UNIVERSITÉ DE SHERBROOKE

Compétences en littératie visuelle chez les étudiantEs en biologie au niveau collégial: bilan des apprentissages selon des activités digitales ou des activités de dessins à la main

VISUAL LITERACY SKILLS OF STUDENTS IN COLLEGE-LEVEL BIOLOGY: LEARNING OUTCOMES FOLLOWING DIGITAL OR HAND-DRAWING ACTIVITIES

par

Justine C. Bell

Essai présenté à la Faculté d‟éducation
En vue de l‟obtention du grade de
Maître en education (M.Éd)
Maîtrise en enseignement au collégial

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A été évalué par un jury composé des personnes suivantes:

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Essai en maîtrise accepté le

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SUMMARY

This study examines the role of visual literacy in learning biology. Biology teachers promote the use of digital images as a learning tool for two reasons: because biology is the most visual of the sciences, and the use of imagery is becoming increasingly important with the advent of bioinformatics; and because studies indicate that this current generation of teenagers have a cognitive structure that is formed through exposure to digital media.

On the other hand, there is concern that students are not being exposed enough to the traditional methods of processing biological information - thought to encourage left-brain sequential thinking patterns. Theories of Embodied Cognition point to the importance of hand-drawing for proper assimilation of knowledge, and theories of Multiple Intelligences suggest that some students may learn more easily using traditional pedagogical tools.

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. The study compared learning outcomes following two types of learning tools. One learning tool was a traditional drawing activity, and the other was an interactive digital activity carried out on a computer. The sample was divided into two random groups, and a crossover design was implemented with two separate interventions. 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 on the material they had learned.

Students were also asked to self-evaluate their performance on each quiz, in an attempt to measure their level of metacognition. At the end of the study, they 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.

In this study, following the first testing phase, 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. The difference was lost with the second “cross-over” trial. There was no correlation for either group between the grade the students thought they had earned through self-evaluation, and the grade that they received. In terms of different measures of task engagement, there were no significant differences between the two groups. One finding from the study showed a positive correlation between grade and self-reported time spent playing video games, and a negative correlation between grade and self-reported interest in drawing.

This study provides little evidence to support claims that the use of digital tools enhances learning, but does provide evidence to support claims that drawing by hand is beneficial for learning biological images. However, the small sample size, limited number and type of learning tasks, and the indirect means of measuring levels of metacognition and task engagement restrict generalisation of these conclusions. Nevertheless, this study indicates that teachers should not use digital learning tools to the exclusion of traditional drawing activities: further studies on the effectiveness of these tools are warranted. Students in this study commented that the computer tool seemed more accurate and detailed - even though the two learning tools carried identical information. Thus there was a mismatch between the perception of the usefulness of computers as a learning tool and the reality, which again points to the need for an objective assessment of their usefulness. Students should be given the opportunity to try out a variety of traditional and digital learning tools in order to address their different learning preferences.

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RÉSUMÉ

Cette étude porte sur le rôle de la littératie visuelle dans l'apprentissage de la biologie. Les enseignantEs de biologie font la promotion de l'utilisation d'illustrations digitales dans leurs stratégies d'enseignements pour deux raisons : premièrement parce que la biologie est une des sciences parmi les plus visuelles, et l'imagerie numérique devient de plus en plus importante avec le développement de la bioinformatique; aussi des études démontrent que la génération actuelle d'adolescentEs utilisatrice de cette technologie depuis leur plus jeune âge possèderait un schéma de développement cognitif particulier, propre à cette exposition.

Par contre, certains sont préoccupés par le fait que les étudiantEs ne sont plus mis autant en situations d'apprentissage des informations propres à la biologie là où les efforts à fournir stimulent davantage l'hémisphère gauche du cerveau, siège de la pensée cognitive, du raisonnement logique et séquentiel. La théorie de la cognition incarnée (ou de l'énaction) insiste sur l'importance du dessin à la main dans l'assimilation de connaissances, et la théorie des intelligences multiples suggère que certaines personnes apprennent mieux avec les outils pédagogiques traditionnels.

Dans le but de mettre à l'épreuve l'affirmation que les outils d'apprentissage numériques augmentent la capacité d'assimilation, ou d'intégration de l'information de la connaissance des sciences biologiques chez les étudiantEs de la génération actuelle, une expérience a été entreprise auprès de trente-trois étudiantEs inscritEs au cours d'introduction à la biologie au niveau collégial. L'étude a permis de comparer les résultats obtenus à travers deux types d'outils d'apprentissage. L'un était de type traditionnel, c'est-à-dire des activités de dessins à main; l'autre, des activités interactives à l'ordinateur. Le groupe fut divisé en deux de manière aléatoire, et le protocole d'expérience permettait aux deux groupes séparément et lors de deux interventions différentes d'être "soumis" aux mêmes deux types d'outils d'apprentissage. Lors de la première expérience (ou rencontre), les étudiantEs avaient à apprendre à dessiner et à identifier une cellule. Le groupe no. 1, travaillait à l'ordinateur alors que le groupe no. 2 dessinait à la main. Lors de la deuxième expérience (rencontre), les étudiantEs avaient à dessiner les différentes phases de la mitose mais cette fois-ci les outils d'apprentissage furent inversés pour chacun des groupes. De cette manière, les groupes no. 1 et no. 2 avaient eu l'occasion d'utiliser les deux types d'outils d'apprentissage de cette expérience. À la fin de chacune des deux activités, les étudiantEs ont été soumis à un test portant sur la matière qu'ils venaient de voir. On leur a même demandé d'auto-évaluer leur performance à chacun de ces tests dans le but de tenter de mesurer leur niveau de métacognition. À la toute fin de leur participation, il a été

demandé aux étudiantEs de répondre à un questionnaire pour qu’ils évaluent le niveau d’effort qu’il avait dû fournir lors de leurs deux activités d’apprentissage.

L’étude démontre que les étudiantEs du groupe ayant utilisé la technique du dessin à la main lors de la première expérience (ou rencontre) avaient significativement de meilleures notes test en comparaison avec les étudiants du groupe qui avaient commencé l’expérience en utilisant le matériel d’apprentissage par ordinateur. Ce ne fut pas le cas lors du deuxième test où les résultats comparés n’étaient pas significativement différents. Il n’y a pas eu de corrélation entre les notes obtenues et celles estimées par l’auto-évaluation autant pour le groupe no.1 que pour le groupe no. 2. Même résultat concernant l’auto-évaluation de l’effort fourni. Une trouvaille de cette étude montre une corrélation positive entre la note obtenue et le nombre de temps dit par l’étudiant consacré à jouer à des jeux vidéo, et une corrélation négative entre la note obtenue et le degré d’intérêt dit par l’étudiant envers le dessin.

Cette étude ne vient donc pas soutenir l’argumentation que l’utilisation d’outils d’apprentissage numériques favorise les apprentissages; cependant, elle montre que le dessin fait à la main par l’étudiant aide à l’assimilation des informations des illustrations. Toutefois, le petite taille de l’échantillon de l’étude, le petit nombre et le peu de variétés de types de tâches d’apprentissage exigés, ainsi que les moyens indirects pris pour mesurer le niveau de métacognition et d’investissement dans la tâche, limitent la portée des conclusions et la généralisation qui pourraient s’en suivre. Néanmoins, cette étude indique que les enseignantEs ne devraient pas accorder trop d’importance aux outils d’apprentissage numériques si c’est au détriment des outils plus traditionnels du dessin à main, et que des études plus approfondies sur l’efficacité des ces outils d’apprentissage sont nécessaires. Les étudiantEs participant à cette étude ont fait le commentaire que les outils numériques paraissaient plus précis et refléter davantage la réalité – même si les deux types d’outils d’apprentissage expérimentés affichaient des informations tout à fait identiques. Cela veut donc dire qu’il y a distorsion entre la perception de l’utilité des ordinateurs en tant qu’outil d’apprentissage et la réalité des résultats… scolaires; de là l’intérêt de poursuivre les études objectives à ce sujet. Les étudiantEs devraient avoir l’opportunité d’essayer une variété d’outils d’apprentissage tant ceux dits traditionnels que ceux de la technologie numérique afin d’être en mesure de développer à leur plein potentiel leur littératie visuelle.

LIST OF ABBREVIATIONS, INITIALISMS AND ACRONYMS

CEGEP	Collège d'enseignement général et professionnel (College for pre-university and professional education).
DNA	Deoxyribonucleic acid
PSE	Program of Systematic Evaluation
PI	Protein Investigator

DEDICATION

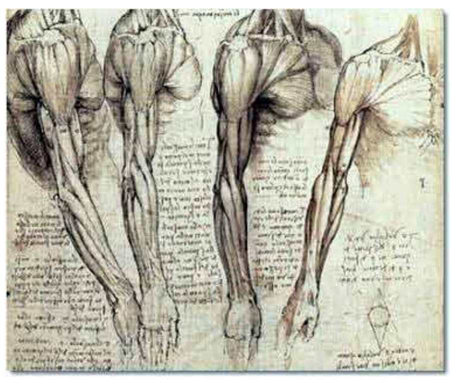
For Louis, Rose and Eric

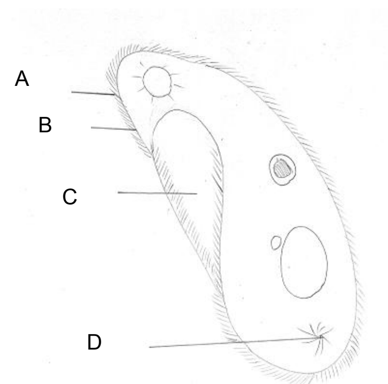
ACKNOWLEDGMENTS

Many thanks to Dr. Caroline Hanrahan for patiently reading the numerous drafts, and sending back suggestions. Also many thanks to Dr. Stephen Taylor for administering the consent forms and acting as the “Coder”, by removing the students“ names from the survey sheets, quizzes and questionnaire forms and replacing them with a code. Grateful thanks to Peter Woodruff for marking the quizzes, and to Shernaz Choksi for verifying the statistical analyses. *Merci* to Denise Tanguay for help with the translation into French. Thank you to the students of Champlain College for participating in this study with such good humour, and thank you to Champlain College- Saint Lambert for helping me pursue this research.

INTRODUCTION

Biology is the most visual of the sciences. It has a long history of the use of imagery for defining and linking concepts in living systems. For example, biology traditionally uses anatomical drawings to understand the functioning of the body, drawings and paintings to identify botanical specimens, and drawings to study microscopic specimens. Some examples of these types of drawings are shown in Figure 1.





a) **b)**

Figure 1. Examples of traditional imagery in biology a) Anatomical drawing of arm muscles by Leonardo da Vinci, and b) *Paramecium* (original: J. Bell).

In the digital age, bioinformatics has radically expanded the importance of imagery in biology because the massive amounts of data can only be conceptualised using a visual format. For example, Figure 2 shows a way of interpreting the human genome through digital imagery, and Figure 3 shows a phylogenetic tree – a graphical representation of the evolutionary relationship between species, in terms of their degree of sequence homology. Figure 4 shows a visualisation of protein structure: the software converts the data from X-ray diffraction patterns to a three-dimensional structure that can be rotated and manipulated. These types of images have drastically changed our way of learning about protein structure because students can now easily interact with the image. Something that was very abstract can now be seen to have a shape that can be intuitively related to its function.

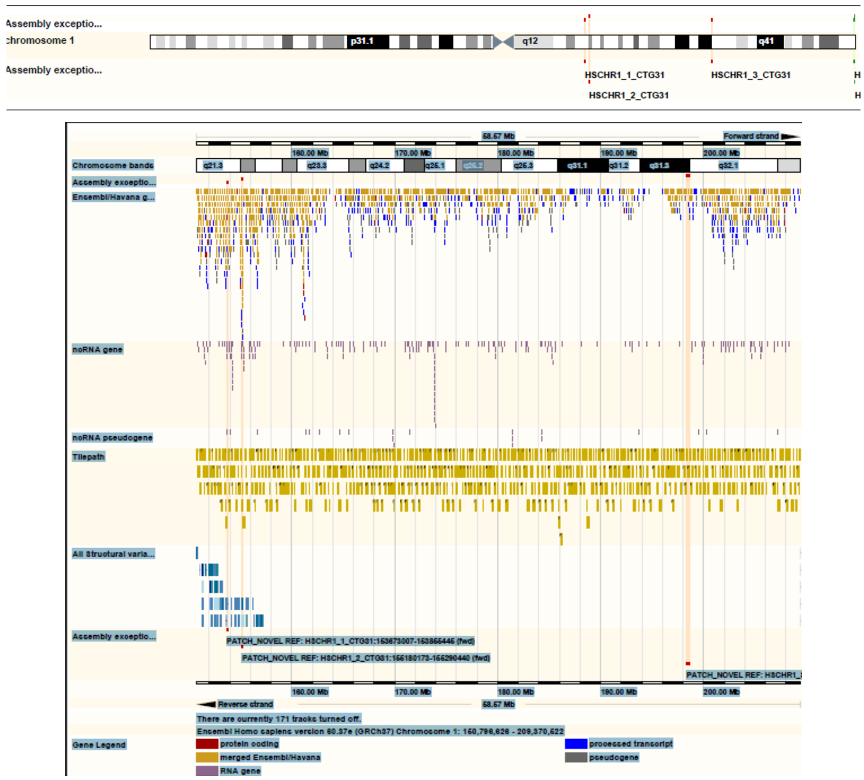


Figure 2. Graphical representation of section of human chromosome 1 created using publicly available free-ware from the Ensembl project at www.ensembl.org (original: J. Bell).

