students could get feedback through self-assessment by comparing their drawing to the original, there was no animation, and it would have been more laborious for the student to go back and change their drawing rather than to simply re-drag or re-type an entry as was the case in the digital activity. In both the digital and drawing exercises, students were given a rubric (based on content, style, clarity and presentation) that defined how their drawing would be assessed.

Participants in this study were recruited from a convenience sample of pre-university science program students enrolled in an introductory biology course in an English CEGEP (from the French: Collège d'enseignement général et professionel - a Community College of General and Vocational Education) in Quebec. The class had 39 students. Of these, 33 students agreed to participate in the study: twenty-seven males and four females, who were all between the ages of 18 and 21. The study design attempted to control for several possible confounding variables such as age, mother tongue, attitudes towards learning biology, experience with computing and drawing. This was done by conducting a survey at the beginning of the study. The survey included questions about learning style taken from an online survey created by Fleming and Mills (1992, 2009) (with permission: copyright is held by Neil D. Fleming, Christchurch, New Zealand). Fleming and Mills questions follow VARK (Visual –Auditory – Read/Write – Kinaesthetic), adapted from the Fernald VAK model that was developed in the 1920s.

As detailed in Table 1, after an introduction of the theory to all the students, the two randomly created groups each used one of the two different instructional approaches to carry out the learning activity to study the same topic. The first topic was: labelling the structures in an animal cell. For this first topic, Group 1 used a digital instructional tool on a computer, while Group 2 used a traditional drawing instructional tool. Following the learning activity, the students were given a formative assessment (Quiz 1) to assess their ability to draw and label an animal cell.

This formative assessment was corrected but did not contribute to the final grade for the course. Students were also asked to self-evaluate their performance on the quiz. At a later date in the course, the intervention was repeated for another, similar and equivalent topic. The second topic was: learning the phases of mitosis (cell division) in an animal cell. For this second topic, Group 1 used a traditional drawing instructional tool, and Group 2 used the digital instructional tool. Students were then given a quiz (Quiz 2) so that their ability to draw and label a phase of mitosis could be assessed. They were again asked to self-evaluate.

The cross-over design ensured that both groups had a chance to take part in both the digital and hand drawing activities. This meant that one group would not have an unfair advantage over the other on the final grade of the course. This crossover design also controlled for differences between the two groups and allowed the students to make comparisons between their experiences of the two types of instructional tools.

Table 1
Protocol for order of application of crossover design for learning interventions for each group.

Learning Topic	Treatment	Group 1	Group 2
	Survey	Students fill in a demographic survey, and are asked about learning styles, computer literacy etc	
Topic 1 Cell Structure	Theory	Class is introduced to the topic of cell structure.	
	Learning Activity #1	Group 1 learns how to draw, identify and assign functions to the parts of the cell using a **Digital Activity.**	Group 2 learns how to draw, identify and assign functions to the parts of the cell using a **Traditional Drawing Activity.**
	Quiz #1 (Post-Intervention assessment of learning)	Students a) draw and label a cell b) self-evaluate their drawing.	
	Review	Teacher reviews cell structure to make sure both groups have equal learning opportunities	
Topic 2 Cell Division	Theory	Class is introduced to the topic of cell division by mitosis.	
	Learning Activity #2	Group 1 learns how to draw the phases of mitosis, identifying and assigning functions to structures involved, using a **Traditional Drawing Activity.**	Group 2 learns how to draw the phases of mitosis, identifying and assigning functions to structures involved, using a **Digital Activity.**
	Quiz #2 (Post-Intervention assessment of learning)	Students a) draw a cell in a particular phase of mitosis, labelling specified structures. b) self-evaluate their drawing.	
	Review	Teacher reviews mitosis to make sure both groups have equal learning opportunities	
	Questionnaire on engagement with teaching strategies	Students asked which teaching strategy promoted comprehension and was more motivating.	

