

Pedagogical Assumptions Behind The Use of Animations in Chemistry Lessons

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Introduction

Students' struggle with learning concepts in chemistry has long been known by chemistry educators (Adadan, Trundle & Irving, 2010; Derman & Eilks, 2016; Derman & Ebenezer, 2020). Some explanations as to why this may be the case include:

- a) Some concepts of chemistry are abstract concepts that learners do not encounter in their daily lives (Taber, 2008; Taber & Coll, 2002),
- b) In order to solve problems of chemistry, students need to work with many different concepts and data simultaneously (Johnstone, 2010; Plass, Moreno & Bruenken, 2010),
- c) Success in chemistry requires thinking and making conversions between macroscopic, particulate (also called microscopic, molecular or submicroscopic) and symbolic level representations (Adadan, 2013; Gabel, 1994; Johnstone, 2006; Johnstone, 2010; Derman & Ebenezer, 2020),



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- d) students studying chemistry tend to come to class with previous knowledge that go against scientifically accepted theories, which can hinder learning (Adadan, Trundle & Irving, 2010; Derman & Ebenezer, 2020; Taber, 2002).

Therefore, in order to provide better understanding of the chemistry concepts for students, reaching strategies must be developed and assessed accordingly. Indeed, studies have been conducted on computer aided instruction, born out of the desire felt by teachers use a chemistry module on polymer as they believed its three-dimensional, animated molecular models can explain polymerization and stretching processes more easily (Dori & Barnea, 1997). Furthermore, thanks to computer models, students are able to link their submicroscopic explanations of chemical systems with their macroscopic observations. Through visualisation of submicroscopic processes in chemistry it is possible for students to construct a meaningful understanding of chemical knowledge (White, 1988) such as “strings” (symbols and equations), “propositions” (relationships among concepts), and “logicomathematical understanding” (mathematical problem solving—e.g., working out solution concentration problems). Therefore, chemistry courses can be improved through the application of appropriate teaching strategies that incorporate computer technology (Ebenezer, 2001, p. 74). It is more common to make use of visualisations in secondary and post-secondary chemistry classrooms as here it is possible to provide students with greater access to the central concern of chemistry, namely structure and reactivity (Ebenezer, 2001).

Thanks to the modern-day improvements provided by new educational technologies, it becomes possible for educators to provide students with access to visual representations of atomic structures, molecular interactions, and large datasets, which can be used to aid chemistry learning. Nowadays, it is commonplace to see physical and chemical processes demonstrated through “molecular experiments” used by students and teachers at all levels of education using a wide range of visualizations. It is easy to see the advantage of such tools in order to advance the learning of chemistry: by using these tools that demonstrate visual representations of the phenomena of study that is invisible to the eye, students can develop a richer and deeper understanding of

chemistry concepts. In chemistry education and research community, there are currently two approaches to the design and study of visualizations as part of two major theoretical frameworks. Although these frameworks have a lot of common ground, they are different in kind. First, the aforementioned studies indicate that students have difficulty connecting submicroscopic explanations of chemical systems with their macroscopic observations in addition to finding it challenging to work in both these levels simultaneously and comfortably (Ebenezer, 2001, p. 74).

Many designers considered these difficulties as the central obstacle for learning chemistry, and have come up with new visualizations that present multiple levels at the same time (Adams et al., 2008). This framework puts forward that visualizations are effective because they lift the burden on the student to determine the relationship between different levels. Secondly, researchers of chemistry education state that what makes chemistry is difficult to learn is the challenge students face in coordinating the meaning of multiple representations (Kozma & Russell, 1997; Russell et al., 1997). Students find it difficult to understand the relationship between symbolic representations, such as empirical formulas and structural diagrams, as multiple representations can be used to refer to the same submicroscopic entities.

The application of these two frameworks has provided important insights into how chemistry visualisations can be designed; however, both of these frameworks falls short in their power to explain how and why visualizations can be used more commonly to encourage chemistry learning across the curriculum. For visualizations to take full effect in the classroom, what is needed is a more comprehensive explanation of their role.