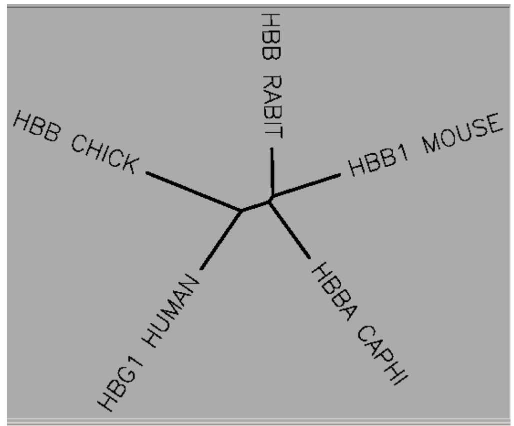


Figure 3. Phylogenetic tree showing sequence homology between human, chicken, goat mouse and rabbit haemoglobin beta, constructed using publicly available free-ware from Biology Workbench at http://workbench.sdsc.edu (original: J. Bell)

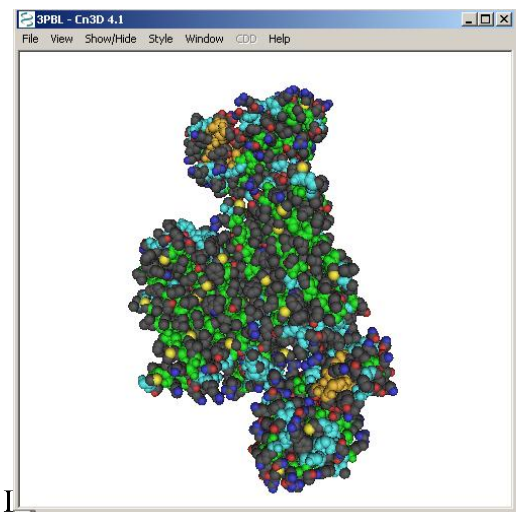


Figure 4. Image of protein (lysozyme (PDB ID 3PBI)) created using Cn3D protein imaging software (downloaded from National Center for Biotechnology Information website at http://www.ncbi.nlm.nih.gov/), from protein structure published in Protein Data Bank at www.pdb.org/pdb/home/home, (original: J. Bell).

In addition, computers are increasingly used for graphing and for system modelling. They are also used for animations and for digital forms of images that were once only found in textbooks. For this reason, it is very important for biology students to be able to interpret, use and create images using conventional and 21st century media – in other words, to become visually literate.

There are now many software-imaging applications available for learning about biological structures and concepts. Some are open source software: many are only available commercially, associated with the marketing of textbooks, and protected by copyright. It is assumed by many that these digital tools will enhance student engagement and improve comprehension, but we do not know whether students really achieve better learning outcomes using digital applications, and we need to examine the role of drawing by hand as part of the cognitive processes involved in learning biology. There has been no prominent study that directly compares how learning using digital tools versus learning the same material through the traditional means of guided drawing can affect visual literacy learning outcomes.

This 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. One instructional tool uses digital technology to learn how to label and assign functions to biological structures. The other uses guided drawing to learn about those same biological structures. The learning outcomes are measured in terms of content knowledge, the ability to self-evaluate (an aspect of metacognition) and task engagement (an aspect of motivation).

This paper begins by identifying the problem to be investigated and then outlining the broad conceptual framework for this study. A literature review presents current views on the importance of using digital tools for learning versus the importance maintaining traditional drawing activities. The research question frames the precise hypotheses that are tested, and the methodology section explains the procedure used for testing these hypotheses.

The problem identified in this study is the increasing use of digital media as a way to teach visual literacy to the current generation of biology students, despite the lack of empirical data supporting its effectiveness as a teaching/learning tool. The way to help solve this problem is to have an objective assessment as to whether there is a difference in visual literacy learning outcomes in college age biology students when using digital media as a tool for instruction versus using traditional guided drawing instruction. Put simply – no-one has yet provided strong evidence that this generation of biology students learn about images better or worse by computer than on paper.

The study rests upon the main concept of visual literacy – which is the ability to communicate knowledge through imagery. A concept map in Chapter Two of this paper depicts how visual literacy is central to the conceptual framework for this paper (Figure 5). The concept of visual literacy is shown to be rooted in the cognitive structure of the brain. The conceptual framework discusses how the brain develops these cognitive structures. It then outlines how different learning styles and different media exposure define the form of visual literacy, which in turn affects the social construction of knowledge. Since the cognitive structures of teachers and students have generally developed within different media, it is possible that there is a mis-match between the teacher‟ expectations for learning outcomes, and the student‟s understanding of what learning is expected from them. The conceptual framework discusses how student performance can be assessed using content knowledge, but also how the students‟ experience of the learning process affects their metacognitive abilities and their motivation to learn.

The Literature Review in Chapter Three describes how the field of visual literacy emerged from theory about the innate ability of humans to think using symbolic imagery. Visual literacy is defined and then follows a discussion on how visual literacy is manifested in teenagers who have been brought up with digital media. The link between visual literacy and the cognitive structure of the brain is established in the next section, followed by a discussion of how the medium of instruction can affect visual literacy learning outcomes. There is then a section describing how visual literacy applies specifically to biology, and finally a section describing recent studies using the digital medium as a tool for instruction for visually-based knowledge in biology. At the end of the literature review, there is a separate chapter describing the research question, which is whether using digital tools to teach visual information really improves learning outcomes when teaching about biological images to students who have been brought up using digital media. Based on this research question, three hypotheses are outlined. These are: For students enrolled in a college level biology course, there is a significant difference between those learning using interactive digital activities compared to those learning using traditional drawing activities in the visual literacy learning outcomes for image-based biology topics, as well as in the ability to self-evaluate and the level of task engagement. This section then operationalises the variables being measured to test these hypotheses.

Chapter Five is the methodology section, which describes the design of the intervention, showing how performance can be compared between two groups of students, where one group will be learning using an interactive digital activity on the computer, and the other group will be learning using a traditional drawing activity. The methodology describes how the different variables are controlled for, and how the human dignity of the participants was protected. The tools used to measure the learning objectives are described, and are presented in Appendices B, E and F.

Chapter Six is the results section. It summarises the data and the main statistical findings. Details of the data and of the statistical tests are presented in Appendices G and H. The results support the hypothesis that there is a difference in learning outcomes when learning using of digital tools or by drawing. In fact, students performed better when using a traditional drawing activity. However students still perceived that computer learning was easier and more valuable. There was no evidence to support the hypotheses that there would be a significant difference between the two groups in the ability to self-evaluate and the level of task engagement. The interpretation of these findings and the conclusions of the study are presented in the final chapter.

CHAPTER ONE
STATEMENT OF THE PROBLEM

This study aims to address the problem that teachers are being encouraged to use digital tools for teaching the highly visual and technological discipline of biology to students who have been brought up with digital media, but there have been very few studies to support the claims that these digital tools enhance learning.

The problem is raised because biology has always been a discipline that relies heavily on visually-based knowledge, and because of the increasing use of imagery in biological research to conceptualise digital information. In addition, students growing up in a culture infused with digital media are thought to find it easier and more motivating to learn through digital media, because their cognitive structures have been developed through immersion in the digital medium.

This study is needed because most published material about the use of digital media in biology teaching is restricted to a presentation of the learning activity as an innovative way to present the concepts. There are very few studies that examine the effect that these tools have on learning outcomes.

This study addresses the question as to whether using digital tools to teach visual information really improves learning outcomes when teaching about biological images to students who have been brought up using digital media. The study specifically tests three hypotheses: that for learning about biological images there are significant differences in learning outcomes, the ability to self-evaluate and the level of task engagement in college-age students when learning using digital activities compared to hand-drawing activities. The study is a comparative analysis of the learning outcomes for a topic (a learning object) in biology that is generally understood and communicated visually, following learning using interactive digital activities on a computer versus learning using traditional drawing learning activities. The study also examines how the traditional drawing or digital learning activity may affect the ability to self-evaluate, or be correlated to task engagement. Both the ability to self-evaluate and the ability to engage with a task are considered to be properties of metacognition and motivation (Taylor, 1999; Pintrich & Scunk, 1996).

The learning outcome in this study is the ability to demonstrate content knowledge in the required format. Mastery of content can be measured using the grades for assessments. The metacognitive component of the task can be measured using self-evaluation for the particular assessment. In addition, the student"s motivation for learning the material can be measured in part using a voluntary questionnaire, wherein the students compare their level of task engagement for learning the topic through the digital activity, or through the traditional drawing activity.

CHAPTER TWO
THE CONCEPTUAL FRAMEWORK

DIGITAL IMAGERY AS A TOOL FOR TEACHING VISUAL LITERACY IN BIOLOGY STUDENTS

1. INTRODUCTION

This chapter defines visual literacy and presents a concept map that depicts the main fields of study that pertain to visual literacy, discussed in the literature review. It outlines how visual knowledge is represented symbolically within the brain, and explains how the cognitive structure of the brain is shaped by experience and developmental processes. The discussion is developed within a framework of social constructivism, and shows how the interplay between the medium of communication and structural development of the brain affects the way that people assimilate knowledge. The importance of acquiring visual literacy in order to learn concepts in biology is explained. An outline of the challenges of teaching and evaluating understanding of biological imagery is presented. This leads to the question as to whether it would be more effective to use tools to teach about biological images to students who have been brought up using digital media.

2. OVERVIEW

This study rests upon the main concept of visual literacy – which is the ability to communicate knowledge through imagery. The concept map below depicts the main theoretical components of visual literacy that are considered to be important for this study (Figure 5).

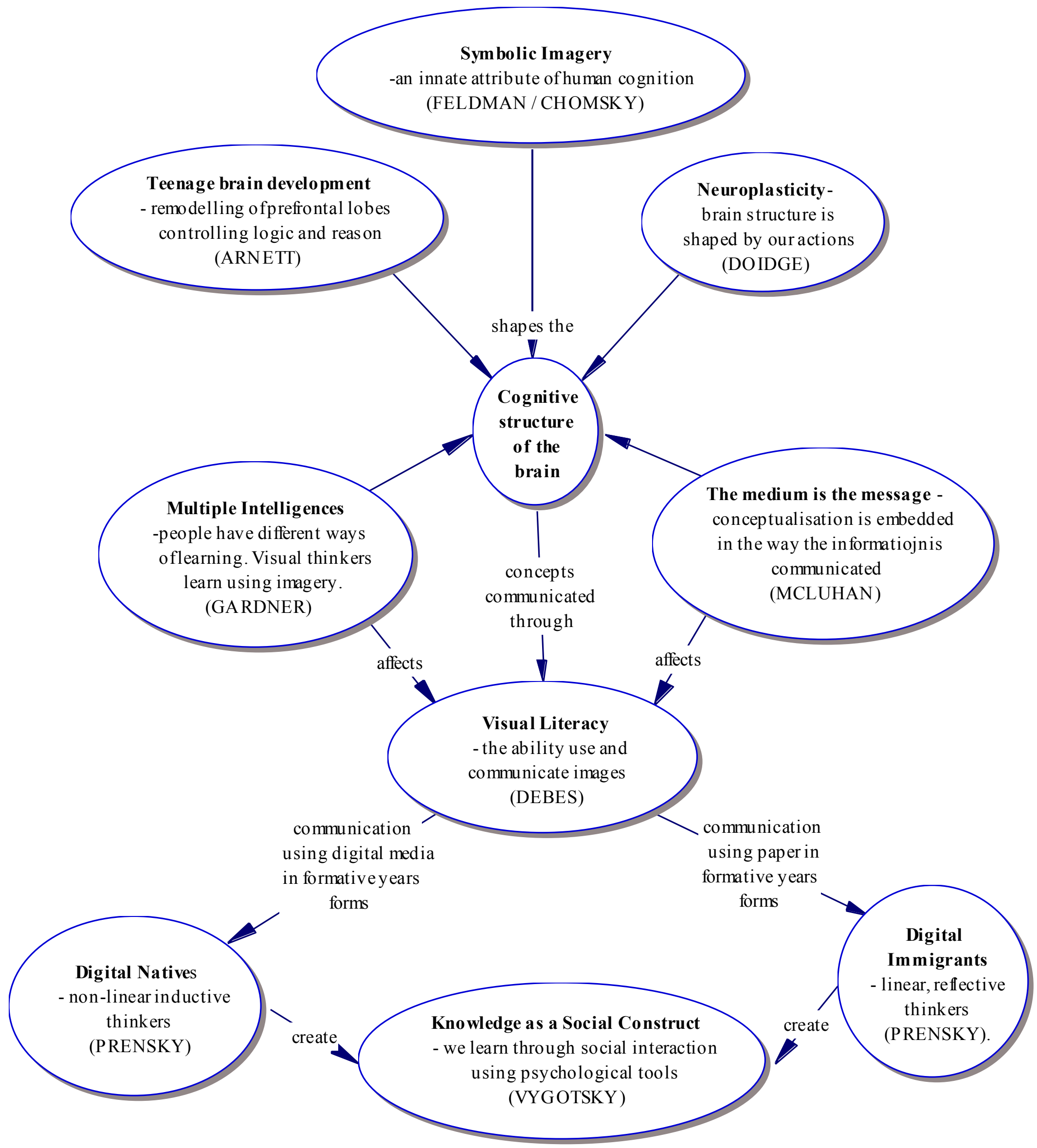


Figure 5. Conceptual framework of study. Major theorists in capitals.

Visual literacy emerges from the cognitive structure of the brain. The main elements identified in this study as being important for the development of cognitive structures are the innate ability of the brain to conceptualise using visual imagery, the neuroplasticity of the brain which allows it structure to be moulded by the way it is used, and the remodeling of the brain that occurs during teenage years to develop the pre-frontal cortex, which controls logic and reason (Arnett, 2000).

