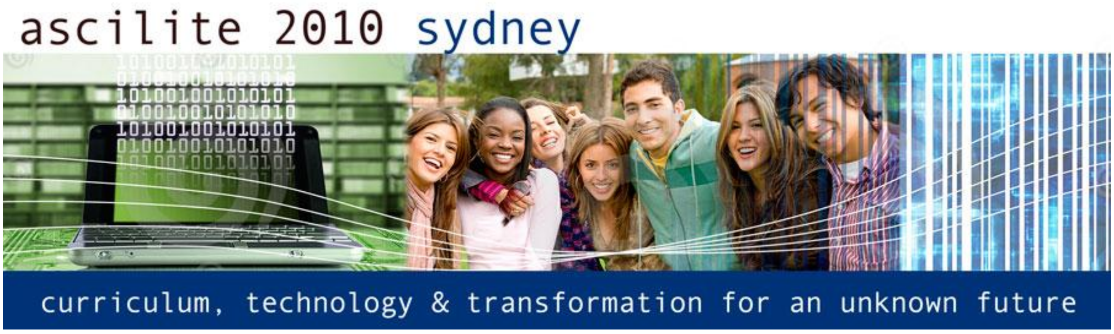

Using students' visual representations as a window to designing learning tools

Ardis Cheng & **Gregor Kennedy**
Faculty of Medicine, Dentistry, and Health Sciences
The University of Melbourne

Edmund Kazmierczak
Department of Computer Science and Software Engineering
The University of Melbourne

We report the preliminary findings of a study that considered how undergraduate students visually represent dynamic processes of a biological complex system. Initial results indicate that students created structure-focused visuals and relied on visual representations they had previously encountered in their studies. We suggest that the results of this paper can inform how computer-based learning tools could be designed to prompt students to think about the relationships between structure, behaviour, and function, thereby aiding their understanding of how biological complex systems work.

Keywords: visual representation, complex systems, student understanding, learning tools

Introduction

Complex systems are difficult for students to understand because of the need to simultaneously contemplate numerous elements and concepts across multiple levels (Cook, 2006; Tversky, 2003). A number of theoretical frameworks have provided a cognitive rationale for students' difficulties in this area. These frameworks suggest that novice students gravitate towards the structural components of complex systems as they are its most visible and tangible components, and pay less attention to the system's behaviour and function (see Jacobson's (2000) Complex Systems Mental Models framework and Structure-Behaviour-Function theory (Hmelo, Holton, & Kolodner, 2000; Hmelo-Silver, Surabhi, & Lui, 2007).

A significant body of work has explored the instructional implications of this approach taken by novice students. This has led to the development of various inquiry-based computer simulations, and learning-by design activities that steer novice students away from structure and emphasize the behavioural and functional processes of the system (Resnick, 1996; Penner, 2000; Liu, Hmelo-Silver, & Marathe, 2005). However, few of these developments have specifically considered *biological* complex systems. These systems are distinct from ecosystems and social systems as the physical structure and arrangement of parts are intricately tied to and dictate how functional processes occur. In biological complex systems where the physical structure can determine the functional process, researchers have suggested that providing learners with rich visual representations may make it easier for them to construct and attain a complete picture or mental representation of the system (Kirschner, Sweller, & Clark, 2006). For biological complex systems, visual representations could potentially be used to help students integrate the structural anatomy and functional processes so that they are able to form a more complete mental model of the system.

This paper reports the preliminary findings of the first study in a program of doctoral research. The overarching aim of this study was to explore how visual representations could help novice students understand how biological complex systems work. More specifically, the aim was to examine how students visually represented the structure, behaviour and function of a complex biological system and explore the variety of visual representations students created while reasoning through and making sense of that complex system. It was expected that the findings from this study would help in the design of computer-based visual learning tools for learning and teaching associated with biological complex systems.

Methodology

We used a mixed-methods approach to explore how students visually represent dynamic processes in the renal system, an example of a biological complex system that is an integral part of the undergraduate biomedical sciences curriculum at The University of Melbourne.