Stieff and Ryan (2013) used three theoretical frameworks founded on cognitive learning theories to explore how molecular visualizations can make a connection with how students learn to the design of dynamic visualizations with the aim of stirring the discussion on the role of visualizations and the design of research programs that look into their efficacy. This innovative look on the theory-research-practice triad explores the ways that; (i) the potential of visualizations in supporting how domain concepts are retained in memory according to the tripartite model of working memory

(Baddeley & Hitch, 1974; Baddeley, 1992). In this model proposed by Baddeley and Hitch's, a multi-component model of working memory is emphasized that includes specific mental structures that process mental representations corresponded by each of the senses (see Figure 1).

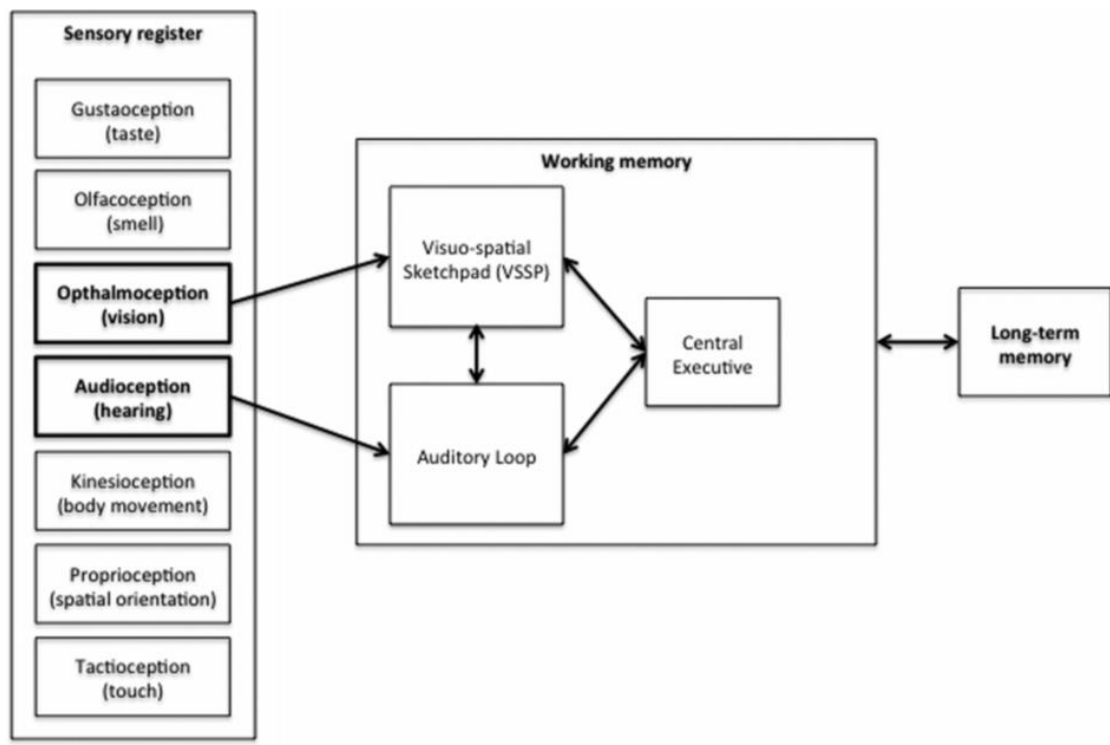


Figure 1. Conceptualization of Baddeley and Hitch's tripartite model of working memory (Stieff & Ryan, 2013, p. 25)

Chemistry education research paradigms are encouraged by the tripartite model of working memory which narrowly look into the ways in which students perceive, encode, and recall the various representations that chemistry visualizations use. In the tripartite model of working memory there are also multiple implications for the design of animations and simulations in the field. First of all, the model claims that through visualizations a primary challenge faced by students in learning chemistry can be overcome. Many of concepts and processes taught in chemistry do not have an equivalence in real life that have visual representations.

