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Learning by Drawing Visual Representations: Potential, Purposes, and Practical Implications

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Abstract

Drawing to learn has received increasing attention in recent years. In this paper, we will present distinct purposes for using drawing that are based on active, constructive and interactive forms of engagement. In doing so, we hope to show that drawing to learn should be widely used and there is good evidence to support its use in many situations. To make the most of these distinct purposes, it is important to note that what learners draw matters, and that this needs to be assessed in relation to task demands. It will also require learners to be supported to engage meaningfully in ways that are matched to these pedagogical purposes.

Keywords: Drawing, Learning, Visual Representations

1. Introduction

Learning is multi-representational. When we learn, we typically engage with a variety of visual forms including pictures, graphs, animations, videos, augmented reality as well as text. There are many good reasons for using visual representations as they can provide particular advantages for learning, for example:

- They limit abstraction and so constrain learners' inferences often rendering them more efficient (Stenning & Oberlander, 1995).
- They exploit perceptual processes by grouping relevant information, facilitating search, recognition and inferencing (Larkin & Simon, 1987).
- They externalize information required for problem-solving, thereby reducing memory demands (Zhang & Norman, 1994).
- They provide a focus for joint attention, allowing collaborators to refer to them by words and gesture; thus, supporting the development of common ground (Roschelle & Teasley, 1995).

Rather than addressing all this research, the purpose of the paper is to review the arguments that learners should construct these visual representations for themselves by drawing or sketching. We will treat both as synonyms to refer to the construction by a learner of a static visuospatial representation (i.e., one in which form or position in space is significant). This construction is intended to be meaningful unlike a doodle, and unlike artistic expression, the primary intention is to learn. Our scope includes both sketches with traditional tools (e.g. pen and pencil) and with a finger or tool on a screen. Learners reading a science text and drawing what they understood from it, physics students sketching graphs, medical students drawing what they observe in anatomy classes and primary school children collaboratively creating drawings in a storybook are all examples of the phenomena we will describe (see Figure 1).

