# A REVIEW OF HOW TO OPTIMIZE LEARNING FROM EXTERNAL REPRESENTATIONS

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**Abstract**

This article reviews research on learning with external representations and provides a theoretical background on how to optimize learning from external representations. General factors, such as the type of material to be learned, learner characteristics and the testing method, are some of the variables that can determine if graphic medium can increase a subject's comprehension and if such comprehension can be accurately measured. These factors are discussed and represented by a model to suggest how external representations can be effectively used in a learning environment. Two key conclusions are drawn from the observation made in these studies. Firstly, the proper design of a particular external representation and supporting text can promote relevant activities that ultimately contribute to fuller understanding of the content. Secondly, external representations must be developed to address the size complexity and variety of the content that must be analysed in order to extract knowledge for scientific discovery.

**Keywords:** External representations, dynamic and static visuals, text.

## 1. INTRODUCTION

According to Jolly (2003), external representations are visual representations of data, information or knowledge using items such as maps, charts, diagrams, models, static graphics, computer animation, hypertext and multimedia that are incorporated into instruction. Jolly further states that external representations demonstrate a spatial relation and may refer to the concrete objects and real-world relations. This review has adopted the view that external representations are data structures for expressing knowledge. As such, visual representations can be used as aids to facilitate innovation and learning by providing an efficient structure for communicating knowledge. The terms dynamic and static visuals are regarded as forms of external representations and will be used in some parts of this article for the purpose of this review.

For some years, there has been considerable interest in developing external representations that can enhance the learning tasks of students in various courses. The general assumption behind the use of external representations is that they have an essential instructional effectiveness in presenting unfamiliar or difficult subject matter like the weather conditions (Lowe 1999), to provide an explanation on how a particular process works (Mayer and Anderson's bicycle pump), or clarity on abstract matters like economics (Weiss, Knowlton & Morrison 2002), and that they are beneficial for learning

(Schnotz 2002). However, the reported effectiveness of dynamic and static visuals in a learning environment varies (ChanLin 1998; Lai 1998; Large 1996; Lin, Chen & Dwyer 2006; Mayer & Moreno 2002; Tversky, Morrison & Betrancourt 2002; Van Schaik & Ling 2004). It appears as if several factors can contribute to a positive or negative effect for a particular external representation. For example, some authors suggests that by looking at the functions that these visual methods can fulfill, many of these varying results could be accounted for (Ainsworth & Van Labeke 2004). Other authors suggest that the use of dynamic and static visuals should take into consideration the cognitive capabilities (Chandler 1995; Bodemer, Ploetzner, Feuerlein & Spada 2004; Rieber 2000; Lewalter 2003), prior knowledge (ChanLin 1998), and the spatial abilities of the users (Guan 2002). One way to investigate these issues is to examine the value in learning of both dynamic and static visuals as representation strategies.

After reviewing some of the theories and empirical studies dealing with the effectiveness of external representation in learning, it was necessary to investigate the above issues and other factors that impact on the effectiveness of dynamic and static visuals - particularly when considering that much of the information in most courses contain content in the form of texts, static or dynamic visuals. Since external representations can be employed for many different tasks in learning, this article reviews studies that used a variety of external representations to facilitate learning tasks. The article also discusses the differences among the theoretical models of learning in terms of their roles in learning. The aim of this article is to provide a review on the value of static and dynamic visuals on learning outcomes and to explore the conditions under which external representations facilitate learning. It is hoped that a better understanding on the application of these representations will assist instructional designers and web and graphic designers to consider what type of external representation technique is the most appropriate for developing a particular learning task.

## 2. THE RESEARCH PROBLEM AND QUESTIONS

In the literature, contradictory results are reported regarding the use of external representations in a learning environment (Lowe 1999; Weiss, Knowlton & Morrison 2002). Some researchers suggest that dynamic visualisations are not always more effective for learning than static visuals and that they may impose additional cognitive demands that are not available to static visuals (Bodemer et al. 2004; Höffler & Loetner 2007). For example, when viewing a frame-by-frame animation or video, one views one frame at a time and once the animation or video has advanced beyond a given frame, the previous frame is no longer available to the viewer (Hegarty 2004). Therefore, this may present a challenge for the working memory, especially in cases when information presented earlier in the animation should be integrated with information that is presented later.

