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Perceiving versus inferring movements to understand dynamic events: The influence of content complexity

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ABSTRACT

Objectives: What type of visual presentation is best in helping learners to understand the functioning of a dynamic system and under what conditions? This study investigated the effect of content complexity on perceived cognitive load and performance resulting from studying depicted movements of team play either in an explicit manner (animation) or via arrow symbols (static diagram).
Design: A 2 (treatment: diagram vs. animation) × 2 (content complexity: low vs. high) between subjects design was adopted in the experiment.
Methods: Forty-eight university students were randomly assigned to the four study conditions and required to perform a reconstruction test and rate their perceived cognitive load following the study phase.
Results: Data analyses revealed that for low-complexity content, participants exposed to the animation treatment learned more efficiently – based on the combination of learning and cognitive load scores – than those exposed to the diagram treatment. On the other hand, for high-complexity content, participants exposed to the diagram treatment learned more efficiently than those exposed to the animation treatment.
Conclusion: The findings stress the importance of considering the task complexity factor when designing and presenting instructional materials to learners.

In team sports, the term "tactical learning" refers to the ability of an individual player to effectively construct a coherent mental representation that exactly depicts spatio-temporal elements of play communicated by coaches (Khacharem, Zoudji, Kalyuga, & Ripoll, 2013). Arrows-containing diagrams constitute the most common instructional method used by coaches to enhance tactical learning. This visual intermediary, generally presented on a blackboard, utilizes arrow symbols to portray dynamic actions of play that are tricky to describe. With current technological advances in education, it has often been advised to use computer animations to support the comprehension of dynamic contents that involve continuous changes. These novel visual representation tools are expected to have the potential to amplify tactical learning as they provide more explicit visualizations of movements taking place in the field, precluding the need to infer them from simple arrows. However, the instructional effectiveness of such novel forms of visualizations as animations compared to traditional ones (i.e., arrows-containing diagrams) remains indistinct. It is possible that additional factors may influence this effectiveness.

The study reported in this paper was designed to explore the potential role of one of such factors – the level of content complexity. More specifically, it tried to identify how varied level of content complexity could affect learner performance and experienced cognitive load when learning from different types of instructional media.

The traditional media: the arrows-based diagrams

Besides oral commentaries, diagrams are traditionally regarded as excellent tools for teaching complex patterns of team play because they use geometric, abstract elements to convey essential information of play (e.g., arrows, lines and crosses). Arrows are an important ingredient of such diagrams (Horn, 1998; Wildbur &

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Burke, 1998), and they are often employed to direct the learners' visual attention to the essential elements of the system, thus preventing needless search processes (De Koning, Tabbers, Rikers, & Paas, 2009; Kriz & Hegarty, 2007; Lin & Atkinson, 2011; Lowe & Boucheix, 2011). An additional, even more crucial role of arrows is to convey change-related information. Indeed, when using asymmetric lines (e.g., with a triangle affixed to one end of a line) such iconographic symbols have the potential to express temporal, one-way direction concepts like motion and time even in static diagrams (Heiser & Tversky, 2006; Monmonier, 1990).

Tversky, Heiser, Mackenzie, Lozano, and Morrison (2008) acknowledged that compared to other geometric symbols, arrows are the paramount tools for indicating motion of elements in static diagrams. Arrow symbols can stimulate the internal animation process and act as guidance "through" the motion that has to be processed (Imhof, Scheiter, Edelmann, & Gerjets, 2013). In the sporting context, arrows are omnipresent in diagrams illustrating tactical movements that are often difficult to describe verbally (e.g., trajectory, crossing, and overlapping). For instance, solid arrows are usually used to describe the movement of the ball (pass) whereas dotted arrows are used to describe the movement of the players (run). Table 1 shows some movement-indicating arrows used to depict dynamic elements of play in soccer.