One-hour one-on-one sessions were conducted with 10 undergraduate students (7 female, 3 male; aged between 19 to 22 years) from the University of Melbourne studying third year biomedical sciences. All participants had undertaken introductory human anatomy and physiology courses prior to this study.

Each session began with a pre-test of general knowledge of the renal system. This was followed by two tasks in which participants were given paper, pens, and coloured pencils to create visual representations. In Task 1, participants were asked to listen to an audio description of a kidney process and to create visual representations to explain the described process. In Task 2, participants were asked to visually represent how a change in the anatomy (a longer loop of Henle) would affect the kidney process described in Task 1. Participants were asked to "think-aloud" during Tasks 1 and 2. Each session was audio-recorded and transcribed. The pre-test scores, visual representations, observation notes, and transcripts were analysed and coded using two schemas as reference points: Structure-Behaviour-Function Theory as outlined by Hmelo-Silver et al. (2007) and the Form and Function model proposed by Boerwinkel, Waarlo, and Boersma (2009). Only a subset of the data will be reported in this concise paper.

Results and discussion

In this study, visual representations were defined as any form of graphic that could be created on paper. This included schematics (e.g. an outline of the anatomy), symbols (e.g. arrows), maps (e.g. a word flow chart), and charts (e.g. a bar graph). All participants saw the value in using visual representations for learning and understanding as indicated in the comments below:

> If you do diagrams you sort of have to have a whole understanding of it, whereas if its just words and they say 'What would happen if this goes wrong?' and you haven't, you've just got words on certain tasks and, you haven't got the idea of the whole process. (Participant 7)

> I think probably a picture like this [referring to nephron outline], when given during lecture, it helps put things into perspective a little bit more. (Participant 4)

> I think diagrams help a lot because you're actually seeing the picture. It's sort of like everything you've learnt, you're sort of putting it through so you can sort of study the mechanisms in the drawing. (Participant 10)

> Because when you read stuff, in your head you're basically picturing it. So when you go to a piece of paper, you don't have to, it's all there permanently. In your head it's sort of temporary. (Participant 10)

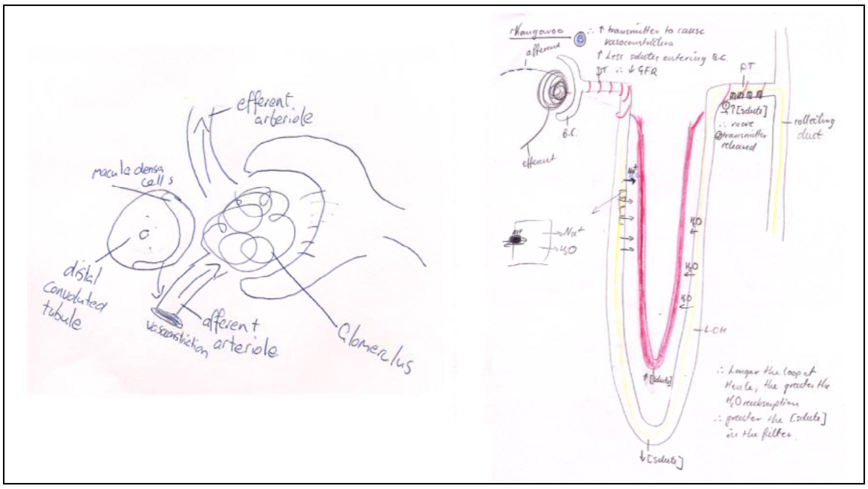

Figure 1: Participant generated visual representations for (a) Task 1 (Participant 5) and (b) Task 2 (Participant 3)

The vast majority of participants (9/10) began both tasks by drawing the key anatomical structures (e.g. glomerulus, afferent arteriole, macula densa cells) involved in the kidney process before visualizing the behavioural and functional processes (see Figure 1a and 1b). This is consistent with the Complex Systems Mental Models framework and Structure-Behaviour-Function theory, which suggest that novices tend towards structure first when grappling with a complex system.

