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The paradox of learning with external representations

Erica de Vries

Introduction

Our shared history starts with my *AIO-schap* as one of Ton de Jong's first PhD students. I defended my doctoral dissertation "Structuring information for design problem solving" almost 30 years ago in Eindhoven (de Vries, 1994). Within these last thirty years, computer technology has had an enormous impact in research, and especially in educational technology. During my defense, I presented slides with an overhead projector and Ton, in his laudation, commented on my *stellingen* using a slide projector. We may wonder which of these mechanical tools was the more innovative at the time. Since then, our research paths crossed multiple times and I am pleased with this opportunity to examine the journey.

Inquire, explore, discover, browse, chat, create, ...

In the beginning of the nineties, the rise of graphical interfaces resulted in an increase of research and development in educational technology. An important consequence of the use of computer technology and graphical interfaces is a change in metaphor. Teaching is no longer thought of as the straightforward, caricatural, filling of an empty container and learning is no longer envisaged as the linear absorption of instructional material. Instead, we both came to view computer-based learning environments as tools for at least three types of learning activities (de Vries, 2005). Learners browse and explore hypertext as the metaphorical "crisscrossing of landscapes" as I studied in my PhD. Learners model and discover physical phenomena through simulations as Ton de Jong so extensively and thoroughly studied throughout his career. Finally, learners collaborate and discuss using multiple textual and graphical tools. In short, researchers, developers and practitioners aim to transform learners from passive listeners or readers into more active explorers, enquirers, and participants in the quest for knowledge. Four broad issues are at the core of this scientific endeavor. The first issue concerns the nature of *learning activities*. Do they arise spontaneously or are they governed by intentional strategies? The second issue relates to how to tweak *properties of*

learning environments in order to elicit effective learning behavior. Is random access sufficient or is some form of guidance required? Third, the vision on *learning outcomes* evolved and resulted in changes in dependent variables. Last but not least, the introduction of graphical interfaces changed the way in which we represent knowledge externally. Learning environments nowadays include a wealth of different ways of expressing instructional conceptual content, such as pictures, schemas, equations, drawings, graphics, animations, videos and diagrams. This brings us to the topic that we both wrote quite a lot about: *external representations* and their role in teaching and learning.

External representations in learning environments

In most learning environments, students neither manipulate nor are directly confronted to the real-world objects and phenomena that they need to learn about. I compared the situation to the allegory of Plato's cave (de Vries, 2011). With today's technologies, the core question remains: What stuff does one need to carry above one's head to cast appropriate shadows on the wall so that prisoners will learn about objects, living creatures, and phenomena outside the cave? Indeed, numerous studies aim to find out exactly what kind of external representations to create in order to provide affordances for learning (de Jong, 2014). In the design of learning environments, we heavily rely on cognitive psychology and cognitive science to comply with constraints of human information processing and human memory. Moreover, as a scientific endeavor, our research relies on the gold standard for assessing learning *independently* of a context, a culture, a target population, a language, or a content domain. At best, the context, the instructional content, or still individual differences such as prior knowledge, are considered moderating factors (de Jong et al., 2023). Furthermore, regarding external representations, researchers often stick to a simplified understanding of external representation involving only two entities: some material inscription (letters, digits, geometrical shapes, marks, squiggles, ...) and some intended conceptual content. In such a dyadic view, the first stands for the second *universally*, i.e., for everybody in all situations and at all times (de Vries et al., 2009; de Vries & Masclet, 2013). Any association between the same material inscription and an alternative *different* conceptual content is simply considered incorrect. For example, although a rectangle in a diagram of a mechanical artifact may suggest very different things, a plank, a beam, a sheet, a cylinder, a brick, or still a box, only one of these corresponds to the intended one for a particular artifact. In reference to the semiotic triangle (Ogden & Richards, 1927), I like to question this and appeal to a triadic perspective instead. In this view, a material inscription stands for a conceptual content in the mind of some third, i.e., in thought. The introduction of the *third entity*, some human mind or artificial agent, implies that, in principle, different individuals, in particular teachers and learners, may not

make identical associations between inscriptions and contents. For example, a rectangle in a diagram of a bicycle pump may bring to someone’s mind a shoebox or a brick instead of the intended cylindrical chamber, which subsequently may lead to misconceptions. Thus, the triadic perspective may help to identify obstacles when relying on external representations for teaching and learning.

The question arises whether we should make sure that the learners and users of learning environments understand all elements of the graphical interface, such as newly designed squiggles, frills and ruffles, in the same way. The most heard reply to this question is that external representations are ruled by convention and that information can straightforwardly be read off provided one knows it. In this vein, knowledge of conventions, and more generally graphical languages, is seen as relatively unproblematic. Ton de Jong wrote “A learner’s awareness of specific conventions governing the construction of learning material assists with processing and thus reduces extraneous cognitive load” (de Jong, 2010). Thus, learners are thought to simply “read off” information from a diagram and straightforwardly “observe” the consequences of their actions in a simulation in order to learn about the topic. However, this may not be as self-evident as it seems. How does this play out in simulation environments with multiple mixed graphical conventions? Let us take one of Ton de Jong’s simulations under scrutiny. The Balance simulation (de Jong, 2006) shown in Figure 1 combines mathematical notations, realistic somewhat childish drawings, such as the green grass and the two people on the seesaw, and domain-specific graphics, such as a diagram of forces. As a rhetorical question, what would a learner with no prior knowledge of physics and seesaws understand from the bluish beachball or the solid tree trunk at the center?