In contrast, when viewing a static visual, viewers can re-examine different parts of the display as much as they wish (Ainsworth & Van Labeke 2004). Other authors suggest that external representations provide clarity mostly when learners are learning complex new ideas such as abstract matters like economics, an explanation of how a particular process works, or extracting information from visuals of weather maps (Mayer 1989; Lowe 1999; Weiss, Knowlton & Morrison 2002; Moreno & Valdez 2005). Considering the previous studies on external representations, the questions that this review intended to answer were: What value do different external representations add to learning for different learning objectives; what are the effects of external representations on learning outcomes? Although dynamic or static visuals may extend beyond the content described in the text that it accompanies, this study only focused on the functions that a particular external representation offer in supplementing text to foster meaningful learning.

## 3. OBJECTIVES

The objectives of this review are:

- To examine the value of dynamic and static visuals, and
- To explore the conditions under which dynamic and static visuals can be used to achieve meaningful learning.

## 4. SCOPE OF RESEARCH

This article's analysis and research focused on the concept of using external representations in the learning environment. This review was limited to a small body of research regarding the use of external representations; dynamic and static visuals within visual communication design. The researcher chose only to examine and then reflect on the issues surrounding the use of these external representations from a theoretical point of view and the emerging developments in recent years of using external representations on graphic design related education. It is believed that a discussion on the effectiveness and influence of these visualisations would be a necessary initial step toward developing a database for later research in visual communication design.

## 5. METHOD

The research included a review of books, published and unpublished, as well as articles discussing the use of a variety of external representations to facilitate learning tasks to explain the variations in their use. Some of the electronic resources that were searched include EBSCOHost, ERIC, ProQuest, and ScienceDirect. The aim was to extract specific conditions in which a particular external representation (dynamic or static) is appropriate or inappropriate and also to determine whether the implementation of several external representations conflict or cancel the effects of another.

Apart from the articles found in databases, cross-references from identified articles helped to locate additional studies. The researcher also selectively reviewed some unpublished dissertations and conference proceedings. The studies were then reviewed and analysed to determine the value of external representations in learning and how the acceptance of this trend has influenced learning it. The reliability and overall value of a content analysis depends on the clear presentation of this topic within the learning environment.

The total number of studies reviewed on learning with dynamic and static visuals was 45. Some of these were about temperature changes in weather maps (Lowe, 2003), the function of the human heart (Kleiman & Dwyer 1999), understanding and retention of languages (Lin et al. 2006), population dynamics (Ainsworth & Van Labeke 2004), how mechanical systems work (Bodemer et al. 2004), and statistical concepts (Bodemer et al. 2004).

## 6. RESEARCH ON EXTERNAL REPRESENTATIONS

### 6.1 The theoretical background for using external representations to support effective learning

One of the reasons for using external representations such as dynamic and static visuals is that they are believed to be beneficial for learning. However, theoretical and educational research has shown that learning with visualisation is not always beneficial. For instance, Rieber's (2000) behavioural and cognitive learning theories suggest that there are times when visuals can aid learning and times when they might interfere with learning. The behavioural theory suggests that this interference might occur where students are unable to shift their attention from a given graphic to text. The cognitive theory suggests that if appropriately designed, visuals can be helpful for learning processes such as encoding and retrieval of information. According to Mayer (2003), students are better able to integrate verbal and visual representations when they receive both verbal and visual materials, rather than when they receive only verbal material. When only verbal material is presented, the learner may construct an impoverished visual mental model that is insufficient to integrate with the verbal mental model. Suwa and Tversky (2002) list a number of benefits for which external representations serve a facilitatory role. One such benefit is on memory. According to Suwa and Tversky, external representations provide extra symbols for those elements that should be stored in one's memory. As a result, the memory is freed from working on mental calculations of the elements, instead of keeping elements and working on them.