When students are expected to learn an idea as simple as an “atom,” this idea is solely represented in the auditory loop as a mere word and its corresponding definition. Hence, thanks to visual representations of atoms provided by animations or simulations, students are provided with a concrete representation that can be encoded in visual working memory. In the same vein, visual representations of quantitative relationships are equally likely to improve retention and recall through visualisation. The model welcomes questions that seek an answer to which representations are most effective, which of them are (in) effectively paired, or how students encode molecular representations.

ii. The potential of visualizations embedded in lessons using the contemporary “knowledge-in-pieces” model of conceptual change to promote understanding of concepts (Smith, diSessa & Roschelle, 1993; diSessa, 1988). Despite the narrow predictions of information processing models about retention and recall, they don’t offer much about the quality of conceptual understanding or complex problem solving. On the contrary, the focus of conceptual change models consists of the knowledge structures developed by the learners from their experiences be it in formal learning contexts or everyday life (Posner, Strike, Hewson, & Gertzog, 1982). From this perspective, conceptual change models are more agnostic about the structure of the mind and refrain from strong statements about the location of information in memory or the processes that are a part of retention and recall. What conceptual change models have in common is the focus on the processes through which students take in information to make sense of the world coherently (Carey, 1986). Hence, in conceptual change models, analyses provided not only supplement, but also extend those of information processing models in order to account for a student’s knowledge before and after instruction.

Today, the validity of multiple competing models of conceptual change is actively debated by cognitive and learning scientists whose arguments differ to a great extent in terms of their underlying assumptions about the nature of knowledge and the processes involved in conceptual change. According to Stieff and Ryan’s (2013) opinion, the three models take centre stage in this debate are: models that focus on

mental model revision (Gentner et al., 1997; Gentner & Gentner, 1983), models that focus on ontological recategorization (Chi, 2005; 2008) and the “knowledge-in-pieces” model (Smith, diSessa & Roschelle, 1994; diSessa, 1988). Despite the contrasting predictions about the efficacy of various interventions for promoting conceptual change offered by these models, all three agree that conceptual change is more complex than simple belief revision. In other words, while each model posits that conceptual change necessarily involves replacing one’s false ideas with scientifically correct models, they each also assert that belief revision alone is not adequate to make sense of the failure of students to comprehend scientific concepts after years of education, or the emergence of difficulties that arise while learning.

According to Stieff and Ryan (2013), each of these models can offer useful explanations for the efficacy of visualizations in addition to clear-cut design principles; however, they argue that the “knowledge-in-pieces” model (KiP model) offers the most utility in terms of chemistry education researchers who study the development of new animations and simulations at multiple levels of instruction. Unlike information processing models, the KiP model gives no inherent value to the visualization itself; rather, the model posits that visualizations are beneficial depending on how they are used to aid students in putting their current understanding within the framework of scientifically accepted ideas. Therefore, if visualizations are designed with the sole purpose of “showing” molecular interactions, it is unlikely that they will lead to any conceptual change in the long run. However, when students are asked to systematically compare their observations from a visualization with their prior understanding, then conceptual change is achieved in learning contexts. Furthermore, it must be recognised that in such environments conceptual change is not likely to occur after a single exposure to a visualization.

Due to the nature of conceptual change as a gradual process, students require repetitive exposure opportunities to explore a visualization any useful conceptual change can be achieved. If sufficient time is not given for the understanding to be revised in due time, students’ accurate understanding can be displayed only briefly after demonstration (DiSessa, 1993; Smith, DiSessa & Roschelle, 1993). According to the knowledge-in-

pieces model, students' prior knowledge is accepted to be a productive resource rather than an obstacle to be eliminated or ignored (DiSessa, 1993; DiSessa & Sherin, 1998; Smith, DiSessa & Roschelle, 1993). Hence, it is imperative that new research agendas with visualizations characterize the quality of students' conceptual understanding not only before and after instruction, but during instruction as well. **(iii.)** the potential of visualizations for supporting social interactions in chemistry through the use of one model of social cognitive learning (Bandura, 1976; Bandura, 1986). Visualizations can promote student interaction with one another. Vygotsky's Theory of Social Development (Vygotsky, 1978; 1986), Lave's Situated Learning Theory (Lave & Wenger, 2003), and Bandura's Social Cognitive Learning Theory (Bandura, 1976; Bandura, 1986) are among the most common theories employed in the cognitive and learning sciences community today.