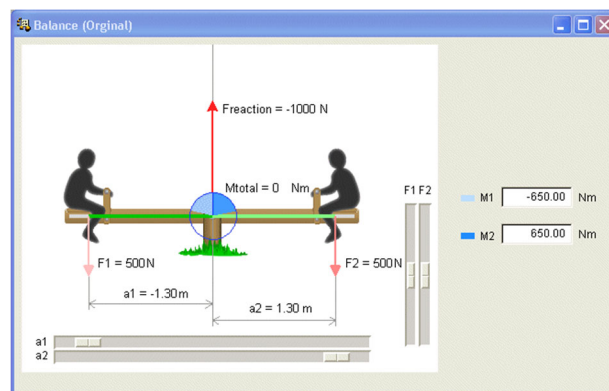


Figure 1. The Balance simulation in SimQuest (de Jong, 2006)

In a triadic perspective, prior knowledge of seesaws precisely seems to be required to “see” that the circle in the middle probably must be taken as a diagram partially overlaying a realistic drawing of the seesaw. Moreover, prior knowledge also strongly suggests that the hidden part in fact cannot be the top part of a tree trunk but must be the turning point of the seesaw (often

represented by a triangle in a diagram). This leads us to the counterintuitive observation that knowledge of both conceptual content and graphical conventions is required to correctly *understand* the external representation in the first place.

A closer look at language and convention

Research on homogeneous student populations with comparable cultural background and prior knowledge has many advantages from a methodological point of view. However, it has also been questioned because it systematically undervalues the role of culture, language, and convention in human cognition. As some researchers pointed out, most people on earth are *not* from Western, educated, industrialized, rich and democratic (WEIRD) societies (Henrich et al., 2010). Moreover, research into the brain and into language shows in fact that diversity might well be more interesting than universality (Levinson, 2012). I propose an excursion into linguistics and philosophy of language to investigate the phenomenon of textual and graphical inscriptions with multiple potential conceptual contents and their repercussions for learning.

Inscriptions with at least two competing interpretations are called ambiguous drawings (pictorial) and polysemic words (textual). For example, the well-known ambiguous drawing from Jastrow can be seen as a duck or as a rabbit (see Figure 2). Polysemic words, such as the word *sound* in English, have multiple different conceptual contents, e.g., sound may mean “healthy”, “noise”, or still “rigorous”. Moreover, non-cognate interlingual homographs, the scientific term for false friends (French & Ohnesorge, 1995), have wildly different meanings in *different* languages despite an identical orthographic form. For example, the letter string *pain* means “hurt” in English and “bread” in French (see Figure 2), *hier* means “here” in Dutch and “yesterday” in French, or still *rot* means “decay” in English and in Dutch, “red” in German, and “burp” in French. In regular homogeneous situations, these inscriptions do not constitute an obstacle because monolinguals exclusively access concepts in one language. However, multilinguals may experience an interdependency between the attribution of meaning and the choice of a language. Multiple interpretations of a given inscription may even flip back and forth in the bilingual mind in the same manner as the duck and the rabbit. In fact, bilinguals of all ages have better executive control than monolinguals due to their training in deactivating one of their languages in favour of any others at all times (Bialystok et al., 2012). As an illustration, consider the following character string taken from Bruijn et al. (2001): “door spot leek die brave dove arts rover met pet”. Depending on their languages, different individuals read different things: a list of unrelated words or a reasonable sentence¹. Thus, conceptual content and choice of a language are interrelated. Instead of applying a language to grasp

¹ Plausibly in Dutch: by mockery that honest deaf doctor resembled robber with cap

meaning, the recognition of meaning *precedes* and leads to *hypothesizing* the language of an inscription, a case of abduction (Eco, 1986).



Figure 2. A drawing, a sign, and a diagram with multiple competing interpretations

The inscriptions in Figure 2 illustrate two related phenomena. First, different interpretations flip back and forth in the mind, but cannot be “seen” simultaneously. For an English-French bilingual in a Canadian supermarket, the sign oscillates between bread and hurt, indicating either a bakery or an aisle with pain relief drugs, but not both at the same time. Similarly, the diagram may convey any number of different things as a function of prior knowledge of graphical conventions: a flow, a point in time, a process, a product, a concept, or a relation, but not all these simultaneously. Thus, our brain cannot perceive multiple things at once and perceiving one content requires active blocking of all others. Second, our brain cannot perceive something of which it has no prior knowledge (Wittgenstein, 1968). For someone with prior knowledge of merely ducks, the drawing is useless in learning anything about rabbits. In conclusion, when looking at external representations, a learner can only “see” things that he or she already knows.

Conclusion and question

The digression into phenomena of language shows the impossibility, in principle, to learn from external representations, since prior knowledge of the represented objects and phenomena is necessary to recognize them in a picture, a drawing or a diagram in the first place (de Vries, 2021). Of course, we expect that confusions resolve dialectically in classroom interactions, but the paradox stands firm. After my thesis defence, Ton confided to me his disappointment with my answer to his question as a jury member. Now I take my turn to ask him about the paradox and the trickiness of designing external representations for learning. Knowing Ton, I have no doubt that he will come up with a suitable riposte.

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