The quizzes were collected and photocopied. The originals were marked and immediately returned to the students to provide feedback. The photocopies were given to a third party, the coder (a retired professional who had not previously taught the students). The coder removed student names on the quizzes, and replaced them with a code. He also administered and collected consent forms, and administered, collected and coded the pre-study survey. Those students who did not wish to participate took part in the course work with the other students, but the data they generated was not used in the study. In order to avoid bias in the data generated, students were given a variety of similar assessments that were not included in the study; in doing this, the two particular exercises of the study were disguised. Without this precaution, the students might have been influenced to adopt a different approach for the two "special" assignments. After the students had completed both quizzes, received feedback, and been tested on the material in a unit test, they were asked to fill out a questionnaire about which instructional tool they had preferred and felt had been more useful for learning the material. The questionnaire, based on one developed by Caulfield (2010), used a Likert scale to compare students' perceptions of interest, effort, difficulty, value, and confidence in the two types of learning activities. Caulfield found very high correlations with task engagement for these variables, ranging from $r = 0.96$ ($p < 0.0005$) for value and $r = 0.79$ ($p < 0.0005$) for difficulty. Students were also asked semi-structured questions to report their feeling about which type of instructional tool they enjoyed the most and found most valuable. In addition, the questionnaire asked students to estimate the time they had spent studying for each of the two quizzes, as a measure of task engagement.

These questionnaires were collected by a student and sent to the coder in a sealed envelope. The photocopied quizzes were marked by a fourth person (also a retired professional who had not previously taught these students). By these measures, the possibility of the introduction of bias into the marking process was reduced. All students had the same teacher and as much as possible the same experience of the course except for the one factor we examined: the digital manipulation compared to hand drawing of images. They were assigned into random groups by the researcher. The instructional tools were equivalent in difficulty level and time requirement.

Results

Controlling for Possible Confounding Variables

Participants were randomly divided into two groups: Group 1 and Group 2. The survey administered at the start of the study revealed a Pure and Applied Science class that was mostly male, highly familiar with digital media, mostly uninterested in studying biology, and with no particular interest in drawing.

Students in both groups exhibited an equal distribution of visual/aural/read/write and kinaesthetic learners. There were no significant differences in learning styles between the two groups. Spearman Rho correlations were carried out for each of the survey responses and Group 1 and Group 2 grades. There were no significant correlations between survey responses and grades except for two instances: for Group 1, there was a weak but significant negative correlation between a higher grade and a higher skill in drawing, where $r(17)= 0.54$, $p= 0.03$; and for Group 2, there was a weak but significant positive correlation between a higher grade and a higher frequency of playing video games, where $r(16) = 0.49$, $p= 0.003$. The lack of any strong correlations between survey responses and grades supports the assertion that the two groups were structurally similar in demographics and skills.

To assess whether the two quizzes were equitable, the data were tested to see if there was a difference in grades between the two quizzes for all of the students. A paired samples t test and a Wilcoxon signed ranks test (for non-parametric data) was carried out for Quiz 1 [mean =16.08 out of 20 (or 80%) with a standard deviation of 2.17 (n= 32)] and Quiz 2 [mean = 15.45 out of 20 (or 77 %) with a standard deviation of 2.67 (n=32)]. There was no significant difference between the two quizzes.

Visual Literacy Learning Outcomes

The first hypothesis tested in this study was that there is a significant difference in the visual literacy learning outcomes between those learning using digital instructional tools compared to those learning using traditional drawing instructional tools. The learning outcomes were assessed using Quiz 1 and Quiz 2, and are shown in Figures 2 and 3. For Quiz 1 (drawing and labelling a cell), the average grade for Group 1 (that learned to draw the cell by computer) was 15.31 out of 20 (or 76%) with a standard deviation of 2.20 (n=16). The average grade for Group 2 (that learned to draw the cell on paper) was higher, at 16.94 out of 20 (or 85%) with a standard deviation of 1.86 (n=17) (see Figure 2). An Independent Means t-test (2-tailed) showed that there was a significant difference between the groups where $t(31) = -2.29$, p = 0.03.