In their research with subjects who struggle with reading comprehension, Hibbing and Erickson (2003) found that if students are not able to construct internal mental images because they are using all their mental energy to interpret words, external visual images can be used to develop understanding. They found that using illustrations, pictures in books, as well as moving pictures, provide students with the ability to build their own internal mental pictures.

While the above background does not include a comprehensive review of the several areas of learning, it can be seen that both external representations (whether dynamic or static) are somehow related concerning their characteristics as presentation strategies in learning. It seems as if there are some areas where dynamic visuals can be used and other areas where pictures and other static visuals are more appropriate. For example, Weiss et al. (2002) stated that users should not use dynamic visuals such as animation to depict a fairly simple procedure if the procedure can be communicated in a simpler medium, because in those cases animation can be distracting. It is interesting how various types of external representations with text have varying functions and help create a “mental model” rather than simply receiving or absorbing knowledge. This means that care has to be taken to characterize dynamic and static visuals independently from learning because the type of visualisation used affects that structure of internal mental models acquired during learning.

## 6.2 Theoretical models and their assumptions

Researchers and theorists have developed several theoretical models in order to explain and understand the process of learning with external representations. This section aims to highlight major differences among the models of learning in terms of their roles, goals and suggestions.

The role of conceptual models can be found in the work of Mayer (1989) in which he explains why models can be used. Mayer explains that conceptual models can be used to provide an assimilative context for students to construct meaningful mental models, particularly if the aim of instruction is to help student to understand explanations. Furthermore, Mayer (1999, 2001 & 2005) presented two models which suggest different channels for processing and storing information according to the concept of dual coding theory: (a) a cognitive model from a multimedia perspective (CTML), and (b) the integrated text and picture model (ITPC). According to these models, the learner is regarded as a constructor of his/her own knowledge, actively seeking to build connections between visual and verbal representations through the selecting, organising and integrating processes.

However, Schnotz and Bannert (2003) argue that Mayer's model is questionable as the sign structures and principles used for texts and pictures are different.

They then suggested a model of text and pictorial understanding, to explain why the type of visualisation used in a picture affects the structure of the mental model created during picture comprehension. Their model is based on the characteristics of description (symbols describing an image) and depiction (physical models which possess particular structural characteristics that allow a viewer to extract relevant information). The model suggests that static visuals can function to remove any possible uncertainties in the verbal presentation of a particular subject matter by providing additional information. It should, however, be noted that this advantage can only be realised if the text and visuals complement each other.

Theoretical models can also be used to build a network of hypotheses which can guide the development of existing and future theoretical models on the learning environment. The model can be complemented by other multimedia elements (like animation, pictures and video) and therefore build a comprehensive basis for testing the effects of instructional representations. For example, Hart (2003) introduced a theoretical learning model which suggests that learning by doing provides the interaction that is present in the interaction learning theory. According to this model, the emphasis is on the interaction between the learner, the animation and the teacher resulting in a cyclical communication process. The interaction between the learner and the animation provide immediate information to each other. In that case, the learner is then able to gain knowledge through practice. The function of the presenter or teacher is to help control the learning situation and to act as a learning model for the student.

In summary, the models that are discussed in the preceding paragraphs appear to be linked to one another in terms of their roles in a learning environment. It appears as if both Mayer and Schnotz developed their models with two common elements: the first element explains why the type of visualisation used affects the structure of the mental model created during picture comprehension. This element is based on the dual coding theory (DCT) provided by Sadoski, Paivio and Goetz (1991). This theory suggests two ways through which knowledge is developed: firstly, by means of a verbal system (otherwise known as logogens) which deals with language, and secondly, as an imagery system (imagens) which is related to pictures and sounds. The other element is that each channel of information has a limited capacity for processing information, based on Baddeley's (2002) and Sweller's, Van Merrienboer's and Paas (1998) working memory theory, and Chandler's (1995) cognitive load theory. Lastly, all these models assume that humans, in actively attending to important information and organizing the selected information into internal representations, are in active learning.