Overall, for both tasks, participants relied on visuals they had been previously exposed to even if they thought these replications of visuals from textbooks or lecture notes were inadequate, for example:

> … I don't like the way they represented it because, when I first looked at the textbook, I had no idea, like how the whole system worked and I had to figure it out for myself but I can't think of a better way to draw it. (Participant 5)

The purpose of Task 2 was to get participants to consider the implications a change in the anatomy would have on the kidney process described in Task 1, thereby prompting students to integrate structure, behaviour, and function of the complex system. Eight of the ten participants were unable to give a correct response to Task 2. The visuals they created did not seem to help them make the connection between structure, behaviour, and function, which was required for successful completion of the task. Instead, the participants were overly concerned about trying to recall material covered in their previous studies even when it was not related or needed to resolve Task 2.

Of the two who responded correctly to Task 2, neither was able to visually represent their answers beyond written text. One possible explanation for this reluctance to create new visuals, other than what the participants had previously seen, could be attributed to students' lack of confidence in the content area. While the material had been covered in students' previous studies, many failed to remember many of the specifics and spent the majority of their time in the session reasoning through the information. When asked about the content that the tasks were based on, one participant said:

> I can't remember. But I remember seeing everything else. We learnt GFR [glomerular filtration rate]. We learnt hydrostatic, all that. I just can't remember what it was because it was all. I just crammed it all in the day before. (Participant 6)

Another commented:

> So it [the content] wasn't something I felt one hundred percent comfortable with. I had to actually think about it so I couldn't go straight ahead I had to think about how the picture was going to look in the end. (Participant 3)

Only one participant attempted to create a visual representation that had not been seen in textbooks or lectures to explain the impact a change in anatomy would have on the kidney process in Task 2 (see

Figure 2b). When asked whether her visuals were based on representations she had seen before, she responded:

> Well, the structure of the kidneys, yes. But that graph, I don't know, I just, the bar graph, I don't think it really, just, I don't know. I just made it up. (Participant 9)

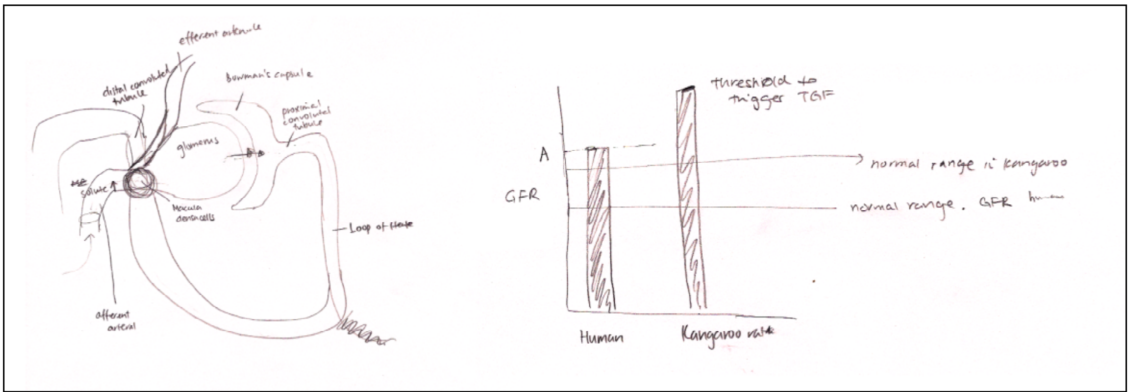

Figure 2: CL generated visual representations (a) structure diagram in Task 1 based on previous studies and (b) a bar graph in Task 2 that she created on her own.