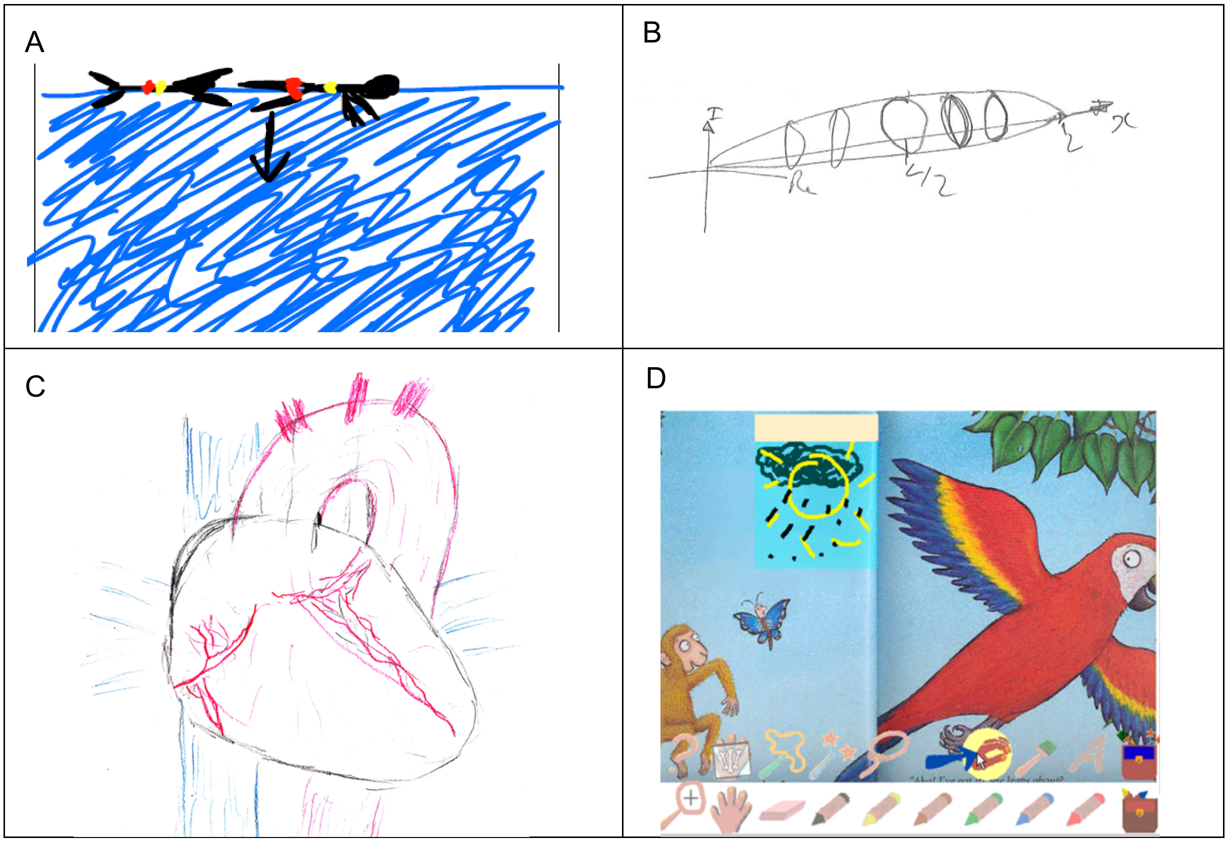

Figure 1: Panel A shows a drawing created by a learner after reading about the law of action-reaction in swimming (Schmidgall, Eitel & Scheiter, 2019); Panel B shows a drawing by a physics student asked to invent a 3d depiction of a quantum-mechanical wave function they had previously only encountered in 1d and 2d depictions (Kohnle et al, in press); Panel C is a drawing by a medical student participating in a dissection class and asked to draw the external features of the heart (Panagiotopoulos, Ainsworth, & Wigmore, 2016); Panel D shows a storybook that collaborating children annotated with drawings to enhance their telling of a story (Gelmini-Hornby, Ainsworth & O'Malley, 2011).

As the drawing practices exemplified in Figure 1 illustrate, there is not only one reason to draw to learn. To help synthesize existing literature on drawing to learn, we will apply the ICAP framework (Chi & Wylie, 2014). ICAP differentiates between **I**nteractive, **C**onstructive, **A**ctive and **P**assive modes of cognitive engagement, each associated with specific learning behaviors, cognitive processes, and outcomes. They are proposed to operate hierarchically as each mode subsumes the earlier ones (e.g. to be constructive, you must already be active) and so become more effective at supporting deeper understanding. When learners are passive, they are minimally engaged, focused on receiving information such as by watching a video. Active engagement involves some overt form of action (e.g. rewinding a video for recap). When engaged constructively, learners generate externalized outputs that go beyond the information they have studied, perhaps by summarizing the video's key points. Finally, when interactive, two or more people are jointly engaged in a learning activity with each partner being (primarily) constructive and with a sufficient amount of turn-taking. This could involve taking different positions on the video and debating it.

2. The Purposes of Drawing

We will now consider how different forms of engagement combine with the properties of visual representations when drawing to learn. Our emphasis differs from Chi and Wylie (2014) as we examine when each type of drawing activity is appropriately matched to intended learning outcomes. There is no passive way to draw; even if unthinkingly reproducing something that is in front of them, learners are actively engaged. Note, we are not claiming that drawing is **automatically** more engaging than interpreting a diagram created by others, as that will depend upon many factors including a learner's goals, task demands, and scaffolding provided all influence how learners' engage when interpreting and constructing visual representations.

2.1 Active Purposes of Drawing

When learners sketch actively, potentially beneficial cognitive processes include activation of prior knowledge, increased attention and better subsequent recall as new information is integrated into long term memory.

When learners successfully retrieve from their memories already understood material, their learning of new content can be enhanced by connecting it with existing knowledge. Wetzels, Kester, and Van Merriënboer (2010) conclude that drawing may be particularly effective at activating prior knowledge as the visual form reduces the load on memory, supports perceptual processing and makes relationships more explicit.