## 6.3 Factors that may impact on the effectiveness of external representations

This section highlights the factors, identified by the author, which influence learning when used in association with various external representations. The results of the literature review indicate that various types of external representations, combined with text, have various functions and can help create a mental model (Mayer 2003), rather than simply receiving or absorbing knowledge. The literature review also suggests that the learner characteristics, such as prior knowledge (ChanLin 1998; Guan 2002), the content of the instructional material (Weiss et al. 2002; Lin, Chen & Dwyer 2006), and the testing methods are but some of the factors that can determine if an external representation can enhance a subject's comprehension. Based on these findings, this review identified some of the factors that may influence the facilitating effect of external representations in a learning environment. The factors are discussed under five main categories, namely: subject's characteristics, type of material to be learned, method of instruction, cognitive factors, and design factors. This, however, does not imply that these factors can be generalised without careful inspection. These factors have been acknowledged and should be regarded as guidelines that can be used to the value of external representations in a learning environment. More factors could be identified according to the specific needs and requirements of a particular learning content.

1. Learner characteristics: individual characteristics such as spatial ability (Höffler & Leutner 2007) and prior knowledge (ChanLin 1998; Schnotz 2002; Kozma 2003; Falvo 2008) can influence whether external representations are better suited to a particular domain. According to Seufert and Brünken (2006) and Falvo (2008), prior knowledge prepares students to learn and retain structured information and process concepts conveyed by dynamic visuals such as animations. With static visuals, the learner is required to construct a dynamic internal mental model using the static information.

2. The type of material to be learned: What is the content and difficulty of the material? How much are they learning? Is it long, short, brief or extensive? Some researchers consider external representations to be more powerful in teaching if the subject matter is complex (Leung & Pilgrim 1995; Weiss et al. 2002; Lin, Chen & Dwyer 2006), while others see the value of external representations in cases where students are not familiar with the concepts displayed (Mckenzie & Danielson 2003). If, according to Large (1996), students already have a mental image of the material, then its value appears to be diminished.

3. The functions that various external representations offer in supporting comprehension: Why are they reading or viewing a picture - to learn, for pleasure, or for business? Rieber's study on this area (2000) provides considerable insights. He suggests that external representations should be designed in such a way that the functions for which they were designed will be attained. For example, they should form part of integration into the instructional design from the beginning stages right up to the end.

4. Cognitive factors: Another important factor mentioned by several of the papers in this review (Chandler 1995, 2004; ChanLin 2000; Rieber 2000; Lewalter 2003) is that learning with external representations has been associated with cognitive tasks, particularly if the external representation is new to learners. For example, Ainsworth (2006) states that when learners are first presented with a new representation, they must understand how it encodes information and its relation to the content it represents. Furthermore, learners may need to select or construct one representation which is suitable to them, which can provide advantages but also new cognitive tasks.

5. Design factors: Although there are multiple ways of presenting complex concepts and data to students, some authors urge caution with regard to designing dynamic and static visuals for use in learning. For example, Large (1996) advises that designers must consider the realism and stylisation measures in an animation, the duration of the movie, and whether it will be broken into sequences, and if so, whether the user will have access in the execution of each sequence. In addition, Weiss et al. (2002) suggest that designers should ask whether animation has the ability to add value to student learning, before advancing to the design process.

## 7. THE PROPOSED MODEL

A model was constructed to summarise all the factors discussed (see figure 1 below). The model consists of five factors that are crucial for the facilitating effect of external representations: (1) subject characteristics; (2) cognitive factors; (3) design factors; (4) type of material to be learned; and (5) the functions that various external representations offer in supporting comprehension. All of these factors interact to produce a whole or comprehensive facilitative effect. This model of the facilitating effect of external representations is presented in figure 1 below.