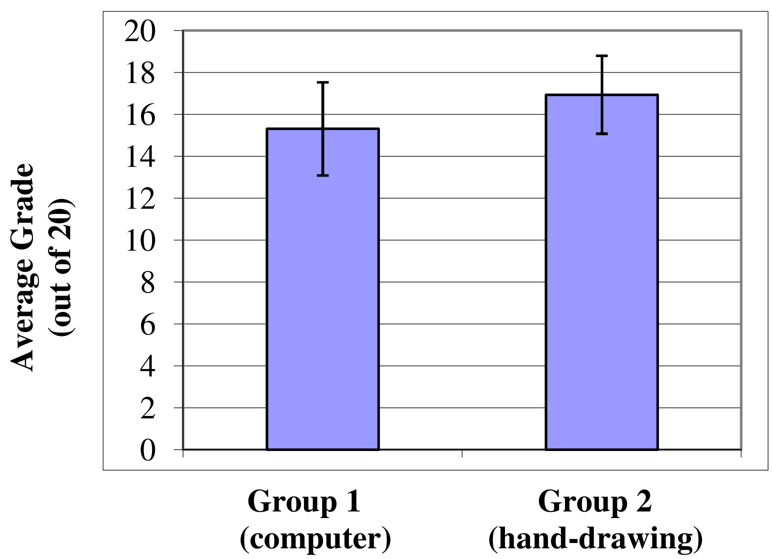

Figure 2. Average grades (out of 20) and standard deviations for Quiz 1.

The evidence supported the hypothesis that there is a significant difference in the visual literacy learning outcomes between those learning using digital instructional tools compared to those learning using traditional drawing instructional tools. Furthermore, the evidence suggested that learning outcomes were improved when students learned by drawing than when they learned on the computer. The sample size was small, but the homogeneity of the sample validated this outcome.

For Topic 2 (drawing and labelling a cell in anaphase of mitosis), the groups crossed over so that Group 1 used a traditional drawing instructional tool to learn the material, and Group 2 used a computer to learn the material. For Quiz 2, the effect of the choice of learning tool was less clear. As shown in Figure 3, there was no significant difference between the groups. The average grade for Group 2 (that learned to draw the phases of mitosis using a computer) was

16.56 out of 20 (or 83%) with a standard deviation of 2.31 (n=17). The average grade for Group 1 (that learned to draw the phases of mitosis on paper) was higher, at 16.88 out of 20 (or 84%) with a standard deviation of 3.28 (n=15; one student was absent, and one quiz was discarded for marking as it was illegible).

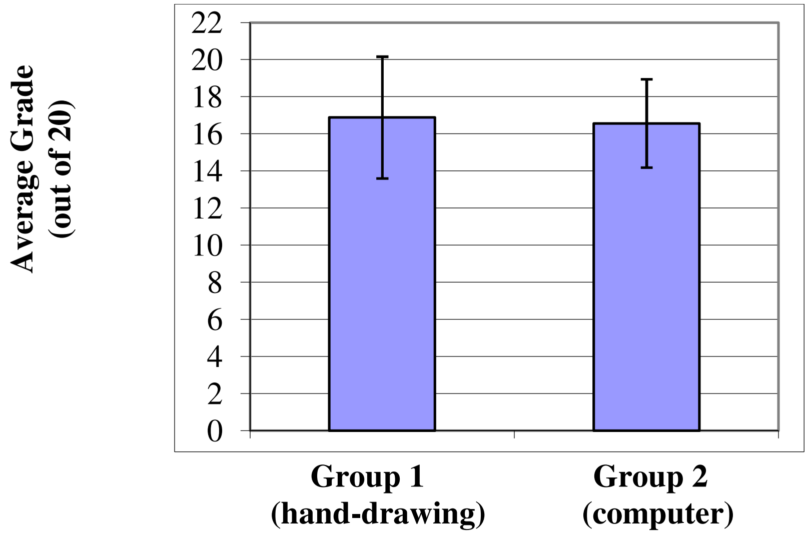

Figure 3. Average grades (out of 20) and standard deviations for Quiz 2.