This study considers visual literacy to be similar to the ability to speak a language. All humans can speak a language, but some people are more gifted at using a language. The language one speaks is determined by one‟s culture. In a similar way, some people are more gifted at communicating and thinking using visual images, while the medium through which the imagery is conveyed is determined by one‟s culture. For example, there were probably some Ancient Egyptians who were uniquely gifted at making and understanding hieroglyphics, but they would not understand modern road signs. This study describes two different cultures that communicate using two different media: the Digital Natives that were brought up to think and communicate in the digital medium, and the Digital Immigrants that were brought up to think and communicate on paper (Prensky, 2001a). Each culture has its own way of creating and communicating knowledge, and so this study rests on the premise that knowledge is a social construct, shaped by the psychological tools of learning – that is the vehicle through which learning takes place: the computer or a piece of paper.

Biology is a very visual discipline and has its own sub-culture of visual imagery. For this reason, biology students have to develop the form of visual literacy that is specific to biology in order to understand and communicate biological knowledge. Biology teachers frequently evaluate their students according to visual literacy learning objectives, such as being able to correctly draw and label a cell.

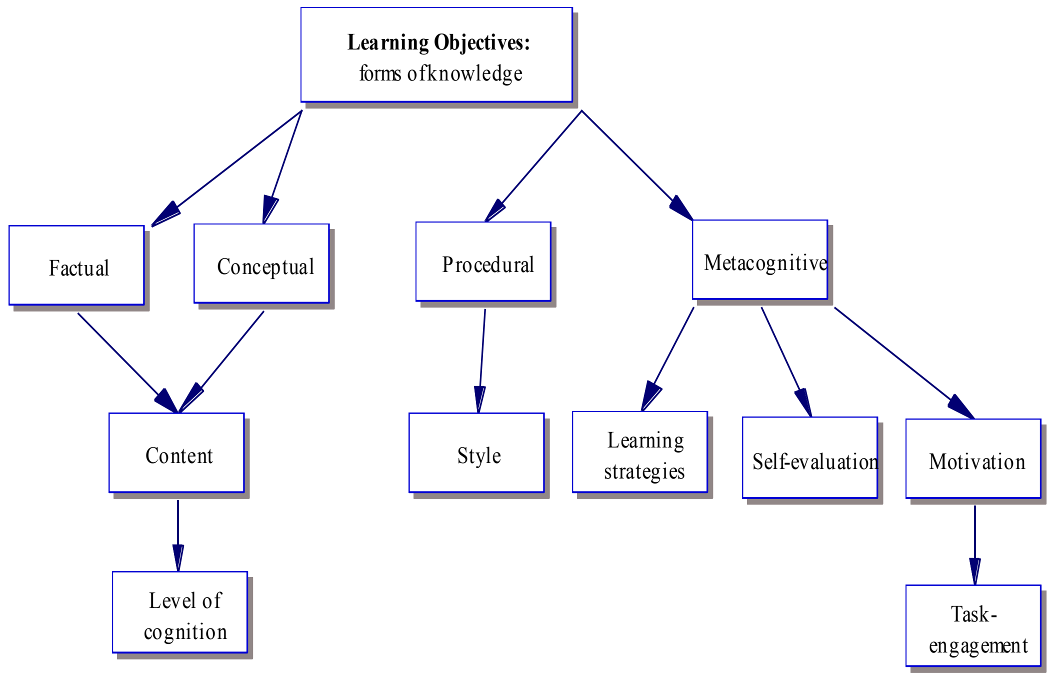


Figure 6. Conceptual framework for assessment of learning objectives.

In order to assess learning, it is necessary for this study to identify measurable visual literacy learning objectives. The concepts underpinning this process are depicted in a second concept map (Figure 6). One learning objective is content knowledge at any particular level of knowledge. Another learning objective is procedural knowledge – the ability to communicate the knowledge visually, while respecting stylistic conventions. However, this study is also interested in examining how the medium of instruction affects metacognition – the ability to think about thinking. This paper discusses the different aspects of metacognition and selects self-evaluation as the easiest way to quantify metacognition. Since metacognition is the ability to strategise about learning, and since motivation to learn is linked to the feeling that one"s learning strategies are effective, it is considered important to examine motivation as an aspect of metacognition. This paper identifies task- engagement as a way of measuring motivation.

3. VISUAL LITERACY AND THE COGNITIVE STRUCTURE OF THE BRAIN

Humans have evolved to attach symbolic meanings to images, and to conceptualise the world using visual neural pathways. Visual literacy is the ability to understand and use images for thinking and communication. The concept was first identified by John Debes in the 1960s (Moore & Dwyer, 1994). Moore and Dwyer explain that Edmund Feldman applied Chomskyian ideas to this concept to imply that there is an innate grammar to visual literacy – we have an innate ability to understand symbols, and we think through imagery. Like verbal language, the visual language must be learned in a social context, but we have an innate capacity to learn any human visual language. Later on in life, we learn to attach meaning to abstract symbols. This requires higher levels of processing, and is culturally specific. According to Piaget (1951), the foundations of visual literacy are laid down during the sensorimotor phase of early childhood (0-2 years old), as the child develops mental imagery and the abilities of memory and reflection. It is because we develop these capacities that we are able to remember after the age of two, but very rarely from before this age. This is why Amey (1976, p.7) defines visual literacy as equal to "seeing plus cognition". However, according to Gardner"s theory of Multiple Intelligences (Gardner, 1993), visual, or spatial, intelligence is more important in some people than in others.

Vygotsky explained that the way that we learn is through social interaction using psychological tools, such as symbols (Daniels, 2007). This is social constructivist theory. In the digital age, knowledge is transmitted through a digital medium and then internalised, so the way we conceptualise is shaped by that digital medium. At the same time, in accordance to social constructivist theory, we interact with digital media and construct new knowledge. Thus, the knowledge constructed by people brought up in the digital age may differ from the knowledge constructed by people brought up in the pre-digital age.

Marshall McLuhan (1964) postulated that the way that we conceptualise information is embedded in the way that the information is communicated. That is, “the medium is the message”. Thus the cognition processes of pre-literate societies are different from those of societies that use printed media, which are in turn different from those of societies that make extensive use of digital media. In the digital age, definitions of visual literacy have to include an ability to use, understand and cogitate using 21st century media. Marc Prensky (2001a) is an influential writer in this area. He coined the term “Digital Natives” to describe those who have grown up immersed in digital media. He believes that Digital Natives are better at multi-tasking and networking. They are highly visual, but they are less proficient at linear thought processes, compared to the previous generation.

Neuroscientists such as Doidge (2007) believe that our brain structure is moulded by the actions that we perform, such that our brains exhibit neuroplasticity. This implies that the brains of Digital Natives are structurally different from those of previous generations. College-age students are in a phase of development that involves extensive brain re-modelling. This developmental phase is called Developing Adulthood, and has been described by Arnett (2000) as a stage in life when the pre-frontal lobes controlling logic and reason are in the process of transition to the state needed to take on adult roles in society. Since college students are in this phase of development, their abilities to use logic and reason - their actual brain structure, is shaped by the media through which they learn.

4. VISUAL LITERACY IN BIOLOGY

Biology is the most visual of the sciences. Much of biology involves dynamic systems, which are difficult to represent as a static image. For this reason animations have become a very popular way of showing mechanisms such as the sodium–potassium pump in nerve cells, DNA replication, or protein synthesis. Interactive software is also used to carry out virtual dissections and other animated lab procedures, or to learn genetics using computer-generated genetic modelling problems. The importance of visuals has increased with the advent of bioinformatics and digital imaging.

Maura Flannery is a researcher on the visual aspects of biology and the relationship between art and biology. In a paper written in 2006, she explains the importance of conventional and "high-tech" digital imagery in teaching biology. Conventional drawing and labelling methods involve techniques such as drawing and labelling the structures of a dissected specimen, drawing and labelling the structures of a microscope specimen, and drawing and labelling structures on a schematic representation of a structure or system. It also involves drawing laboratory apparatus set-ups, as well as drawing, designing and interpreting graphs and tables.

Biology students must learn to understand schematic diagrams that represent metabolic pathways or mechanisms within a system such as a cell, an organism or an ecosystem. There are implicit assumptions built into the imagery of these diagrams, and much of biology teaching consists in explaining the meaning of these diagrams. These types of diagrams are often very rich in information, and the student has to read the accompanying text in order to be able to understand them. The skills needed to understand these diagrams are similar to the skills needed to interpret a graph: the onlooker has to work out the relationships between the elements of the drawing, and understand the main message that is being imparted (Svinicki, 2005). Svinicki explains that visuals fulfill four roles in learning: information, organisation, conjuration and inspiration. Visuals contain information in a structured and condensed way. This information has to be organised in order to make explicit links between concepts. Conjuration is the ability of the image to provide more information than is in the image itself. Images can also be used to inspire learning.

5. LEARNING VISUAL LITERACY IN BIOLOGY

In the educational system of the province of Quebec, most students pass through colleges that either prepare students for university, or for a technical career. This type of college is called a CEGEP - a French acronym for Collège d'enseignement général et professionnel (College for pre-university and professional education). Programs in Health Science, Pure and Applied Science, Commerce, Social Science, Nursing and most career programs include obligatory or optional biology courses. Whatever program they are in, all students enrolled in biology courses at CEGEP need to learn the skills of visual literacy.

Most students at the CEGEP level are in the age range of 17-19, and so they are in the stage of Developing Adulthood and have been brought up in world of digitised media. This changes their way of thinking and learning compared to previous generations. Their teachers need to use digital media to exploit their intellectual strengths, but must also instruct them in the more traditional forms of visual literacy, so that students can develop their cognitive structures and be able to operate in both types of media. To be successful in a biology course, students need to develop visual literacy so that they can learn how to interpret and create biology images for assignments and exams. This is a prominent feature for all evaluations in biology, and it is often very challenging for students to understand what is required of them. Such assignments involve all four knowledge dimensions: factual, conceptual, procedural and metacognitive knowledge, and can be evaluated at different levels of Bloom"s revised taxonomy as described by Anderson and Krathwohl (2001).

6. EFFECT OF MEDIUM OF INSTRUCTION ON LEARNING OUTCOMES

Learning outcomes for a particular topic include mastery of content in different domains of knowledge and at different levels of cognition, as well as affective outcomes, such as motivation to learn, self-efficacy and task engagement. The medium of instruction affects learning outcomes, because student cognition is shaped by the medium they have grown up in. Thus, Digital Natives may prefer to carry out learning activities in a digital medium, but this may not necessarily help them develop linear sequential thinking, which may be the learning outcome required by the teacher.

An example from biology of a learning object that involves a high degree of visual literacy is to learn the functional structure of a cell. To demonstrate an understanding of the concepts involved, it is necessary to be able to identify each part of the cell and know what each does. At higher levels of cognition, the student should be able to draw the parts correctly, within the context of the entire cell, and according to the level of detail required for the assignment, making links between the different roles of the structures within the overall system if required to do so. Learning activities such as this, which involve a high degree of visual literacy, may be taught using traditional or interactive digital media.

Metacognition, or thinking about thinking, includes the ability to develop study strategies, as well as the ability to self evaluate, according to Taylor (1999). Taylor shows how a student"s ability to self-evaluate affects their motivation and self-efficacy. If a student is able to accurately evaluate their work according to the criteria set by the teacher, then they are using metacognition. Therefore, a way of measuring one aspect of metacognition is to compare student self-evaluation grades to their actual grades. It is possible that a student who has learned using either digital media or through traditional drawing may not be able to judge what the teacher expects of them for a task, because the teacher may have a more linear approach to learning than the student.

Motivation is defined as the reason to take an action (Ryan, 2000). It can be extrinsic or intrinsic. One way of measuring motivation is by measuring the level of task engagement: that is, how much time and effort was the student prepared to invest to accomplish the task (Pintrich and Schunk, 1996). It is possible that Digital Natives may be more willing to spend time on an activity that uses interactive digital media, but it may be more or less useful to them in terms of actually learning the material.

Thus, the learning outcomes for a Digital Native in terms of mastery of content, metacognition and motivation may be affected by the medium through which they carry out a learning activity.

7. CONCLUSION

Biology is a discipline that depends heavily upon visual literacy. The successful biology student learns how to interpret and create biological images for assignments and exams. Students may have difficulty achieving this if their brains have developed within a culture that exposes them to interactive digital images rather than to the static images with accompanying texts that are found in textbooks. Therefore many educators suggest that the current generation of students would benefit from learning about biology through interactive digital media. Use of this technology may also improve metacognition and motivation in the student, as it supplies more instant feedback.

CHAPTER THREE
LITERATURE REVIEW

1. INTRODUCTION

This chapter begins with a description of how the field of visual literacy emerged from theories about the innate ability of humans to think using symbolic imagery. Visual literacy was defined as a field of study in the 1960s by John Debes. The advent of digital technology changed the process of acquisition of digital literacy in young adults. The literature review explains how Marc Prensky coined the term “Digital Native” in the early 2000s to describe how the cognitive structure of the current generation of teenagers differs from those of previous generations. A discussion follows on how different types of sensory input affects brain structure and integration of new concepts, with an examination of how the medium of instruction can affect visual literacy learning outcomes. The importance of the acquisition of visual literacy in biology is established in the next section, and then follow some examples of current studies using the digital medium as a tool for instruction for visually-based knowledge in biology.