The potential benefit of using arrows in static diagrams was empirically investigated by Heiser and Tversky (2006). Two groups of undergraduate students were instructed to describe what was presented in diagrams of mechanical devices with or without arrows. Results indicated that participants who had studied diagrams without arrows provided structural descriptions of the systems (i.e., the spatial arrangement/organization of the parts). On the other hand, students who had studied diagrams with arrows provided functional descriptions (i.e., the sequence of operations performed by the systems and the outcomes of each operation or action). Jian, Wu, and Su (2014) also examined the influence of numbered arrows on construction of mechanical kinematic representations. Undergraduate participants viewed a two-stage diagram depicting a flushing cistern with or without numbered arrows and then answered questions about its function. The arrow group demonstrated greater overall accuracy and made fewer errors on the measure of continuous relations than did the non-arrow group, suggesting that arrows in diagrams could be effective in conveying information concerning the motion of objects.

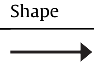
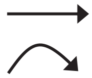
The contemporary media: the computer-generated animations

Certainly, the existence of arrow symbols in a diagram encourages people to mentally simulate the related motions in order to construct a coherent mental representation of the depicted system. However, such cognitive activities may require significant resources, increasing cognitive load and jeopardizing learning effectiveness. Replacing the static indicators of movements (i.e., arrows) by an animation that unequivocally conveys dynamic aspects in the operation of a system may eliminate these problems. By their nature, animations are able to present events and actions that change over time and space, providing an external support for learners in building their dynamic inner representations. Hence, learners do not have to mentally infer the spatial changes of a system on their own as the dynamical changes are directly shown by the animation (Hegarty & Kriz, 2008). Additionally, in static diagrams arrow symbols have to be interpreted and integrated with the pictorial information. These processes may impose significant levels of cognitive load and lead to misinterpretations and consequently, to a deficient mental model (Lewalter, 1997).

However, according to the proponents of static visualizations, the "inferring" and "interpreting" cognitive activities should be encouraged because they involve constructive, relevant processing that increases germane cognitive resources and consequently leads to deeper learning. Indeed, since dynamic visualizations like digital videos and animations are usually associated with entertainment they may seem to be easy to understand, which in turn may result in an illusion of comprehension (Betrancourt, 2005), as well as a less germane cognitive resources involved (*underwhelming*; Lowe, 2003). Furthermore, an animation conveys ephemeral and non-stable information, which means that "one views one frame at a time, and once the animation or video has advanced beyond a given frame, it is no longer available to the viewer" (Hegarty, 2004, p. 346). Hence, the attempts to maintain elements of information active in working memory while concurrently receiving new elements may result in high levels of cognitive load and therefore be detrimental to learning (*transient information effect*: Leahy & Sweller, 2011; Sweller, Ayres, & Kalyuga, 2011).

In order to assess the impact of using arrows in static pictures – as a medium to depict temporal changes – in comparison to using explicit animation, Münzer, Seufert, and Brünken (2009) compared three experimental conditions with participants learning the cellular molecule structure and the associated biological processes: animations, static pictures (without arrows) and enriched static pictures (with arrows). Although animations enhanced the acquisition of process knowledge in comparison to static pictures without arrows, the results have not demonstrated a significant difference between animations and enriched static pictures, suggesting that arrows in diagrams could effectively convey temporal information about the biological processes.

Table 1
Types of arrow symbols used in depicting soccer activity.

Types of arrows	Shape	Meaning
Simple solid arrow		Simple pass
Curved arrow		Chip pass
Simple dotted arrow		Movement without ball (run)
Waved arrow		Movement with ball (dribble)

Present study

The aim of the study was to investigate the relative instructional effectiveness of using an arrows-containing diagram (which is called the diagram treatment) in comparison to using a computer-based animation (which is called the animation treatment). It particularly examines the influence of level of content complexity in learning from such representations. To explore relationships between these two factors (i.e., visual representations and complexity level), soccer activity was selected in this study given its dynamic nature and the complex interaction occurring between numerous elements of play.

The term "complexity", for our purposes here, refers to the internal complexity of the situation, that is, the intrinsic cognitive load associated with it (e.g., Pollock, Chandler, & Sweller, 2002). Based on cognitive load theory, complexity can be manipulated by varying two main factors: the amount and the connectivity of the presented information (Sweller, Van Merrienboer, & Paas, 1998). For instance, in tactical scenes of play, altering the number of players, as well as the number of interactions between the players – their relative movements – is a useful means of manipulating the cognitive complexity of a situation (Raab, 2002, 2003). So, the more players are involved in the situation and more interactions exist