Self-evaluation Outcomes

The second hypothesis tested in this study was that students who used digital instructional tools to learn more accurately assessed themselves compared to those who used traditional drawing instructional tools. To test this hypothesis, students were asked to complete a self-evaluation of their work for each of the two quizzes, using the same assessment criteria as the teacher. There was no significant correlation of these self-evaluation grades with the teacher's grades for either Quiz 1 or Quiz 2, regardless of whether the student learned the material by drawing or by using a computer (see Table 2). Therefore there was no evidence to support the above hypothesis.

Table 2
Correlation between student self-evaluation and teacher grade for Quizzes 1 and 2

	Quiz 1		**Quiz 2**	
	ρ	Significance (2-tailed)	ρ	Significance (2-tailed)
Group 1	0.062	0.841	0.512	0.051
Group 2	0.011	0.966	-0.13	0.631

Note. ρ is the Spearman Rho correlation coefficient (between self-evaluation and teacher grade).

Task Engagement Outcomes

The third hypothesis was that there is a significant difference in task engagement when using digital instructional tools for learning compared with using traditional drawing instructional tools for students enrolled in a college-level biology course. The data showed that students had a higher task engagement when using digital tools, but the effect was not significant. Students were asked to fill out a questionnaire about which instructional tool they had preferred. Of the 29 students who replied to the question, "Which type of learning activity did you enjoy most?," 59% chose the computer. Students in this study also felt that they learned more when using the computer: 64% of the 28 who replied chose the computer when asked, "Which type of learning activity did you feel had more value?" Most students (60% of the 30 who replied) said that they would prefer to use a computer if they had to learn a new topic. However, a chi square test showed that, for these measurements, there were no significant differences in task engagement between using the computer and drawing on paper. Students were also asked to rank their engagement in the instructional tool on a Likert scale according to interest (corresponding to the level of engagement); effort (how much time and effort was put into the exercise); difficulty of material; value of exercise (how valuable the exercise was for learning the material); and confidence (corresponding to the level of self-efficacy). A one-way ANOVA was carried out for Quiz 1 and for Quiz 2 for each of these categories of task engagement. There was no significant difference between Group 1 and Group 2 in task engagement for any of these categories.

Another way of measuring the level of task engagement is to measure the time spent on task. In this study, the students were asked to retrospectively estimate the time they spent on each task. There was a certain degree of subjectivity inherent in these estimates. In terms of the time spent carrying out each activity, for the topic of drawing the cell, Group 1 students reported that they spent an average of 22 minutes studying using the digital instructional tool, with a standard deviation of 10 ($n=13$). Group 2 students reported that they spent an average of 32 minutes studying using a traditional drawing instructional tool, with a standard deviation of 12 ($n=16$). For the topic of learning to draw the phases of mitosis, Group 2 students reported that they spent an average of 37 minutes studying using the digital instructional tool, with a standard deviation of 14 ($n=15$). Group 1 students reported that they spent an average of 22 minutes studying using a traditional drawing instructional tool, with a standard deviation of 19 ($n=9$).

An Independent Means *t*-test (2-tailed) showed that for Quiz 1, Group 2 students spent a significantly longer amount of reported time than Group 1 $t(27) = -2.38$, $p = 0.024$. For Quiz 2, Group 2 spent a significantly longer amount of reported time than Group 1, where $t(22) =-2.32$, $p = 0.03$. For the first quiz, Group 2 students were studying by drawing.

For the two questions, "Which type of learning activity did you enjoy the most?" and, "Which type of learning activity did you feel had more value (that you actually learned more from)?," students were asked to explain why they had responded computer or hand-drawing. A content analysis of their answers was used to categories their responses. The numbers in each category are too small for statistical analysis, but some themes can be observed. Most students (17 out of 29 responses) preferred the computer. Of these 17, most (10) said that it was because it was more interactive. One student thought that the information was more detailed and precise on the computer, and one student thought it helped him/her to retain the information better. Four students thought it was easier to use the computer. On the other hand, many of the students who preferred hand drawing said that this was because they loved to draw (5) and that it was easier and simpler (2). They said that drawing was more hands on and individual (2), and four of them felt that they retained more information from drawing. There was no attempt to match these responses to performance on the assessment, since the numbers were too low to attain statistical significance.