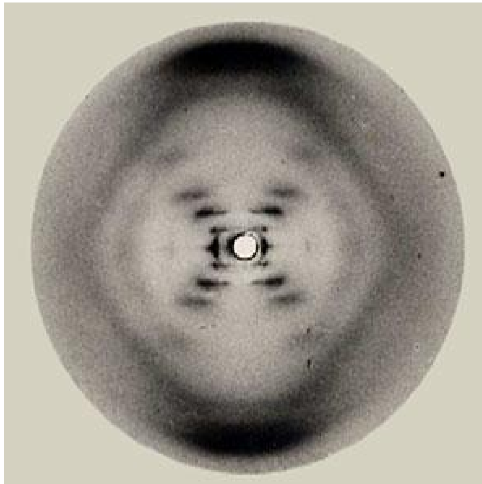
2. VISUAL LITERACY

Humans have evolved to attach symbolic meanings to images, and visual symbolism is closely linked to language and reasoning. Visual symbolism also has powerful effects on the emotions (Dake, 2007). The beginning of symbolic imagery can be seen in petroglyphs and cave paintings. The invention of the alphabet instead of pictograms introduced a greater degree of abstraction to symbolic imagery, since letters represent phonetic sounds rather than things. Imagery is intuitive and the meaning is implicit, whereas reading is a very linear, explicit and non-intuitive process. This is why reading and writing help develop logical thought, and why people have to invest a great deal of time, effort and practise in learning how to be literate (Shlain, 2005).

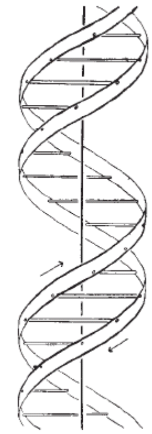
Noam Chomsky, in his book “Language and Mind” (1968), said that humans have an innate structure of mind and a universal grammar. What this means is that all humans have an ability to construct a language following certain basic rules. This idea was extended by Edmund Feldman (1976) to include a visual language, where we have an innate ability to think using images, and we have a universal structure of mind that allows us to encode these images in a symbolic manner. Just as there are many different languages, but they are all *human* languages, there are many visual languages, but they are all *human* visual languages. That is, humans are primed to recognise and make associations with certain shapes and sounds in a way that another species is not. To put it another way, a dog has an olfactory language that can extract meaning from smells in a way that humans cannot, but a human has a visual language that can extract meaning from sights in a way that a dog cannot. According to Piaget (1968), we develop the ability to represent images in the sensorimotor phase of early infancy (also the period that we are acquiring language). Our earliest sense of self is associated with images, because we only begin to be able to form concepts as we develop a vocabulary of words and images. The visual centres of the brain are so important for our conceptualisation of the world around us that even in people who are born blind, the visual areas of the brain are used to process auditory signals instead of visual signals. This is why blind people are able to develop such a refined understanding of the world around them from hearing and touch alone (Renier *et al.*, 2010).

During the Renaissance, there was a revolution in imagery because of the investigation of the properties of light by scientists such as Newton, and the application of scientific and mathematical principles and technologies to art by artists such as Leonardo da Vinci. Artists developed innovations such as the use of perspective. After the development of the science of optics, the idea began to take hold that vision is a function of processing of images by the brain, and people began to investigate perception and how perception can be affected by illusion. With the invention of the printing press, the new attitudes towards vision and imagery were disseminated rapidly throughout the population (Wade, 1999).

The invention of photography, and the later discovery of other forms of radiation, led to a reaction against realism in art, seen in the Impressionism movement and more abstract art (Crowther, 2005). Meanwhile, science moved towards seeking truths revealed through the enhanced vision of radiographic techniques, by using X –ray diffraction, for example, to study molecular structure, or by using electron microscopes to examine objects at an ever more tiny scale. However, the images produced by radiography require special methods of interpretation. Scientists had to learn these methods of interpretation and analysis, and it became apparent that these may be just as subject to perception as paintings or drawings. For example, an X-ray diffraction of Deoxyribonucleic acid (DNA) does not evidently display a double helix unless the onlooker has highly specialized training and insight in the analysis of X-ray diffraction patterns.



a)



This figure is purely diagrammatic. The two ribbons symbolize the two phosphate—sugar chains, and the horizontal rods the pairs of bases holding the chains together. The vertical line marks the fibre axis

b)

Figure 7. Two iconic images of the double helix a) Photo 51: the X-ray diffraction of DNA produced by Rosalind Franklin in Franklin, R. & Gosling, R. G. (1953). Molecular Configuration in Sodium Thymonucleate. *Nature*, *171*, 740–741, and b) the sketch (with its caption) of the DNA double helix drawn by Francis Crick‟s artist wife and published in Nature by James Watson and Francis Crick in Watson J.D. & Crick F.H.C. (1953) A Structure for Deoxyribose Nucleic Acid. *Nature* ***171***, 737 – 738.

The Figure above shows Photo 51, the X-ray diffraction photograph developed by Rosalind Franklin in 1953, which was used by James Watson and Francis Crick to elucidate the structure of DNA. The sketch of the DNA molecule is an iconic image that represents a critical shift in our perception of the structure and function of the gene. Although Franklin had the necessary expertise to interpret the image, she failed to make the leap in perception that permitted Watson and Crick to see that it represented a double helix, made up of anti-parallel strands, with the bases pairing in the middle to form the genetic code.

In the 1960s, a new field of research into visual literacy began to emerge, in order to explore the ways that people were learning how to understand information that was increasingly presented in the form of man-made images. Visual literacy was first identified as a concept by John Debes, in the early 1960s. Debes, who as a member of "Rochester School" founded and strongly influenced The International Visual Literacy Association (Moore & Dwyer, 1994), defined visual literacy in this way:

> Visual literacy is a group of vision-competencies a human being can develop by seeing and at the same time having and integrating other sensory experiences. The development of these competencies is fundamental to normal human learning. When developed, they enable a visually literate person to discriminate and interpret the visible actions, objects, symbols, natural or man-made, that he encounters in his environment. Through the creative use of these competencies, he is able to communicate with others. Through the appreciative use of these competencies, he is able to comprehend and enjoy the masterworks of visual communication. (as cited in Braden, 1993, p.19)

Another definition of visual literacy was written by Braden and Hortin (1982, p.37), who said that, "Visual literacy is the ability to understand and use images, including the ability to think, learn, and express oneself in terms of images".

Literacy in reading requires not only the ability to decode the letters and words, but also to comprehend the meaning of what is written. In a similar way, visual literacy requires that the person can not only identify the images, but also examine the relationships between elements of the image and understand what the images mean – the message that they are trying to convey. When creating images, the visually literate person has to be able to see the image through another person"s eyes, in order to be sure that the message is accurately conveyed (Thibault & Walbert, 2003).

The field of visual literacy covers a broad range of foci. In fact, Debes compared the field of visual literacy to an amoeba with pseudopods representing different sub-fields extending and retracting out in different directions. One branch of visual literacy that is of interest for this study is that of visual learning / visual teaching. An example of the type of research in this field is a large series of experimental studies called the Program of Systematic Evaluation (PSE), carried out by Francis Dwyer in the 1960s.

The PSE began at Pennsylvania State University. It began as an attempt to determine which visual aids were most effective in delivering instruction, and this was identified as being an important undertaking because we live in a visually orientated society. Visual materials are often used in teaching, but in the 1960s the prevalent attitude was that one type of visual material was as good as another. The PSE criticised the published research into visual learning at that time, for the following reasons (Dwyer, 2010):

1. Lack of scientific method (no hypotheses or predictions based on theory, lack of control treatments, inadequate experimental design, lack of validated assessment instruments to measure learning, small sample sizes);
2. Over-simplified learning objectives that were not relevant to the material of the course;
3. Over-simplified assessments that did not really measure different learning objectives;
4. Failure to identify variables such as the dependent variable (learning objectives) the independent variable (types of visualisations and how they were being used.);
5. Failure to implement pilot studies.

The PSE addressed these problems by developing a generic instructional unit focussed on the anatomy and physiology of the heart. Pilot testing and item analysis were used to identify locations in the instruction where students were having difficulty learning through conventional methods. These areas were identified using the principles of the instructional consistency / congruency paradigm. The idea of this paradigm is that the level and type of instruction should match the learning objectives, and the learning objectives should be appropriate for the type of student. Dwyer used this instructional unit for over twenty years of study, using it to examine the effect of using different types of visual presentation on various measures of learning outcomes.

In Dwyer‟s study, four criterion measures were designed to test four different learning objectives, and these were measured using four 20-item tests. These were a) an identification test where the student had to label a diagram, b) a terminology test where the student had to recognise symbols, c) a drawing test where the student had to be able to draw the heart, and d) a comprehension test where the student had to be able to understand the functions of the parts.

The results of these tests were combined to make one individual criterion measure. Students were pre-tested to establish homogeneity within groups and then were randomly assigned to different instructional treatments. The results were analysed by ANOVA. Two of his findings were that illustrations in text promote learning, and that increased realism in illustrations reduces their effectiveness for learning. In later studies, he also found that self-directed computer learning is less effective than using embedded cueing strategies in computer instruction (Dwyer, 1972). His statistical methodology has been criticised by Reinwein and Huberdeau (1998) who used principle component analysis of his twenty years worth of results. The study refutes Dwyer‟s conclusions because he did not really test the learning objectives that he thought he was testing, as his testing process introduced a confounding factor into the results, and because analysis of the four criteria became too complex to draw significant conclusions, so that it was better to collapse them into just two criteria.

3. VISUAL LITERACY IN THE DIGITAL AGE – THE LITERACY OF EMERGING ADULTHOOD

Dwyer"s studies were carried out before the digital age – the age of personal computers, the Internet, and cell phones. There has never before been a time when images were so pervasive and so easily available. Images created using digital technology are changing our understanding of what it means to be visually literate. Visual literacy was defined by John Seely Brown as "a screen language as the new currency for learning" (as cited in Bleed, 2005, p.5). To be a literate member of society in the digital age, one has to be able to access and interpret visual media, or risk becoming marginalized.

The US Department of Education-funded North Central Regional Education Laboratory has published a brief list of components of digital age literacy, on their web site called "Literacy in the Digital Age". The list includes a) information literacy – the ability to access electronic information, b) technological literacy – the ability to work out how to use new technology, c) scientific literacy – the ability to use scientific thinking and understand scientific thinking, d) media literacy – the ability to construct coherent meaning of information obtained from a wide range of media, e) cultural literacy and global awareness – the ability to manage information in a global village, f) critical literacy – the ability to assess validity of information, g) cognitive literacy – the capacity to build cognitive models, and h) visual literacy –" the ability to interpret, use, appreciate and create images and video using both conventional and 21st century media in ways that advance thinking, decision-making, communications, and learning" (Holum & Gahala, 2001).

There is a generation gap developing between Digital Natives (young people who have been brought up with the Internet), and Digital Immigrants (people who were not born into the digital world, but who are learning to use the technology) (Prensky, 2001a). Most students are Digital natives, whereas most teachers are Digital Immigrants. According to Prensky, by the age of 21, the average student will have spent 10,000 hours playing video games, sent or received 200,000 emails, talked for 10,000 hours on a cell phone, and read for less than 5000 hours. (This was written before Twitter and texting became so widespread). Digital Natives like to receive their information instantly ("just Google it!"). They like to multitask, and to network, and they like to see images before the text, rather than afterwards. They like to learn through play. Digital Immigrants learned through serious study, step-by-step, focussing on one thing at a time. In their formative years, they learned from textbooks that were full of text, with few illustrations. The illustrations themselves were generally simple line drawings. When a Digital Immigrant tries to teach a Digital Native, it is as though they are talking to the students in a heavy foreign accent – the students have no idea what the teacher is saying, while the teacher gets frustrated by the students` lack of comprehension. Prensky says that " Digital Immigrant instructors, who speak an out-dated language (that of the pre-digital age), are struggling to teach a population that speaks an entirely new language." (Prensky, 2001a, p.2).

On the other hand, an empirical study by Eva Brumberger (2011) examining student interpretation of visual material refutes the argument that digital natives have particular skill in visual literacy. Her study demonstrates that these types of students are not particularly adept at visual communication, and that they need to be taught how to interpret visual images. This introduces a division within pedagogy as to the degree to which students should be taught using the newer digital tools, versus the more tradional instruction that focussed on drawing and writing.

It is important 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). However, Prensky

(2001b) says that they also need to learn using the digital media that they are familiar with and enjoy, in order to remain engaged in the learning task. Moreover, the digital medium is able to supply instant feedback, which improves the ability of the student to evaluate the state of their knowledge and develop better learning strategies (Peat & Franklin, 2002).

4. VISUAL LITERACY AND THE BRAIN

Prensky claims that Digital Natives prefer to learn through images, based on studies on the effects of computers on thinking skills in children. Visual literacy is very important in our society. David McCandless, the author of Information is Beautiful – a book about how new media can be used to create images that change the way we process and understand information, says, “The eye is exquisitely sensitive to variations in colour, shape and patterns. It loves them and calls them beautiful; it‟s the language of the eye. And [sic] if you combine the language of the eye with the language of the mind, which is about words and numbers and concepts, you start speaking two languages simultaneously - each enhancing the other, and we can use this new kind of language to alter our perspective or change our views.”(McCandless, 2010).

According to Howard Gardner‟s theory of multiple intelligences, spatial / visual learners are those who are able to perceive the visual world accurately, and who are able to recreate these experiences in some medium (Gardner, 1993). The Fernald VAK (Visual –Auditory – Kinaesthetic) model was developed in the 1920s, and is still used today (as cited in Fleming, 1992). This model recognises that people learn in different ways: Visual learners learn through observing, Auditory learners learn through listening, and Kinaesthetic learners learn through doing. Drawing by hand is helpful for visual and kinaesthetic learners, whereas interactive digital media can be helpful for all three types of learners, since sounds can be incorporated into the software.