Drawing can also support observation as learners need to pay increased attention to reproduce what they are studying. Science education, in particular, is replete with examples of students being asked to sketch what they see: helping them focus on details by slowing down the process of viewing and enhancing understanding of the value of observation (Quillin & Thomas, 2015). This may take the form of attempting a faithful depiction of one's observation such as a single cell seen through a microscope; it could also be more abstracted in a geological field sketch that "strips away" surface features such as soil and plants to reveal the structures present beneath. What is sketched could also be another visual representation of the same type such as when students are asked to copy a graph to ensure they are paying attention to its formal properties (Kohnle, Ainsworth & Passante, in press).

Drawing can also serve a mnemonic purpose. People can recall words and pictures better if they had drawn them, even very swiftly rather than simply imagine them or provide verbal labels. This is true even when people spend the same amount of time semantically elaborating by writing and for both longer and shorter time frames. Drawing aids retrieval as it helps people remember the source of the memory (Fernandes, Wammes, & Meade, 2018).

2.2 Constructive Purposes of Drawing

Arguably, the majority of recent research concerning drawing to learn has considered drawing as a constructive activity whereby learners create visual representations that go beyond the information they are given. Hence, drawing does not simply externalize what learners have in mind; it changes their mind.

The most frequently seen practice is when learners are asked to read textual material and then transform some of that text into a drawing based upon this new input and their prior knowledge. Meta-analyses (Cromley, Du, & Dane, 2019; Fiorella & Zhang, 2018) have concluded that this is a particularly effective way to learn with effect sizes (comparing drawing to only reading text) of between 0.22 and 0.86 depending on the measure. According to Van Meter and Firetto's (2013) model, learners first form a propositional network of the text's structural elements and relations. A drawing is then created based upon a perceptual image influenced by the drawer's prior knowledge, their goals and developing insight. Thus, drawing serves as a metacognitive strategy requiring deep engagement with the text, the emerging drawing and the learner's increasing understanding.

Constructing pictures from text is a specific instance of the general case that involves learners transforming (some of) the content from one format into a second visual form. Chemistry, in particular, is replete with examples of students learning how to construct new (to them) visual representations as a form of model-based reasoning (Cooper, Stieff, & DeSutter, 2017). For example, to explain the boiling point of water, students can be taught to draw the molecular structure of water and coordinate that with their understanding of energy transfer as sketched in a graph. Also drawing to support learning from simulations can be a constructive activity if students are asked to predict what they expect to see or to revise (repeatedly) the drawings they made as a consequence of interacting with a simulation (Cooper et al., 2017).

A final form of constructive drawing is when learners are asked to invent novel forms of visual representations. This capacity is synonymous with scientific discovery but is also common in more everyday practices. diSessa (2004) argues children have rich "meta-representational competence" allowing them to design representations that make inventive use of space. Then, through instruction, they develop their understanding of what makes scientific representation suitable for specific purposes (e.g. parsimony) and how perceptual attributes (e.g. color) are exploited to convey meaning. Inventing representations can facilitate the learning of new concepts and practices. Schwartz and Martin (2004) found requiring students to invent their own representations (even if incorrect) before learning about expert solutions can help deepen understanding by preparing students to appreciate their value. Kohnle, et al. (in press) successfully tasked students to invent 3d representations of a complex function that they had only previously encountered partially in 1d and 2d depictions before they interacted with a canonical form in a simulation.

2.3 Interactive Purposes of Drawing

The roles that interpreting a shared visual representation can play in support collaboration is well documented (e.g. Roschelle & Teasley, 1995): learners have a focus of joint attention, can refer to it non-verbally and this helps overcome fragmented conversation. Thus, it can serve as an anchor of which to develop common ground. When learners collaborate to construct a shared visual representation, these processes can be enhanced. In particular, collaborators become aware of the need to discuss and agree upon changes to it (Suthers, 2014). They must externalize their own knowledge whilst eliciting the viewpoints of peers. The evolving representation enables collaborators to elaborate new shared understandings that have been made memorable and salient by being made explicit.