Discussion

This study addresses a gap in existing literature by examining the outcomes of learning biology using either guided drawing or a digital activity. It is centred on the idea that Digital Natives and Digital Immigrants have different cognitive structures and communicate differently, especially in the use of imagery. Many commentators agree with Oblinger and Oblinger (2005) who say, "The Net Gen [sic] are more visually literate than previous generations; many express themselves [sic] using images. They are able to weave together images, text, and sound in a natural way" (p. 25). Brain structure can be changed by the actions that we do (Doidge, 2007), and it has been shown that learning through electronic media alters the way that learners process the material (Moore, 2003). However, there are challenges to the view that there is a generation of Digital Natives. Kirschner & van Merriënboer (2013) report on studies that show there is little evidence that the current generation of students is particularly proficient at using technology for learning.

For proponents of the existence of Digital Natives, the expectation would be that the students in this particular study learn better using digital tools, because they are male teenagers, highly computer literate and used to using electronic media, and can be considered to be Digital Natives. According to Prensky (2001b), the brains of Digital Natives are actually physically different from the brains of Digital Immigrants. The fact that they have been playing several hours of video games per week, with a sharp focus of attention, frequent rewards, problem solving challenges, with repetition and reinforcement, means that their brains are programmed to deal with digital technology, just as the brains of a previous generation were programmed to be able to read (Prensky, 2001b). Reading requires linear, explicit and logical thought carried out by the left hemisphere, whereas the brains of Digital Natives use more right hemisphere types of thinking (Prensky, 2001b). From studies on teenage brain development (Arnett, 2000), the male teenage brain develops the frontal lobe areas controlling logic and reason more slowly than the female teenage brain. This study tested the hypothesis that these male teenage Digital Natives would have better learning outcomes when using digital tools than when using guided drawing, which is slower, more linear and more labour intensive.

In fact, this study showed that when learning to draw the cell, students gained significantly higher grades when they learned using the traditional drawing instructional tool compared to when they learned using the digital instructional tool. The difference was less clear for the second drawing exercise, but it is presumed that by this time the students had gained experience from the first exercise. Group 2 students reported that they spent more time studying for Quiz 1, and this may account for the improved performance of Group 2 students in Quiz 1. However, for the second quiz, when students studied using the computer, there was no significant difference in mark compared to Group 1. Therefore, extra study time alone was not enough to improve the grade. It is still possible to conclude that the improvement in Quiz 1 was linked to studying by drawing alone.

The observation in the present study was that there were benefits to learning when drawing by hand. This concords well with studies in the field of Embodied Cognition, which demonstrate that body movement is linked to learning. A summary of research in the area of Drawing and Cognition, presented at the 2012 symposium of the Drawing Research Network (Brew, Kantrowitz, & Fava, 2012), highlighted the importance of drawing as a "visible trace of our cognitive processes" (p. 1), and as a way of exploring and developing new ideas. The present study points towards the importance for present-day college students to be exposed to traditional drawing tasks because these are thought to enhance construction and integration of knowledge (Van Meter & Garner, 2005).

The students in this study were not very successful at evaluating their own performance – regardless of the type of instructional tool they had used. This reflects the findings in a study by D'Éon, Sadownick, Harris and Nation (2008), which shows that individual self-assessments are often inaccurate and subject to bias. In the present study, there was little correlation between the student's self-evaluation and the teacher's grade. Self-evaluation is an aspect of metacognition – thinking about one's learning. The fact that students could not accurately assess their own performance means that even though they made comments such as, "It is easier to learn my mistakes by seeing them and interacting on the PC", for learning on the computer, they were not actually able to identify their own mistakes when the computer was not there during the quiz. It is possible that the students who had learned on the computer would have performed better than the students who had learned by drawing, if the assessment itself had been on the computer. This points to an interesting area of research to address a possible disconnect between using digital tools for learning, when most exams are written on paper. That is, should the means of assessment be in the same medium as the means of learning?