In terms of how sensory information is processed by the brain to form concepts, some recent work has been carried out in the area of visual intelligence by cognitive scientists such as Donald Hoffman (2000), who proposes that visual intelligence is constructed in part by the eye as an intelligent part of the brain. By mapping eye scan movements, it can be shown that the eye selects what areas of an image to concentrate on. This occurs before any impulse reaches the primary visual processing centres in the occipital lobe of the brain, The brain and the eye together identify important patterns in the environment, and decide which patterns should be sent to other parts of the brain for further processing. (Dake, 2007). The eyes are like mobile extensions of the brain that can actively seek out areas of visual interest.

According to Dake, the right hemisphere processes a fuzzy holistic, overall view of the environment, to pick out major patterns, and link them with emotions, while the left hemisphere focuses in on more detail, and analyses images in a linear and explicit manner. This type of pattern recognition explains why observers develop an “eye” for a scene: with experience, a biologist can pick out structures on a microscope slide, where an inexperienced observer would only see a chaotic jumble. When the observer sees a structure, there is an emotional quickening of interest, and then the eyes fix on the object, to analyse exactly what it is. It is important that images have this initial recognition factor. This is the reason that artists can suggest a scene from a thumbnail sketch, or that we see faces in a cloud formation.

The brain is impelled to construct patterns from what it sees, because this is inherent in the physiological nature of the brain. Nerve cells are constantly seeking out new synaptical connections. This means that the brain is constantly being remodelled, and displays neuroplasticity. Brain structure can be changed by the actions that we do (Doidge, 2007). During development, particular types of actions can model our brain in a particular way. It is similar to the way a tree grows: it always retains the ability to grow in a way that maximises the exposure of its leaves to light, but pruning or a constant strong wind will set a particular pattern of growth.

The emerging field of Embodied Cognition proposes that motor and cognitive skills are linked together (Lakoff, 1999). Thinking is associated with haptics – the tactile perception associated with active movement. Exploratory hand movements and object manipulation have been shown to be associated with learning because fMRI (functional Magnetic Resonance Imaging) of the brain shows that writing letters by hand activates areas of the brain linked to cognition (Mangen & Velay, 2011). Mangen and Velay propose that people learn better when writing by hand instead of typing because writing by hand is unimanual and so engages the left hemisphere (in right handed people), which is thought to favour logic and language functions. When writing by hand, attention is focussed on the pen tip, so that visual and haptic input are linked, whereas when typing, visual input from the screen is detached from haptic input from the keyboard or mouse.

The brains of Digital Natives are thought to be 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. 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, 2001a). Prensky quotes William Winn, a prominent researcher in the field of educational technology, who said that the cognitive structures of digital natives are “parallel, not sequential” (Prensky, 2001a, p.3). It has been shown that learning through electronic media alters the way that learners process the material (Moore, 2003). One particular concern, expressed by Kozma in 1991, is 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 thinking skills that are enhanced by digital media are the ability to see two dimensional images as representative of three dimensions, multidimensional visual- spatial skills, mental maps, the ability to mentally manipulate and rotate three dimensional objects (without actually having to physically do so), inductive discovery (making observations, and making and testing hypotheses), attentional deployment (monitoring multiple locations simultaneously) and fast responses. What Digital Natives are less good at doing is reflection and linear sequential thinking (Prensky, 2001b).

In summary: college age students are in the stage of early adulthood. Their brains have just gone through an intense phase of remodelling due to the effects of reproductive hormones released during puberty. Their brain structures are still changing, but more slowly than before. The pre-frontal lobes controlling logic and reason are still in the process of developing – especially in boys, since they finish puberty at a later age than girls (Arnett, 2000). Their teachers have to understand that their brains have been formed by their exposure to digital media, and so they need to find ways to use digital media to attract and hold their attention, and to exploit their strengths in areas such as problem solving, multi-tasking, and three dimensional modelling. However, the teachers also have to use writing and drawing by hand to help students develop their abilities of reflection and linear logical procedures.

5. MEASURING METACOGNITION AND MOTIVATION

Visual literacy can be a tool for processing knowledge at low or high levels of cognition. For example, labelling an image can require simple remembering – the lowest level of thinking on Bloom‟s Revised Taxonomy, but drawing an image from a live specimen involves thinking at the highest level (Van Meter & Garner, 2005). The seminal work on understanding drawing as a tool for learning was carried out by Richard Mayer (1993). Mayer concluded that illustrations support the cognitive processes of selecting, organising, integrating and encoding information. Van Meter and Garner (2005) present a synthesis of articles that provide evidence that drawing and interpreting images requires skills in all four general knowledge categories from Bloom‟s revised taxonomy of learning: factual, conceptual, procedural and metacognitive knowledge.

While the lower levels of knowledge required for an image-related task can be evaluated using a well-designed rubric, it is more difficult to evaluate higher levels of knowledge. It is also more difficult to assess metacognitive knowledge than it is to assess factual, conceptual or procedural knowledge. Metacognition is the ability to think about how you are thinking. Taylor (1999) defines metacognition as:

> …an appreciation of what one already knows, together with a correct apprehension of the learning task and what knowledge and skills it requires, combined with the agility to make correct inferences about how to apply one‟s strategic knowledge to a particular situation, and to do so efficiently and reliably. (as cited in Peirce, 2004, paragraph 1)

According to Marzano *et al.* (1988), there is an interplay between the metacognitive process and three dimensions of thinking: motivation, study strategies and self-monitoring. If the student wants to succeed, then they will develop strategies for successful learning, and monitor the success of these strategies through reflection and self-evaluation. The success of these strategies can in turn affect motivation through feelings of self-efficacy, as well as attribution of causes for success or failure.

From Taylor, it can be seen that the ability to self-evaluate can be used as a partial indicator of metacognitive ability. It has the advantage that it can be measured relatively easily according to the difference between how the student believes they have succeeded at the task compared to how the evaluator believes that the student has succeeded at that task.

Another aspect of metacognition that can be relatively easily quantified is motivation. According to Ryan (2000), motivation is the impetus to take an action. Pintrich and Schunk (1996) make the link between self-efficacy and motivation to carry out a task, or task-engagement. Task engagement is defined as the time and effort that the student is prepared to invest in order to accomplish a learning task. This could be measured objectively by documenting time on task, but has also been measured using a model that links student perception of level of task engagement with task success (Caulfield, 2010). In this model, a survey was developed that operationalised the student"s perceptions of the value of the learning task, the effort invested in the task and the level of engagement in the task. The author assessed graduate student engagement with attributes from the affective, behavioural and cognitive domains. The affective domain included feelings of self-efficacy and perceived value of the task; the behavioural domain includes attendance and participation in the task; while the cognitive domain includes perceived difficulty and effort needed to complete the task.

The study showed that Likert scale questions on effort, difficulty, value and confidence (the word substituted for “self-efficacy” on the student questionnaire) could be used to predict level of engagement (called ”interest” in the student questionnaire). There was a very high correlation of value ($r = 0.96; p < 0.0005$) and effort ($r = 0.91$, $p < 0.0005$) with engagement. Difficulty had the lowest correlation with engagement ($r = 0.79; p < 0.0005$). The model was validated using behavioural observations of time spent on task and a semi-structured questionnaire asking which tasks students “enjoyed” the most (where “enjoyment” was substituted for the word “engagement”). Students were found to have significantly higher grades on assignments that they enjoyed the most ($t = 4.73$; $p < 0.003$). The Caulfield study represents a way of measuring task-engagement using a questionnaire on student perceptions of various components of task-engagement, and makes the link between task-engagement and motivation, which is an element of metacognition.

6. VISUAL LITERACY IN BIOLOGY

Visual literacy is very important in biology, since biology is the most visual of the sciences. Biologists have traditionally used drawings to study and describe structures in living organisms. Drawings are used to link concepts, draw connections between different processes, and to describe relationships within a system. Biologists also make, use and interpret graphical representations of data. In the digital age, the field of bioinformatics has expanded the importance of imagery in biology, and biologists now use digital imagery to study proteins and DNA sequences, to make graphic representations of the evolutionary relationships between genes, and to make models of dynamic systems such as genetic systems, metabolic pathways or ecosystems.

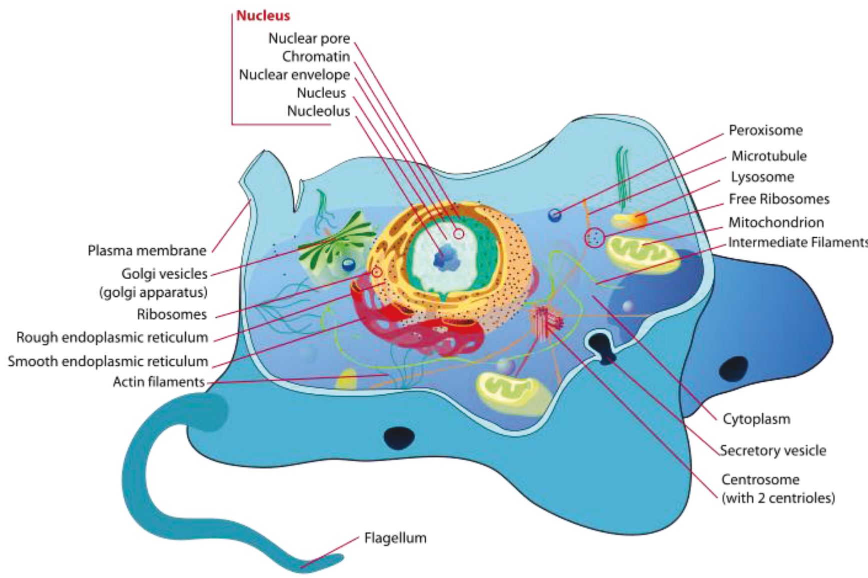


Figure 8. Illustration of a cell from Wikimedia Commons.
http://en.wikipedia.org/wiki/File:Animal_cell_structure_en.svg

Visual literacy is important for being able to interpret figures, understand to what extent they represent reality, and evaluate to what extent they are generalised and stylised representations of reality. For example, the typical textbook illustration of a cell, such as the one shown in Figure 8, incorporates all the main features of a cell, but you would never find a real cell that displays these elements in exactly the same way as represented in the drawing. Just the use of colour to add clarity to the graphic gives a misleading impression of what the cell actually looks like.

Marshall McLuhan (1964) coined the phrase “the medium is the message”, meaning that the way the information is understood and perceived is embedded in the medium through which it is presented. Gunther Kress (2004) gives an example from biology. He asks us to consider the phrase, “Every cell has a nucleus”. The sentence has a meaning given by the verb “has”, but if the sentence is changed to “In every cell, there is a nucleus”, the change of the verb confers a completely new meaning to the sentence. If, as shown in Figure 9, the cell is shown as an empty circle with a small black dot in it to represent the nucleus instead of writing about the cell, a number of implications apply. For example, the drawing implies that a cell is always that shape, that there isn‟t much else that is important in the cell apart from the nucleus, and that the nucleus is in that specific location.

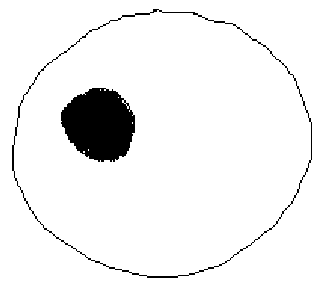


Figure 9. Simple drawing of a cell (original: J. Bell)

7. STUDIES OF USING DIGITAL TECHNOLOGY TO ENHANCE VISUAL LITERACY IN BIOLOGY STUDENTS

There are many examples in the literature showcasing the use of computers in the biology classroom, but they are not generally presented as a comparative study. Most publications are presentations of a new teaching method, without any analysis of their effectiveness. This recalls the criticism made by Dwyer of studies in Visual literacy prior to the PSE project.

One example of a comparative study of traditional versus computer-assisted visual learning, compared student satisfaction in a taxonomy class where students classified trees using traditional classification methods or called Conifer ID (a computer application) (Strain, & Chmielewski, 2010). In this study, students either use dichotomous keys – a series of yes / no questions on observations about the specimen that lead to its identification, or a computer program that can address several questions at once (a polychomous key) and a comparative approach to identification. The comparative approach normally requires an expert in the field who has a large experience of the differences between trees. Students used the traditional approach to classify deciduous trees, and the computer-assisted approach to classify conifers.

The main complaint from students studying taxonomy is the frustration they experience when trying to identify specimens using keys that use unfamiliar technical terms, and with specimens that have ambiguous characteristics. You really need to be quite an expert in the field to begin to be able to use a dichotomous key, so the level of frustration experienced by students is quite understandable. The computer program helps move students more quickly through the process, and uses visual aids to help explain technical terms.

To assess the effectiveness of each method, students were asked to complete a survey form at the end of the activity. A total of 171 students enrolled in nine sections of an Introductory Biology course were sampled. About 70% of the students preferred the computer-assisted method. A test for independence between comfort level with computers and preference for using the conifer identification computer program showed that the level of comfort with computers did not affect preference for the computer assisted conifer identification program. This means that even students who were not familiar with computers preferred to use the computer program. One problem with the design of the experiment was that students were only sampled at the end of the activity, and they were not assessed for attainment of learning objectives.

Brian White has developed several computer programs for visualising concepts, and developing critical thinking and a problem solving approach for learning about important concepts in biology - particularly in biochemistry and genetics: two of the most abstract and non-visual areas of biology. One of his most recent publications involves a comparison of student learning between those taught by lecture only, and those taught by lecture and a lab involving two imaging softwares that are used to visualise and explore protein structure (White, 2010). The first imaging software involves the use of JMol – a program produces images of proteins from X-ray crystallography data published in protein data banks, an example of which is shown in Figure 10. The second imaging software involves the use of Protein Investigator (PI) – a program that simulates the forces involved in folding a virtual polypeptide that has been created by the user. The paper summarises the results of four studies, the first three of which contributed to the development of the fourth study.