Each theory focuses on different aspects of the social environment and offers convergent perspectives on human learning and development. Collectively, in social learning theories, learning is studied as a process occurring between teachers and students as well as among individuals. Thus, in each theory, the focus is on the active role of social agents and learning is framed as a process rather than an outcome. According to Stieff and Ryan (2013), Bandura's (1976) Social Cognitive Learning Theory offers a more precise model of to explain the role social agents in human learning and offers a clearer bridge to conceptual change and information processing models of learning. Building on previous cognitivist perspectives, social Cognitive Learning Theory offers a model of learning that examines how learning takes place within a social context. Thus, social cognitive learning theory does not downplay the analysis of mental representations: the theory attempts to explain the active role played by social factors to help an individual learner to build mental representations during the process of learning. For that purpose, social cognitive learning theory differs from other social earning theories in how it directly addresses the role of motivation and human agency in learning.

Consequently, the theory provides a basis for research on visualizations and offers design principles for curricular structure and pedagogical methods. According to social

cognitive learning theory, when research agendas focus on how students learn with visualizations together and how they learn from teachers who model their thinking using visualizations. It is emphasized in social cognitive learning theory that social interactions in the classroom and broader societal and cultural factors play an important role. These studies involve examining changes in individual learning which occur as a result of social factors or the quality of social processes in classrooms where visualizations are employed. Thus, the way visualisations encourage meaningful social interactions and the way teachers can make use of them to model their thinking effectively as well as the way visualisations can be used to promote self-efficacy and agency can be studied through these research paradigms

As a result of the application of social cognitive learning theory to chemistry visualizations, two clear design principles emerge. First, the theory suggests that visualizations should be used in ways that encourage interaction among students and teachers, which can enable teachers and peers to use the visualization as a resource to model their thinking and help students learn through observation of others (as opposed to working with a visualization in isolation). As such, the visualization considered a resource that the teachers can use to improve their thinking. Second, a high degree of control should be offered to students in visualizations. In this way, students can perceive the control they have of their learning, which as a result will promote self-efficacy and agency. It is possible that students regard visualizations as environments that offer little control in which they have no impact on the progress of their own learning. Thus, it is advised that molecular visualizations should be designed that focus on the ‘heart of chemistry’, which is the relationship between chemical structures and reactivity at the molecular level. Through the exploration of this relationship, students are able to ‘see’ representations of unseen phenomena.

Some of the issues that have a negative impact on students’ abilities to learn chemistry concepts include chemical theories and chemical education theories. Nevertheless, some of these other issues are actually related to psychology or cognitive learning theories as well as theories on the optimal design and usage of multimedia programs (Schönborn, Höst & Lundin Palmerius, 2010). Therefore, these and other chemical,

chemical education, psychology/cognitive, and multimedia theories should be considered (Suits & Sanger, 2013, p.2).

Molecular-Level Animations

Wikipedia (“animation”, 2022) defines animation as “the rapid display of a sequence of static images and/or objects to create an illusion of movement.” The visualizations that display a scripted sequence of events for passive viewing constitute animations (Oakes & Rengarajan, 2002). Using these visualizations, students are usually able to set an initial set of conditions and restrict the displayed information, thereby highlighting only those features most relevant to the represented concept (Stieff & Ryan, 2013, p.18).