The evidence did not support the hypothesis that there is a difference in level of task engagement for the two types of instructional tool. Group 2 students reported spending more time studying for both Quiz 1 and Quiz 2, compared to Group 1 students, but for both groups there was no significant difference between the amount of time spent on the digital activity and the hand-drawing activity. The results from the questionnaire indicate that students found that using the computer was more interesting, required less effort, was less difficult, and was more valuable as a learning tool (although these differences are not significant), even though students reported spending the same amount of time on average on each activity. Many of the students said they enjoyed the computer learning because it was "less work." They made statements such as, "It is easier to learn on the computer and you can practice as many times as you want.", "It was interactive and a newer way of learning", and "With the computer it was easier to visualize the information". It should be noted that the students frequently used the term "interactive" to describe a benefit of engaging in the digital activity. Interestingly, this term came from the students themselves, as the word was never used by the teacher with the students to describe the tool. This could be interpreted as a positive feature of the digital activity. Similarly, students described the positive aspects of drawing on paper, making statements such as, "Because by drawing it myself, I find it sticks in my head better. And I could really make it my own", "I liked drawing it, as I read the instructions. [The computer] was instructive but doesn't beat drawing it as you go", "I greatly enjoy drawing. When drawing or writing things I really learn". Students seemed to feel more ownership of the knowledge they had acquired. This is consistent with a neuroconstructivist view of drawing as a way to structure the brain to organize knowledge (Sheridan, 2004).

Although not a focus of this study, it was noted that the students felt that they learned more when using the computer, even though there was very little difference in performance between the two instructional tools. If anything, they performed slightly better when they learned to draw by hand on paper, but they did not perceive this. Interestingly, they wrote that they learned more using the computer because, "It contained more details," "…it had more information," and "The information is more precise, so learning is facilitated and simple". This was purely a question of perception, because the images and information were identical for both learning activities. This speaks to another element in the conceptual framework of this study – McLuhan's (1964) theory of the power of the medium as the message. Their belief that the digital tool gave better learning outcomes than hand-drawing also speaks to the degree to which our expectations influence our perceptions. The article by Kirschner and van Merriënboer (2013) discusses the problem that the preferred way of learning may not be the most productive way of learning, and suggests that it might be desirable to choose learning activities that compensate for preferences in one learning style or inclination; that is, if students prefer to learn with the use a computer, then that is all the more reason to encourage the use of traditional drawing activities. On the other hand, it could be argued that students might feel more satisfied with their learning when they are using a computer, and therefore be more motivated to learn.

Extension of the findings from this study to a wider context is limited because of the small sample size involved. Though small, the sample is very homogeneous which helps validate the conclusions, but also limits the applications of these findings to other groups of students.

One important limitation to the study is the relatively simple nature of the digital images. This was done deliberately in order to make a direct a comparison with the drawing instruction, but it could be expected that more colourful and dynamic digital tools would be more engaging and motivating to work with. A problem with using high quality images is that they are often protected by copyright, and are therefore less affordable and accessible. It is therefore important that there should be more empirical studies about the real benefit of using these tools, since their use implies a change in decisions about investment into pedagogical resources. This study points the way to developing further studies on a larger scale, with a more in-depth examination of how these tools affect metacognition, as well as perceptions about learning, and feelings of self-efficacy and motivation to learn.

Conclusions

This study was designed to test the hypotheses that for students enrolled in a college level biology course, who are learning visual material in the form of diagrams, there is a significant difference in the visual literacy learning outcomes, accuracy of self-evaluation and task engagement between those learning using digital instructional tools, compared to those learning using traditional drawing instructional tools. This study found no evidence to support the hypotheses that there is a difference in accuracy of self-evaluation or level of task engagement when learning using a traditional drawing instructional tool or using a digital instructional tool. In terms of learning outcomes, however, students who learned the material by drawing had a significantly higher grade on the initial quiz than students who learned the same material by computer. Therefore, this study does not provide any evidence to support claims that using digital technology improves learning of cell structures to any greater extent than traditional drawing methods. It should be noted, however, that the sample for this study was small and select, and so a general conclusion cannot readily be made, but it does put into question the efficacy of using digital media for teaching, and indicates that further studies are warranted.

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