In the fourth study, students were given an open-response pre-survey consisting of two questions about protein structure that are designed to identify misconceptions about protein structure, and stimulate a desire to experiment to find out the answers to these questions. Students were then given a lecture on protein structure with RasMol-based protein imaging visualisations (RasMol is a protein-imaging software similar to JMol). Half of the students were then given a post-survey with the same questions as the pre-survey. These students were designated the "lecture-only group". All the students were then given a laboratory session where they could use the PI and JMol. The remaining half of the students were then administered with the post-survey these students were designated as the "lecture-and-visualisation lab group".

Figure 10. Image of a protein (squash aspartic acid proteinase inhibitor (PDB ID 2KXG)) created using JMol protein imaging software, from protein structure published in Protein Data Bank at www.pdb.org/pdb/home/home (original: J. Bell).

The sample consisted of 276 students enrolled in General Biology 1 at the University of Massachusetts. It was found that the lecture-and-visualisation lab group showed significantly higher normalized learning gains, using a non-parametric Wilcoxon rank sum test. Survey results indicated that students preferred the PI.

The study is interesting because it shows a technique of creating two different student groups without giving them a different educational experience. This is achieved by the timing of the pre- and post- surveys. However, this introduces the confounding factor that the lecture-and-visualisation lab group had extra exposure to the concepts, which may have been enough to improve their learning outcomes, regardless of the type of learning activity used. The study demonstrates that it is difficult to get statistically significant results, even with a large sample size, because it is very difficult to isolate the variables being tested. It testifies to the challenges involved in carrying out educational research within the constraints imposed by the educational system.

8. CONCLUSION

There is a need for more studies that can directly measure the effect on learning when using digital media. Bennett, Maton and Kervin (2009) note that arguments promoting the use of digital media for learning "have been subjected to little critical scrutiny, are undertheorised, and lack a sound empirical basis" (p.776). Since the adoption of digital media into biology courses involves changes in pedagogical infrastructure and investment decisions, there is an imperative to base these changes on some form of objective assessment of the impact of digital media on learning. This study attempts to address this need by directly comparing learning outcomes when students learn the material using a computer, or that same material using guided drawing instruction.

This is a very interesting topic to study because it involves many areas of educational research. Visual literacy can be studied at the level of neural processing – how images are processed in the brain, and how concepts are encoded with the use of images. It can also be examined from the angle of how the structure of the brain can be moulded by the communication tools that it uses, especially in the context of this generation of emerging adulthood in the digital age. The creation and use of digital images for learning can be interpreted through the Vygotskyan theory of social learning, where digital imagery is a new psychological tool of learning, and where knowledge is internalised through the cultural mediation of modern communication technology. The effect of digital media on learning can also be considered from the standpoint of media theory developed by McLuhan, where the meaning of what is being learned is determined by the vehicle through which the communication occurs. Digital media have generated an explosion of exciting new learning tools, and endless possibilities for investigating their effect on the acquisition of human knowledge, but research in this area is often limited to hyperbolae about the new learning technology tools, without any evaluation of their actual impact on learning.

Since the transmission of knowledge is becoming more image orientated, it is important to consider what effect this may have on our ways of learning about and understanding the world. Some scientists regard images with suspicion, because while eliciting a powerful intuitive response, they side-step dialogue and avoid being challenged by qualification or objection (Northcut, 2006). Pictures can lie to us, because we can‟t argue with them, and we can‟t undo the intuitive emotional response that they generate. Pictures are therefore a form of dogmatism.

Some say that illustrations such as Rutherfords‟ atom are a form of visual hypothesis, but such illustrations can be very misleading because they are only representations of reality, not reality itself; they are models that we use to understand the world. Therefore the use of images in science carries a responsibility. Science teachers have to help their students develop techniques for using, evaluating and creating images, so that they can learn to what extent they can trust the information found in imagery. To do this, science teachers must experiment with and compare different methods of visual learning, and develop an understanding of what it means to be visually literate (Santas & Eaker, 2009). This is especially important for biology teachers, since biology places such an emphasis on teaching through imagery, and because there has been an expansion in the ways that images are used in biology. Therefore, while biology teachers eagerly and necessarily embrace the tools of digital media for learning, growing evidence from the field of embodied cognition cautions us not to neglect the importance for proper assimilation of knowledge of linking hand movements with visual information by the use of direct actions such as writing and drawing by hand.

CHAPTER FOUR
RESEARCH QUESTION

The problem identified for this study is that teachers are being encouraged to use digital tools for teaching the highly visual and technological discipline of biology to students who have been brought up with digital media (Digital Natives), but there have been very few studies to support the claims that these digital tools enhance learning. The question being addressed by this study is whether using digital tools to teach visual information really improves learning outcomes when teaching about biological images to Digital Natives.

This study uses a randomised, cross-over, comparative research design in an attempt to determine if there are any significant differences in the visual literacy learning outcomes of students enrolled in a college level biology course who use interactive digital activities on a computer for learning, when compared to those using traditional drawing activities for learning. More specifically, this study tests the following three hypotheses:

A. Hypothesis 1:
   For students enrolled in a college level biology course, there is a significant difference between those learning using interactive digital activities compared to those learning using traditional drawing activities in the visual literacy learning outcomes for image-based biology topics;
B. Hypothesis 2:
   For students enrolled in a college level biology course, there is a significant difference between those learning using interactive digital activities compared to those learning using traditional drawing activities in the accuracy of self-evaluation for visual literacy learning outcomes for image-based biology topics;

C. Hypothesis 3:

For students enrolled in a college level biology course, there is a significant difference in task engagement when using interactive digital activities for learning image-based biology topics compared with using traditional drawing activities.

The target population is college level students. The sample population is a convenience sample of science program students over 18 years old enrolled in an introductory biology course in an english CEGEP in Quebec.

The variable that is being manipulated (the independent variable) is the instructional tool, or the learning activity given to the students, which is either an interactive digital activity (the treatment), or a traditional drawing activity (the control). The interactive digital activity in this study is an animated image that can be manipulated using the appropriate software, and which illustrates some biological object or principle. The traditional drawing activity is a method of learning about a biological object or principle through guided hand-drawing.

The variables that are being measured (the dependent variables) are: the visual literacy learning outcomes, accuracy of self-evaluation and level of task-engagement. The visual literacy learning outcomes in this study are composed of the ability to correctly localise and identify components of a biological image, the ability to describe how the different parts interact with each other, and the ability to communicate the knowledge in a drawing while respecting stylistic conventions of biological drawings.

These variables are operationalised as follows:

1. Visual literacy learning outcomes:
   Overall grades for a quiz testing visual literacy after the learning activity
2. Accuracy of self-evaluation:

The difference between the teacher-assigned grades and the students" self-evaluation grades for a quiz testing visual literacy;

3. Level of task-engagement:
   Self-reported elements (interest, effort, difficulty, value, confidence) of task engagement quantified using Likert scale responses;

Elements of responses to semi-structured questions on task engagement are quantified using content analysis, and used to validate the Likert scale responses for task engagement..

The study design attempts to control for several possible confounding variables by conducting a survey at the beginning of the study. In the survey, students are assessed for attitudes towards learning biology and for their learning styles, since performance is affected by motivation and attitudes to learning. Students are also assessed for familiarity with computers, since this could have an impact on their preferred learning method.

CHAPTER FIVE
METHODOLOGY

1. INTRODUCTION

The study compared the level of achievement in visual literacy learning objectives; the student"s ability to self-evaluate; and the level of task engagement between two different instructional tools (digital or traditional drawing activities) for selected biology topics within a particular biology course. Comments by the students about their perceptions of the two types of learning activities were collected and analysed.

As detailed in Table 1, after an introduction of theory to all the students during class time, two randomly assigned groups carried out different learning activities to study the same topic. One group used an interactive digital activity on a computer, while the other group used a traditional drawing activity. At a later date in the course, the intervention was repeated for another, similar and equivalent topic, but this time the groups were inverted, such that the group that used interactive digital activity for topic 1 now used a traditional drawing activity for topic 2, and *vice versa*. This was to ensure that one group did not have an unfair advantage over the other for the final grade of the course. The cross-over design also controlled for differences between the two groups, and allowed the students to make comparisons about their experiences of the two types of activities.

Table 1
Protocol

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.	
	Intervention #1	Group 1 learns how to draw, identify and assign functions to the parts of the cell using an **Interactive 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.	
	Intervention #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 an **Interactive Digital Activity.**
	Quiz #2 (Post-Intervention assessment of learning)	Students 1) draw a cell in a particular phase of mitosis, labelling specified structures. 2) 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.	

A pre-study demographic survey was administered to gauge the level of experience in computing, biology and drawing, as well as age, mother tongue and learning styles (see Appendix B). Within a few days after each intervention, students were given a quiz to evaluate content knowledge (see Appendix E). This was a formative assessment. Finally, students were asked to complete a voluntary questionnaire about their experience of the two learning activities (see Appendix F).

2. SAMPLE AND TARGET POPULATION

The target population was college level students. The college where this study was carried out was an English CEGEP in Quebec located in a suburban area of a large international port. Generally these students are between 17-19 years old, although there may be mature students within the population. The students are from a wide range of different ethnicities, and some of them are recent immigrants to Canada. A large proportion of these students do not speak English as their first language, and many of them use French as their first language.

The sample population was a convenience sample of Science Program students in an introductory biology course. The class size was 39. Of these, 33 students agreed to participate in the study: twenty seven males and seven females, who were all between the ages of 18 and 21. To protect the anonymity of the students, the survey did not ask about gender, since it would have been possible to retroactively identify the respondent, given the low number of female students. According to the pre-test survey (see Appendix B), all but six of the 33 students were enrolled in the Pure and Applied Science Program for Pre-University studies at the college. The six remaining students were enrolled in the Health Science Program for Pre-University studies at the college. The remaining data from the survey are summarised in Appendix G.

The researcher created two random groups within the class. Students were not told that they had been divided into groups until after the second intervention.

3. DATA COLLECTION

3.1 Demographic Information

During the first class of the course, the study was explained to the students by a third party (the Coder: a trusted retired professional who had not previously taught those students), in as much detail as possible without biasing the results of the study. The students were asked to review and sign a consent form to agree to participate in the study (see Appendix A). The consent form was distributed, explained and collected by the Coder. They were told that some of their work may be reproduced and published anonymously, but only if they had given specific permission for this, wherein their consent would only be known after they had completed the course and received their final grade. The Course Teacher (researcher) could never know which individuals had or had not consented to take part because the Coder kept the consent forms until after the final grades have been submitted at the end of the course. The consent forms were then released to the Course Teacher, after having been coded so that no particular consent form could be associated with any particular student. 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.

The Coder asked all students to fill out a survey identifying demographic information, familiarity with computers, learning styles and interest in biology (see Appendix B). Students were told that they did not need to answer the questions if they did not wish to participate, but that their survey sheet would be collected anyway. The survey sheets were collected, coded and preserved by the Coder until after the Final Grade submission, when they were released to the Course Teacher for analysis.

The questions in the survey relating to demographic information (age, mother tongue etc.) and about experience in and attitudes to biology and computing were designed by the researcher.

The questions about learning style were taken from an online survey created by Neil Fleming and Colleen Mills at Lincoln University, New Zealand (Fleming & Mills, 1992), 2009) (with permission: copyright is held by Neil D. Fleming, Christchurch, New Zealand). A simple online survey was chosen because it gives the students an opportunity to find out about their own learning styles, and to identify study strategies for different learning styles. The questions follow the standard format for the Fernald VAK (Visual –Auditory – Kinaesthetic) model that was developed in the 1920s. In this version of the model students are classified as Visual Learners (people who prefer to learn using symbols to replace words), Aural Learners (people who prefer to learn through heard or spoken information), Read /Write Learners (people who prefer to learn through text) and Kinaesthetic Learners (people who prefer to learn through movement).

By these and other measures described in section 3, the study respects human dignity by adhering to the principles of Minimum Risk, Free and Informed Consent, Privacy and Confidentiality, Inclusion and Avoidance of Conflicts of Interest, as outlined in the Ethics Guidelines for the Research Component for the MTP, Université de Sherbrooke.

3.2 Intervention (Learning Activities)

After the theoretical introduction of each topic, students were given an assignment to learn how to draw, label and assign functions to parts of the biological object studied. One group was given a digital activity on a computer, using an animated PowerPoint to drag objects into the correct position in a structure and then assign labels to them (see Appendix C). The PowerPoint program was chosen because most people know how to use it, and because it requires no special software. The images are scanned hand drawings in order to teach the students the correct stylistic conventions for drawing biological structures. The PowerPoints for both topics were piloted in a previous course, and informal feedback for this activity was positive.

The other group was given a traditional drawing activity on printed-paper, with step-by-step instructions for drawing the object (see Appendix D). Both activities were assigned randomly through Course Management software. Both activities contained a grading rubric that explains how a quiz on this learning object would be evaluated.

To prevent introducing bias into the results, the students were given a variety of similar activities throughout the course, and were not told which specific learning activities were to be used for data until after the study is completed. The study was completed midway through the semester, after which students were told which activities were used. All students experienced both types of learning activities, and had the opportunity to try both learning activities for both topics before their final exam.

3.3 Post-intervention Assessment

After the learning activity, students were given a formative assessment (a quiz), where they were asked to draw and label parts of the object studied, using the criteria described in the learning activity. They were also asked to fill out a self-assessment column (see Appendix E).

A photocopy of the unmarked quizzes was made and kept for analysis. These were coded and marked later by a biology teacher who was not connected to the study. This preserved student anonymity and also reduced the possibility of the introduction of bias into the marking process. Furthermore, it means that the quizzes were graded according to established convention. The original was marked by the Course Teacher and returned to the student, to give timely feedback to the student. No attempt was made to break down the grade according to levels of cognition or type of learning, given the difficulties experienced by Dwyer (2010) when he attempted this.