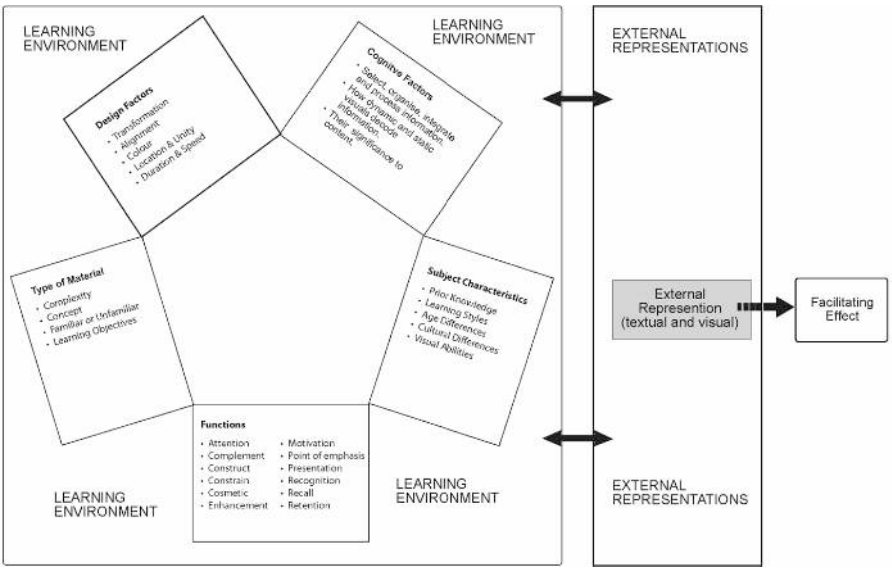


Figure 1. A graphic representation of factors that may influence the facilitating effect of external representations in a learning environment. The five squares represent the interdependence of each of these factors. These factors interact with external representations that may or may not produce a facilitating effect.

## 8. REFLECTION AND CONCLUSION

What value do different external representations add to learning for different learning objectives?

In this article, a number of studies that explored the instructional value of external representations in a learning environment were presented. Two key conclusions can be drawn from the observations made in these studies. The proper design of a particular external representation and supporting text can promote relevant activities that ultimately contribute to fuller understanding of the content. This is in line with Mayer's (2003) and Hibbing and Rankin-Erickson's (2003) findings that pictures are important aids for building internal mental models. This also suggests that external representations should be designed in such a way that they correlate with the material so as to avoid overloading the mind's capacity for processing information. The focus must be on the concepts to be learned, rather than applying too many cosmetic activities.

What are the effects of external representations on learning outcomes?

This article contributes to the growing research base on learning with external representations by raising a number of issues that instructional designers may use in learning.

The first issue relates to the type of material to be learned. Papers in this review have examined learning with dynamic and static visuals about temperature changes in weather maps (Lowe, 2003), biological processes such as the function and the internal processes in the human heart (Kleiman & Dwyer 1999), understanding and retention of languages (Lin, et al. 2006), population dynamics (Ainsworth & Van Labeke 2004), how mechanical systems work (Bodemer et al. 2004), and statistics concepts (Bodemer et al. 2004). Both dynamic and static visualisations have much to offer as learning tools. However, it should be noted that badly designed external representations (be it static or dynamic) can be destructive and interfere with learning.

In summary, the results of this review suggest that instructors should consider the characteristics that affect comprehensibility of external representations. Instructional designers and educators using external representations in their programmes should:

1. Consider the relationship between the external representation and how it relates to the content of the learning material.
2. Analyse the students' learning styles and how this affects the potential facilitating effect of an external representation.
3. Consider the effect of graphic cueing tools such as arrows and shading techniques as an aid to improve comprehension of learning material.
4. Consider the visual abilities of the students. External representations can play a major role in addressing some of the factors that characterize a disadvantaged context. However, the ability to which students can benefit from these representations is to some extent related to their level of visual abilities.

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