The collaborative representation that emerges must be capable of coordinating different perspectives. For example, in Schwartz (1995) students solved problems that required them to produce a representation that described organisms in habitats. Dyads produced abstract visual representations (such as a matrix) more frequently than those working individually. He argued that the joint representation needed to express multiple viewpoints and supported peer dialogue as the students sought to make common ground.

Drawings can also be created by individuals as part of an interactive exchange. This is well documented in cases of professional practice where, for example, scientists construct complex visual representations as they attempt to convince peers and students about the validity of their arguments (Kozma & Russell, 2005). It can also be simple illustrations which young children add to stories to enhance a story they are telling together (Gelmini-Hornsby, Ainsworth, & O'Malley, 2011). By externalizing their understanding in a visual representation, not only is a peer's understanding improved but the process of coordinating a drawing with a verbal explanation enhances the creator's understanding as well (Fiorella & Kuhlmann, 2020).

2.4. Moving beyond specific roles

These examples show that drawing can be valuable in active, constructive and interactive ways. There is no reason to choose only one of these drawing activities. For example, Kohnle et al. (in press) used drawing to support visual learning from simulations for six distinct pedagogical purposes in only two classroom tutorial sessions. Each activity had specific learning objectives and these determined how drawing was used, how students drawing activities should be scaffolded and what a successful drawing might look like. This study used different drawings but on other occasions, a drawing may be revisited multiple times changing its role and being annotated, adapted or redrawn. It could move from being an individual attempt to activate prior knowledge, to more accurately reproduce something observed and then form the focus of collaborative work.

Moreover, although drawing serves these domain-independent roles, for many theorists and in many disciplines, drawing is not just a way to learn, it is fundamental to what should be learnt. New meanings are created and noticed when learners engage in representational practices, such as drawing, as they recruit a variety of cultural and cognitive resources to express this understanding externally. In science, for example, drawing can be crucial for modelling and reasoning. Therefore, even young children need to learn the representational work of a discipline. Accordingly, Tytler, Prain, Hubber, and Waldrip (2013) utilize guided inquiry whereby children construct, evaluate, and coordinate representations as they are led towards canonical scientific representational practices.

3. Practical Implications: Making drawing work for everyone

This paper is not meant as an uncritical paean to the wonders of drawing to learn; there are a number of factors that influence when drawing should be used and if so how learners should be supported. Drawing may not always be an appropriate learning strategy and we need to be alert to when students should put their pencils down. Ploetzner and Fillisch (2017) found disadvantages for participants who drew rather than reflected on an animation. They argued that drawing biased attention to structures rather than to important dynamic changes in the animation. It may be that things that are hard to draw (such as complex 3d forms or dynamic systems) should be learnt in other ways such as model building or gesturing. When learners are provided with visual representations that encapsulate the key aspects of a phenomenon and engage with it constructively, this may be equally effective as drawing and may be more time-efficient (Schmidgall, Eitel, & Scheiter, 2019).

If learners are drawing though, there are a number of further considerations to make when supporting students to learn (see Table 1). Firstly, what a learner draws matters. For example, when drawing from written text, students who accurately transform more of the text into their drawings benefit the most (Scheiter, Schleinschok, & Ainsworth, 2017). For other purposes of drawing, however, this may be inappropriate so different assessment criteria are needed. In Kohnle et al. (in press) each of the six different drawing activities was assessed using a different activity-specific rubric. When students were asked to copy a representation, the rubric focused on accuracy and completeness. However, when asked to invent a new form, drawings were assessed on meta-representational features and how they encapsulated key components of Quantum Mechanics.