The mark for the quiz was made up of four components: Content was assessed according to whether all the important structures were drawn and identified. Style was assessed according to whether the drawing respected stylistic conventions for this particular biological object. Proportion was assessed according to whether a scale was shown and the elements of the drawing were in the correct proportion. Presentation was assessed according to whether the drawing was neat, well organised and easily understood by an observer. Content and Proportion comprised both factual and conceptual knowledge. Style and Presentation were components of procedural knowledge. By asking students to self-evaluate their drawing, it was possible to measure their metacognitive knowledge about the learning object.

3.4 Questionnaire on Reflections about Experience of Learning Activity

At the end of the study, when both learning activities had been completed, students were asked to fill out a voluntary questionnaire asking them to estimate their level of engagement with the two learning activities (see Appendix F). The questionnaire was based on one developed by Caulfield (2010), using a Likert scale to compare student 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 learning activity they enjoyed the most and found most valuable. The questionnaire also asked students to estimate the time they had spent studying for each of the two quizzes, as a measure of task engagement.

Students were informed that this questionnaire was anonymous and would not be seen by the teacher until after they had received their final grade. The questionnaire was collected by the Course Teacher, placed in a sealed envelope in front of the students and immediately passed to a staff member, to be forwarded to the Coder. The questionnaires were coded and released back to the Course Teacher after Final Grade Submission.

3.5 Measures to Control Confounding Variables

All students in the sample had the same teacher and the same experience of the course. They were assigned into random groups by the researcher. The learning activities were equivalent in skill level and time requirement. The teacher took precautions against associating particular students with the data they generated. The specific population characteristics of the students enrolled in particular programs cannot be controlled for, but their characteristics could be identified using the demographic information.

CHAPTER SIX
RESULTS

1. INTRODUCTION

The hypotheses tested were that for students enrolled in a college level biology course there is a significant difference between those learning using interactive digital activities compared to those learning using traditional drawing activities in, a) the visual literacy learning outcomes, b) the accuracy of self-evaluation for visual literacy learning outcomes, and c) in task engagement for learning for selected biology topics.

The study split the sample randomly into two groups: Group 1 and Group 2. A survey was administered at the start of the study to establish that there was no significant difference between the two groups for possible confounding variables such as level of experience in computing, biology and drawing, as well as age, mother tongue and learning styles. Two quizzes were administered to each of the two groups, and the grades for each quiz were compared to establish that the two quizzes were equitable. Students were asked to complete two learning tasks. The outcomes of the first learning task were assessed using Quiz 1, and the outcomes of the second learning task were assessed using Quiz 2. Group 1 used an interactive digital activity on a computer to learn the material for Quiz 1, and a traditional drawing activity to learn the material for Quiz 2. Group 2 used a traditional drawing activity to learn the material for Quiz 1, and a digital activity to learn the material for Quiz 2.

The difference in grades for Quizzes 1 and 2 was compared between Group 1 and 2, to establish whether the evidence supported the hypothesis that there would be a difference in learning outcomes when learning by drawing or by using a computer. Students were also asked to self-evaluate their grade on each quiz, and the correlations between the self-evaluation grades and the teacher grades were evaluated, to establish whether the evidence supported the hypothesis that there would be a difference in the accuracy of self-evaluation when learning by drawing or by using a computer.

At the end of the study, students were given access to both learning activities for both learning tasks. A questionnaire was administered that was designed to measure levels of task engagement. Different measures of levels of task engagement were compared for learning by drawing and learning by computer, to establish whether the evidence supported the hypothesis that there would be a difference in the level of task-engagement when learning by drawing or by using a computer.

2. ASSESSMENT OUTCOMES

2.1 Possible Confounding Variables

A pre-study demographic survey was administered as a measure to control for confounding variables such as level of experience in computing, biology and drawing, as well as age, mother tongue and learning styles. The data is summarised in Appendix G (Table 4). The study split the sample into two groups (described in the following section): Group 1 and Group 2. There was found to be no significant differences between the two groups for any of the variables identified. The difference in gender distribution between the two groups was not tested, to preserve the anonymity of the participants, but given the high proportion of male students (82%), gender was deemed unlikely to have been a confounding factor in the study. Therefore the two groups were comparable with respect to the characteristics identified.

A minority of the students (30%) said that they spoke English as their mother tongue, but most (73%) said that they were fluent in English, (both written and spoken), and the remainder (27%) said that they spoke English conversationally. A high proportion of students (40%) had attended a French language private high school, and about half of the students had attended either an English or a French public high school, in approximately equal numbers. Most students (79%) said that they had studied biology at high school for between 5 and 20 months.

At the start of the course, most (52%) of the 33 students surveyed liked watching nature documentaries quite well, but most students (55%) were neutral or did not enjoy looking after and observing plants and animals. Most students (60%) were neutral about the subject of biology, and most students (91%) were not interested in a career as a biologist, health specialist, vet or naturalist. Most students were able to program a computer very well or passably well (64%), make a blog or a website very well or passably well (54%), could download software very well (64%), and used a computer several times a day (79%). Most students also used a cell phone, MP3 player or iPad several times a day (70%). Most students used social media such as Facebook at least once a day (54%), and 70% played video games more than once a week. Most students (27%) said that they drew or painted quite well, but that they mostly just doodle. A picture emerges of the archetypal pure and applied science class: mostly male, highly familiar with digital media, and mostly uninterested in studying biology.

The survey included a questionnaire designed by Neil Fleming and Colleen Mills at Lincoln University, New Zealand (Fleming & Mills, 1992), 2009) (with permission: copyright is held by Neil D. Fleming, Christchurch, New Zealand). to categorise different learning styles. Students were categorised as visual, aural, read/write or kinaesthetic learners, as described in the

Methodology section, but could be any combination of the four styles. Most of the students were aural learners (61%), while 51% were visual learners, 58% were read/write learners and 54% were kinaesthetic learners. There was no significant difference in the distribution of learning styles between Group 1 and Group 2.

To assess whether the two quizzes were equitable, the data was tested to see if there was a difference in grade 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)) (see Figure 11). There was no significant difference between the two quizzes.

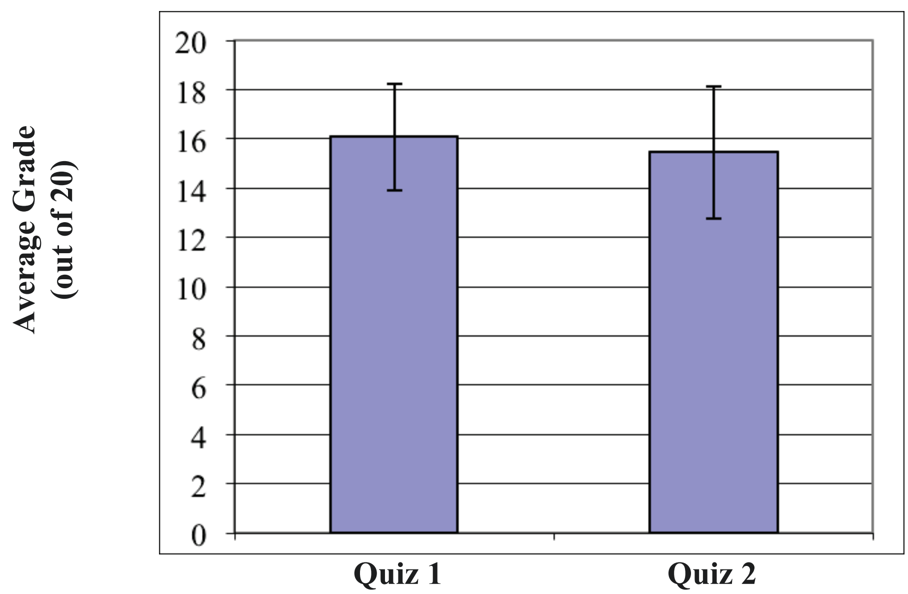


Figure 11. Total average grades and standard deviations for each quiz.

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.

2.2 Significant Differences in Results Between Group 1 and Group 2

The first hypothesis tested in this study was: For students enrolled in a college level biology course, there is a significant difference between those learning using interactive digital activities compared to those learning using traditional drawing activities in the visual literacy learning outcomes for selected biology topics.

To test this hypothesis, students were asked to complete two learning tasks. The first learning task was to draw and label a cell, and the second learning task was to draw and label a cell during the phases of mitosis (see Appendices C and D). The learning outcomes were assessed using Quiz 1 and Quiz 2, respectively (see Appendix E). Group 1 used an interactive digital activity on a computer to learn the material for Quiz 1, and a traditional drawing activity to learn the material for Quiz 2. In Group 2, the situation was reversed, such that these students used a traditional drawing activity to learn the material for Quiz 1, and a digital activity to learn the material for Quiz 2.

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 using a traditional drawing activity) was higher, at 16.94 out of 20 (or 85%) with a standard deviation of 1.86 (n=17) (see Figure 12). 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 (see Appendix H; Tables 8 and 9). The evidence supported the hypothesis that there is a significant difference between those learning using interactive digital activities compared to those learning using traditional drawing activities in the visual literacy learning outcomes. Furthermore, the evidence suggested that learning outcomes as tested in this study, were greater when hand drawing activities were used compared to digital activities. The sample size was small, but the homogeneity of the sample validated this outcome.

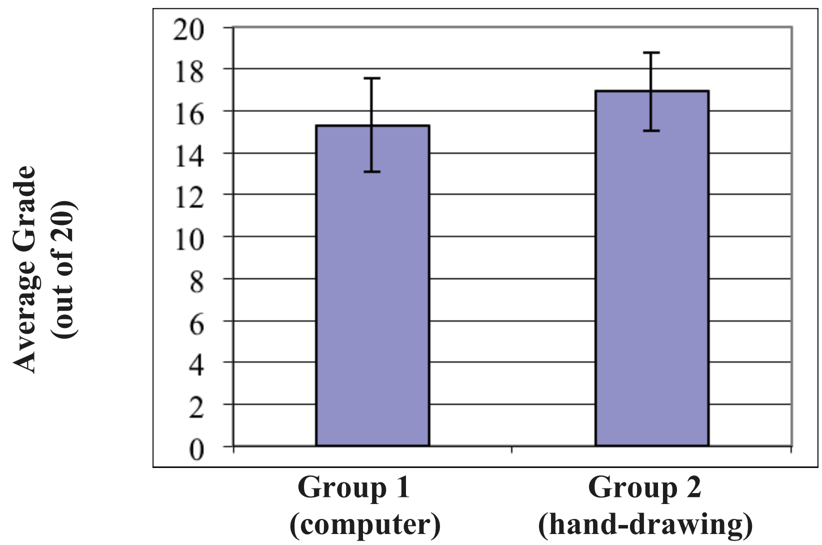


Figure 12. Average grades (out of 20) and standard deviations for Quiz 1.

For Quiz 2 (drawing and labelling a cell in anaphase of mitosis), the groups had been inverted so that Group 1 used a traditional drawing activity to learn the material, and Group 2 used a computer to learn the material. For the second quiz, the students had gained experience from their first quiz, and the effect of the choice of learning tool was less clear. In this case, there was no significant difference between the groups (see Appendix H; Tables 10 and 11).

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 using a traditional drawing activity) 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) (see Figure 13).

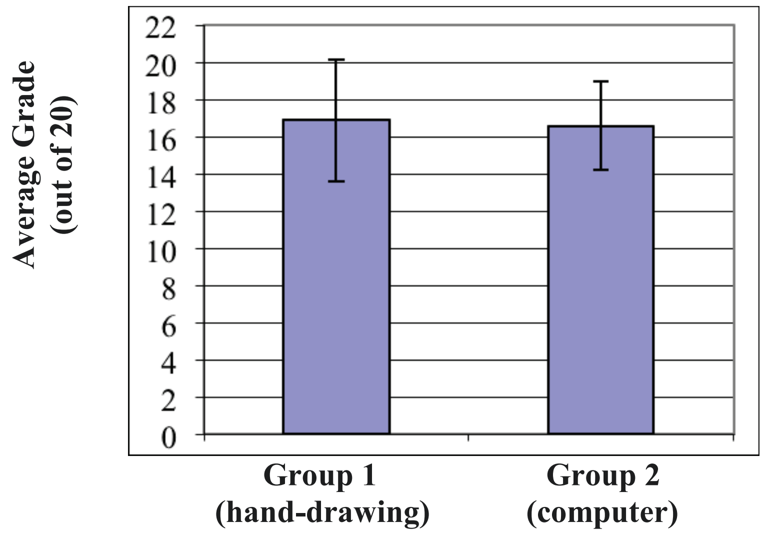


Figure 13. Average grades (out of 20) and standard deviations for Quiz 2.

3. SELF-EVALUATION OUTCOMES

The second hypothesis tested in this study was: For students enrolled in a college level biology course, there is a significant difference between those learning using interactive digital activities compared to those learning using traditional drawing activities in the accuracy of self-evaluation for visual literacy learning outcomes for selected biology topics.

To address this question, 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**	
	Spearman Rho correlation coefficient (between self-evaluation and teacher grade)	Significance (2-tailed)	Spearman Rho correlation coefficient (between self-evaluation and teacher grade)	Significance (2-tailed)
Group 1	0.062	0.841	0.512	0.051
Group 2	0.011	0.966	-0.13	0.631

4. TASK ENGAGEMENT OUTCOMES

The third hypothesis tested in this study was: For students enrolled in a college level biology course, there is a significant difference in task engagement when using interactive digital activities for learning compared with using traditional drawing activities.