Unlike her earlier visual representation (see Figure 2a), which showed the structural anatomy, this student showed a clear lack of confidence when she was creating the graph. Despite the fact that her response to Task 2 was inaccurate, she felt positive about her answer. Her uncertainty during the task reflected the difficulties she felt not with the content, but with producing visual representations that best illustrated her answer. More than once she stated:

> I don't think my graph is very good and not sure it makes sense. (Participant 9)

Conclusions and future work

In this paper we started to explore the role visual representations may have in helping novices understand how biological complex systems work. We found that visual representations were perceived as valuable tools in learning biological complex systems, that students gravitated towards structural diagrams at the outset and, due to their uncertainty about the content, relied heavily on visual representations they had seen previously in their studies. These preliminary findings suggest that we – educators, designers, textbook authors, and lecturers – need to think very carefully about how we visually present biological complex systems to students. Visual representations need to incorporate the anatomy and dynamic processes to help novice students consider and understand the relationships between structure, behaviour, and function. Given this, there is clearly scope for computer-based visual tools to help students develop their understanding of how a biological complex system works. The seminal work of Mayer (1999), on the way in which multiple representations of phenomena can be combined for effective multimedia learning, and Jones and Scaife's (2000) research on the use of animation in learning, provide a clear basis for this endeavour.

In the next study, we will look at how novice students visually represent the structure, behaviour, and function of a complex biological system when they have to *teach* other students how the system works. We will explore whether students will approach the biological complex system differently and generate distinct visual representations when placed in the role of educator and are no longer reliant on a teacher or their resources to reason through the content. Combined, these two investigations will provide critical evidence-based information upon which to develop computer based learning tools that help students understand biological complex systems.

References

Boerwinkel, D. J., Waarlo, A. J., & Boersma, K. (2009). A designer's perspective: the perspective of form and function. *Journal of Biological Education*, 44(1), 12-18.

Cook, M. P. (2006). Visual representations in science education: the influence of prior knowledge and cognitive load theory on instructional design principles. *Science Education*, 90, 1073-1091.
Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *The Journal of the Learning Sciences*, 9(3), 247-298.
Hmelo-Silver, C. E., Surabhi, M., & Lui, L. (2007). Fish swim, rocks sit, and lungs breathe: expert-novice understanding of complex systems. *The Journal of the Learning Sciences*, 16(3), 307-331.
Jacobson, M. J. (2000). Problem solving about complex systems: differences between experts and novices. In B. Fisherman & S. O-Connor-Divelbiss (Eds.), *Fourth International conference of the Learning Sciences* (pp. 14-21). Mahwah, NJ: Erlbaum.
Jones, S., & Scaife, M. (2000). Animated Diagrams: An Investigation into the Cognitive Effects of using Animation to Illustrate Dynamic Processes. In M. Anderson & P. Cheng (Eds.), *Theory & Applications of Diagrams. Lecture Notes in Artificial Intelligence: 1889,* (pp. 231-244) Berlin: Springer-Verlag. https://doi.org/10.1007/3-540-44590-0_22
Kirschner, P. A., Sweller J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist,* 41(2), 75-86.
Liu, L., Hmelo-Silver, C.E., & Marathe, S. (2005). How representation matters: comparing collaborative learning with alternative versions of hypermedia. Paper presented at the *Proceedings on Computer support for collaborative learning: learning 2005: the next 10 years!*, Taipei, Taiwan.
Mayer, R. E. (1999). Multimedia aids to problem-solving transfer. *International Journal of Educational Research,* 31, 611-623. https://doi.org/10.1016/S0883-0355(99)00027-0
Penner, D. E. (2000). Explaining systems: investigating middle school students' understanding of emergent phenomena. *Journal of Research in Science Teaching,* 37(8), 784-806.
Resnick, M. (1996). Beyond the centralized mindset. *The Journal of the Learning Sciences,* 5(1), 1.
Tversky, B. (2003). Some ways graphics communicate. In K. Nyiri (Ed.), *Mobile communication: Essays on cognition and community* (pp. 143-156). Wien: Passagen Verlag.

Author contact details:
Ardis Cheng
Faculty of Medicine, Dentistry, and Health Sciences
The University of Melbourne
Victoria 3010, Australia
Email: a.cheng@pgrad.unimelb.edu.au

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