Table 1. A drawing to learn checklist

Recommendation	**Explanation**
Consider whether drawing is a suitable approach	Drawing is particularly suited for tasks requiring visuospatial reasoning in 2D. Dynamic or 3D phenomena may benefit more from approaches such as gesturing or modelling.
Ask what function(s) drawing will serve	Decide on the specific role(s) for drawing, noting that a drawing can change its function over time and be revised to serve a new purpose.
Address the tools to be used	Practically, drawing with pen and paper is easy to implement in classrooms. If drawings are to be shared, edited by others, or revisited as artefacts, digital drawing offers advantages.
Make the drawing activity purposeful, valuable and non-threatening	Typically, learners are unfamiliar with drawing as a way to learn and can be anxious. Explain why it can be useful for this purpose and that they will not be judged on aesthetic qualities.
Make the intended audience explicit	Learners' views about who they are drawing for influences what and how they draw. Drawing as a cue for memory need not be meaningful to others but must be to share understanding.
Match assessment criteria to the function of the drawing	Depending on its function, a drawing can be evaluated for its accuracy, completeness, meta-representational awareness, or its innovative use of representational tools.
Scaffold drawing activities towards their intended purpose	Learners often need scaffolding to draw in the ways laid out by the assessment criteria. This can include training, models, partial templates or prompts.
If possible, provide feedback on the drawing	Learners can often benefit from feedback on their drawings and be encouraged to revise them meaningfully by peers, teachers or even automated systems. Drawings reveal misunderstandings that can become a focus for feedback and future learning.
Use drawings as artefacts in subsequent lessons	Making a drawing should not be an isolated activity. Consider how they fit in the wider curricula and re-use drawings as an anchor for engaging learners in further reasoning, discussion or future learning activities when appropriate.

Secondly, learners may need support to draw. Fiorella and Zhang's (2018) meta-analysis found that being trained to draw, being provided with partial illustrations to complete or expert drawings as a model all enhanced the effectiveness of drawing from text. Less research has explored how to support collaborative drawing although it is notable that many studies ask learners to create an individual drawing before merging them to create a shared one (Gijlers, Weinberger, van Dijk, Bollen, & van Joolingen, 2013). For many purposes of drawing, especially those that connect to disciplinary purposes, drawing should not become a "Hands-on - Minds off" activity, whereby students create sketches but reason with them with little understanding of the deeper causal model. Scaffolding should be provided that not only helps learners sketch accurately but then helps them reason by understanding both the model's explanatory power and its limitations (Cooper et al, 2017).

Thirdly, this raises the related question of whether everyone can draw to learn. Do you need to be able to draw well to learn by drawing or do some learners need to draw to compensate for poorer spatial ability? The answer is almost certainly a robust “it depends”, as it is likely to be specific to the purpose of drawing. Drawing as a mnemonic strategy, for example, is unlikely to require expert drawing skills. However, when sketching to observe a complex system like the cardiovascular system in anatomy education (Panagiotopoulos, Ainsworth, & Wigmore, 2016), then this may be more important. The relationship is likely bidirectional - spatial skills may be important in drawing performance and engaging in drawing may also improve spatial skills (Uttal, et al., 2013). Furthermore, spatial skills are not the only factor that explain drawing skills, fine and gross motor skills, perceptual feedback, cultural engagement and social and emotional factors all play an important role (Cohn, 2012). We spend many years in education teaching children to write, partly so they can read and write to learn. In most countries, it is notable we now spend little or no time teaching children to draw.

A final point to raise is whether drawing is changing as it is increasingly done digitally; does the tool learners draw with changes what and how they draw to learn. It is clear that digital drawing affords new opportunities for drawing: learners can be given immediate feedback on the accuracy of their sketches (Bryfczynski et al., 2015) or they can directly program computer models by drawing them (Heijnes, van Joolingen, & Leenaars, 2018). Merging collaborative drawings is made possible (Gijlers et al, 2013). However, there is as yet little consensus about whether drawing with a computer offers the same benefits as drawing by hand (Cromley et al., 2019). As technology evolves, how we interact with visuospatial representations is likely to change rapidly. Thus, we may need to be aware that drawing sometimes may be best conducted to take advantage of digital interactivity whereas at other times pen and paper may still be preferred.

This review is far from complete as drawing to learn is a very active arena for research. We have focused on drawing for learning without space to consider how drawing can be used by teachers to support student learning or drawing as a form of assessment. We have mostly considered drawing in the context of formal education and not how drawing can be best used outside of schooling such as in enhancing engagement and understanding in museums. However, what is clear even in such a short review is that although drawing may not always be effective, depending in part upon the support provided and the appropriateness of the match to the task demands, there are many good reasons to encourage people to draw to learn.

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An up-to-date review of this literature that taxonomizes drawing to learn in a different but complementary way