To address the third question, students were given access to both learning activities for both topics, after they had taken both Quiz 1 and Quiz 2. This permitted them to use either learning technique to learn the material for a Unit Test covering all of the material for the first third of the course. Following the Unit Test, they were asked to fill out a questionnaire about which learning technique they had preferred. The responses to the questionnaire are presented in Appendix G.

For all the 29 students who replied to the question, “Which type of learning activity did you enjoy most?” 59% chose the computer. They 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. In contrast, more students said that they would be more likely to put off doing the assignment if it was with a computer (53% of the 30 who replied), but it was possible that they did not properly understand the question (the phrasing was slightly confusing). A chi square test showed that none of these differences were significant (see Appendix G; Table 5). Therefore, in this respect, the hypothesis that there is a difference in the level of task engagement for the two learning tools was not supported.

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 categorise their responses, as shown in Appendix G (Tables 6 and 7). The numbers in each category are too small for statistical analysis, but trends can be observed. Most students who preferred the computer said that it was because it was more interactive. About a quarter of the students who preferred the computer thought that the information was more detailed and precise and that they retained the information better. Many students did not like drawing and thought it was easier to use the computer. On the other hand, many of the students who preferred hand-drawing said that it was because they loved to draw and that it was easier and simpler. They said that drawing was more hands on and individual, and most of them felt that they retained more information from drawing.

A model developed by Caulfield in 2010 was used to measure task engagement. Students were asked to rank their engagement in the learning activities on a Likert scale according to Interest (corresponding to the level of engagement), where 5 represented, "very interested" and 1 represented, "not at all interested"; according to Effort (how much time and effort was put into the exercise), where 5 represented, "a lot of effort" and 1 represented, "no effort"; according to Difficulty of Material (how difficult was the material) where 5 represented, "very difficult" and 1 represented, "very easy"; according to Value of Exercise (how valuable the exercise was for learning the material), where 5 represented, "very valuable" and 1 represented, "not valuable"; and according to Confidence (corresponding to the level of self-efficacy), where 5 represented, "very confident" and 1 represented, "not confident". The means and standard deviations for each category for Groups 1 and 2 are shown in Table 3.

Table 3
Means and Standard Deviations (in brackets) for Likert Scale Responses for Interest, Effort, Difficulty of Material, Value of exercise and Confidence for Computer or Hand-drawing Activities for Quizzes 1 and 2

	Quiz 1		**Quiz 2**	
	Computer (n=13)	**Hand-drawing (n=15)**	**Computer (n=14)**	**Hand-drawing (n=10)**
Interest	3.85 (0.90)	3.47 (1.19)	3.64 (0.75)	3.20 (0.63)
Effort	3.00 (1.47)	3.47 (1.19)	3.57 (1.16)	3.20 (0.63)
Difficulty	2.54 (0.88)	2.60 (0.99)	3.07 (1.07)	3.40 (0.70)
Value	3.61 (1.19)	3.33 (1.11)	3.86 (0.86)	3.22 (0.67)
Confidence	4.15 (0.90)	3.60 (1.06)	3.64 (0.84)	3.60 (0.84)

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 or Group 2 in task engagement for any of these categories.

Therefore the responses to the questions pertaining to task engagement did not support the hypothesis that there is a difference in level of task engagement for the two types of learning tool.

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 21.92 min studying using the digital activity, with a standard deviation of 9.91 ($n=13$), and Group 2 students reported that they spent an average of 31.88 min studying using a traditional drawing activity, with a standard deviation of 12.09 ($n=16$) (see Figure 14). For the topic of learning to draw the phases of mitosis, Group 2 students reported that they spent an average of 37.00 min studying using the digital activity, with a standard deviation of 13.73 ($n=15$), and Group 1 students reported that they spent an average of 21.67 min studying using a traditional drawing activity, with a standard deviation of 18.54 ($n=9$) (see Figure 14).

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 again spent a significantly longer amount of reported time than Group 1, where $t(22) =-2.32$, $p = 0.03$ (see Appendix H; Tables 12, 13, 14, 15). For the first quiz, Group 2 students were studying by drawing. This may account for the improved performance of Group 2 students in Quiz 1. However, for the second quiz, they were studying using the computer, and there was no significant difference in mark compared to group 1. Therefore, extra study time alone was not enough to improve the grade, so it is still possible to conclude that the improvement in Quiz 1 was linked to studying by drawing alone. However, in terms of task engagement, the evidence did not support the hypothesis that there is a difference in level of task engagement for the two types of learning tool.

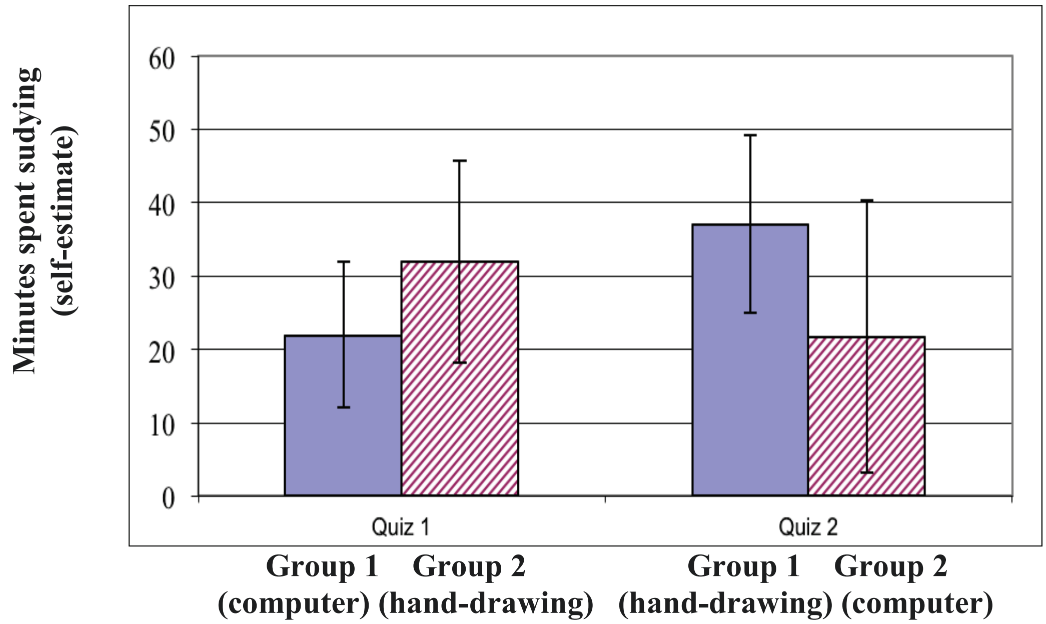


Figure 14. Self-estimated time spent studying for Quiz 1 and Quiz 2.

CHAPTER SEVEN
DISCUSSION

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 interactive digital activities, compared to those learning using traditional drawing activities. The hypotheses were designed to address the research question that asks whether using digital tools to teach visual information really improves learning outcomes when teaching Net generation students about biological images. The question derives from the problem that teachers are being encouraged to use digital tools for teaching the highly visual and technological discipline of biology to students who have been brought up with digital media, but there have been very few studies to support the claims that these digital tools enhance learning. 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 activity or using a digital activity. 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 in the classroom to any greater extent than traditional methods. It should be noted, however, that the sample size of this study was small, 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.

This study rests on the central concept of visual literacy – the ability to use and communicate images. Visual literacy is critical for learning science, because making visualisations is “integral to scientific thinking” (Ainsworth, 2011, p.1096). This is because humans think in terms of symbolic imagery, according to Chomsky. The conceptual framework for this study describes how visual literacy is a social construct, and is mediated through learning tools such as drawing on the one hand, and digital media on the other hand. The author Marc Prensky (2001a) coined the term Digital Native to describe how students brought up with digital media have a different way of thinking and communicating compared to previous generations (the Digital Immigrants). This study is centred on the idea that Digital Natives and Digital Immigrants communicate differently, especially in the use of imagery, and have different cognitive structures. Many commentators agree with Oblinger and Oblinger (2005, p. 25) 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.” It was thought that students in the particular age group of this study, who are considered to be Digital Natives, might learn the material better using digital tools. The students in this particular study were highly computer literate and used to using electronic media. They were mostly male, all about 18, and in the same program (Pure and Applied Science).

The conceptual framework of this study links the cognitive structure of the brain to the neuroplastic processes that shape the brain as it develops, according to the way it is used. According to Prensky (2001a), the use of digital media is thought to favour right-brain, non-linear inductive thinking, whereas reading favours logical, linear, left brain development. 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. The expectation then would be that the students in this study would learn better using digital tools, because they are male teenagers and spend so much time using digital media.

The results of this study actually showed that when learning to draw the cell, students gained significantly higher grades when they learned using the traditional drawing activity compared to when they learned using the digital activity. This is more in accordance with studies in the field of Embodied Cognition. Embodied cognition is linked to the concept of neuroplasticity in that it is thought that haptic (exploratory movement) information is involved in shaping the brain‟s cognitive structures: that is, how one moves one body shapes the way one thinks (Lakoff, 1999). 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 Charles Hulme in 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, 2011).

The students in this study were not very successful at evaluating their own performance – regardless of the type of learning activity they had used. There was little correlation between their 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.

There was also no clear difference in level of task engagement between the two types of learning activity. The results from the questionnaire indicate that students found that using the computer was more interesting, less effortful and difficult, and 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 visualise the information". It should be noted that the students frequently used the term "interactive" as a benefit of using the digital activity, but that this term came from the students themselves, as the word was never used by the teacher with the students to describe the tool. This implies that this was considered to be a very positive feature of the digital activity. However, students also described the positive aspects of using the traditional drawing activity, 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 organise knowledge (Sheridan, 2004).

Although not a focus of this study, it was noted that the students felt they learned more when using the computer, even though there was very little difference in performance between the two learning techniques. If anything, they performed slightly better when they learned to draw by hand on paper, but they did not perceive this. Although the differences were not significant, more students stated that they preferred learning using the computer, felt that they learned more when they used the computer and would choose the computer if they had to learn a new topic. Interestingly, they wrote that they learned more using the computer because, "It contained more details", and "…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 theory of the power of the medium as the message. It also speaks to the degree to which our expectations influence our perceptions.

One interesting outcome of the study was that there was a negative correlation between a higher grade and students who rated themselves as being skilled at drawing. It seems to support the popular perception that artistic skills are not associated with success in science, in spite of the widespread importance of imagery in science. On the other hand, there was a positive correlation between a higher grade and a higher reported frequency of playing video games for one group of students. It may be that the type of students who get high grades are also the type of students who play video games. However, according to Gee (2003), video gaming incorporates principles that promote learning, and playing video games promotes visual literacy and problem solving. To date, research on the effects of gaming on brain function is still in its infancy, but it is believed that gaming may enhance cognitive development. Bavelier (2010) reviews studies that demonstrate improved brain plasticity in adults who play video games. In these studies, adults who lost vision in one eye due to the eye being non-functional during a critical developmental period in infancy were able to learn to see using that eye by playing video games. The gaming environment stimulated the formation of neuronal connections between the eye and the brain. Her premise is that higher cortical areas of the brain retain plasticity into adulthood, and are able to modulate brain function according to the sensory and motor stimulation that the brain is exposed to. In short, the brain continues to be remodelled and shaped by its environment, even into adulthood, and the gaming environment provides a rich source of stimulation, promoting cognitive development. From this, it would appear that there are neurocognitive arguments in favour of using both drawing and digital tools for learning. Shaaron Ainsworth, from the University of Nottingham, is exploring ways of teaching complex scientific imagery through drawing by hand combined with the use of digital tools (Ainsworth, 2011).

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 would 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 this leads to a related issue concerning the use of digital imagery in teaching. Publishers use copyrighted online tools as an incentive to buy their products. Access to these images is expensive, but teachers are eager to adopt them, since they believe that they will enhance learning. It is 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.

CONCLUSION

This study addresses the question as to whether college age biology students achieve better visual literacy learning outcomes if they learn using digital images rather than through drawing images on paper. The study showed that between the two learning techniques there was either no difference in performance or a slight improvement in performance when learning by drawing on paper. Neither learning technique improved the student‟s ability to assess their own performance, or was associated with enhanced task engagement. Slightly less than half of the students preferred learning by drawing, and showed a strong attachment to the drawing process, but the majority of students preferred learning using the computer, and felt that it was more valuable as a learning tool because it was interactive. They perceived the quality of information they were learning to be superior, even though the information was identical. In conclusion, teachers should give students the opportunity to try both drawing and digital learning activities, in order to satisfy their different learning requirements. Similar studies to this one should be carried out with larger sample sizes, more sophisticated images, and using methods to better assess metacognition and attitudes to learning.

So far, there have been no studies that directly compare the effect of learning the same material through the two different media: digital or on paper. This study is one of the first to attempt this in an empirical way. The study indicates that students do not show improved learning using digital tools, even though they are members of the Net Generation, who are purportedly highly skilled in the use of new media. On the other hand, it shows that students perceive their learning experience to be more valuable when using a computer, despite the fact that there is no real improvement. Those students who prefer drawing are very attached to the process of drawing as a learning process and make very positive comments, with the use of terms such as “love” and “owning” their work.

Because students need to develop skills in visual literacy, and because the digital medium is so powerful for framing the perception of information, teachers should make use of digital tools to develop visual literacy, but should also be aware that these technologies are not magic recipes – the students may not learn more information, they may just think that they have learned more. Neither might they be any better at assessing their own level of knowledge. However, they might feel they have had a more positive learning experience when using the digital tools, mostly because the interactive element reassures them by giving them instant feedback when they make mistakes. Despite this, students should also be given opportunities to exercise their drawing skills, because slightly less than half of them enjoy drawing very much, learn just as well from drawing as from the computer, and feel greater ownership of the material.

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