Animations have the potential to promote a deep understanding of chemistry (Rieber, 2005), by allowing retention of not only facts and concepts, but also an appreciation of the processes and practices of science-making. Dynamic representations can change the texture as well as the outcome of classroom interactions by making it possible for students to see what they cannot normally see, manipulating variables and observing the results of their activity, and collaborating with others to negotiate meaning and reach conclusions. However, there are involves a number of critical design decisions involved in developing or choosing these resources—as well as integrating them into the chemistry curriculum—(Schwartz, Milne, Homer & Plass, 2013, p.70).

Animations of system behavior may be used to aid learners to interpret simultaneous changes in variables by showing an underlying computational model (van der Meij & de Jong, 2006), and embedded signalling or guidance can scaffold the learner’s successful use of a multimedia resource by directing attention to relevant points (de Jong, 2005; Plass, Homer & Hayward, 2009). Using animations can prove to be an effective tool in directing students’ focus on a specific aspect of a phenomenon at the submicroscopic level, such as the process of dissolution (Tasker, Bucat, Sleet, & Chia, 1996). Animations are representations that involve change over time (Tversky,

Morrison, & Betrancourt, 2002), created through the generation of a series of images or frames (Betrancourt & Tversky, 2000).

In the context of science education, an animation can be used to paint a picture of a process or phenomenon in real time, slow motion, or visualized from different points of view; while it may also show abstract information such as a change in pressure or the relationship between two variables (Hegarty, 2004). Using scaffolding, such as visual cues, to draw the viewer's attention to specific features, and incorporating interactivity, allowing the user to stop, start, or repeat portions of the presentation can constitute examples of animations. (Schwartz, Milne, Homer & Plass, 2013, p. 47).

Computer animations that are used to demonstrate chemical processes at the molecular level have been subjects of study for almost two decades (Williamson & Abraham, 1995; Sanger & Greenbowe, 2000; Tasker & Dalton, 2006), and it has been shown that they have a potential to improve students' conceptual particulate-level understanding of chemistry (Sanger, 2009).

Computer animations are generally divided into two categories (Rieber, 2005): Presentation animations (which are used to present new information or to elaborate on information presented earlier) or conceptualization animations. In most visualizations (Williamson, 2011) that are designed for chemistry instruction, depictions are used of atoms, molecules, and/or ions and their interactions (the particulate representation), either as static images or as dynamic visuals with both animations (Sanger, 2009) and simulations (Tasker, 2005). The benefit of particulate visualizations (static or dynamic) in the chemistry education is the possibility to provide students with a view of the behaviours and interactions between the chemical particles, which are often abstract and challenging for students to generate by themselves. Therefore, thanks to these visuals, the abstract interaction of atoms, molecules, and ions become more concrete (Sanger, 2009), and the cognitive load on the student is reduced (Johnstone, 2006, Tasker, 2005, Tasker & Dalton, 2006; Kelly & Jones, 2007). Furthermore, these visuals, combined with effective instruction, can help students make connections between the macroscopic, particulate, and symbolic representations (Kelly & Jones, 2007; Kelly, Phelps & Sanger, 2004; Sanger, 2009; Williamson, 2011), as a result of

which they can grasp more scientific conceptions (Tasker, 2005; Sanger, 2009; Williamson, 2011).

Depiction of dynamic visuals can be especially helpful for chemistry students as for most chemistry concepts students need to understand how the chemical systems change over time (e.g., reactants vs. products, before-and-after gas law experiments, equilibrium reactions, etc.). Rieber (2005) indicated that while dynamic computer animations were generally useful to students studying science, they can actually be distracting if the lesson does not involve visualization, motion, or trajectory. Animations can be considered student-centered forms of instruction (Sanger, 2009; Williamson, 2011), which can support student learning as they develop a conceptual understanding of chemistry topics. While molecular-level animations have been shown to provide a deeper learning for students in chemistry, these animations can also misfire, causing new student alternative conceptions that were not present before viewing these animations (Kelly & Jones, 2007; Sanger, 2009; Tasker & Dalton, 2006) and can prove distracting to students if the concepts that they focus on are not visual in nature (Sanger & Greenbowe, 2000).

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