Reducing the Cognitive Load: Facilitating Learning in Organic Chemistry by Incorporating Mechanism Videos

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Abstract

Chemistry as a science about the structure, properties and transformation of substances heavily relies on adequate forms of visualization. Due to the high complexity and abstractness of representations, organic chemistry in particular is regarded as a challenging subfield of chemistry. When working on complex reaction mechanisms, students must spend high amounts of their cognitive capacities on the processing of symbolic language, which means that fewer resources are available for actual learning [1].

In this respect, cognitive psychology calls for consideration of the architecture of human working memory. According to the Cognitive Theory of Multimedia Learning, working memory is divided into two autonomously working subsystems [2]. Both subsystems process information according to their codality (symbolic vs. linguistic). Traditional teaching formats of organic chemistry most often exhaust capacities of the symbolic subsystem while valuable resources of the linguistic system remain unused. Meaningful learning could hence be fostered by evenly distributing information between both subsystems. Furthermore, the symbolic subsystems of the working memory can be relieved by outsourcing cognitively demanding processes (e.g. complex rearrangements within a mechanism) into the learning environment [3].

Unpublished preliminary work has shown that it is possible to apply the design features derived from the Cognitive Theory of Multimedia Learning to videos with learning contents from higher organic chemistry (electrophilic aromatic substitution). Within the framework of a doctoral project, it shall now be investigated to what extent learning with dynamic representations differs from learning with static representations. In addition to measuring cognitive load, transfer and retention in a control group design, it will also be examined whether spatial ability and prior knowledge influence learning success.

This paper presents the Cognitive Theory of Multimedia Learning as a theoretical framework for video-based learning with complex mechanisms in organic chemistry. Based on this consideration, hypotheses for higher transfer and retention performance when learning with videos are derived.

Keywords: *chemistry education, organic chemistry, animation, multimedia, reaction mechanism*

1. Introduction

Chemistry as a science about the structure, properties and transformation of substances heavily relies on adequate forms of visualization. Since particles on the sub-microscopic level cannot be observed chemists developed various tools to visualize and share information in their field of work. Most of these visualizations, with the structural formula as the most prominent one, hold a lot of implicit information which are not readily accessible for novices.

Studies in higher education show that organic chemistry in particular is perceived as a challenging sub-discipline of chemistry by many students. This is due to the frequent change in levels of representation as well as the expansive and information-rich symbolic language of the subject [4]. Complex reaction mechanisms in particular pose a challenge for students, as many cognitive resources must be devoted to interpreting the symbolic language. As a result, students increasingly focus on surface features such as functional groups and do not recognize the underlying structural properties of the molecules [5]. However, it is these properties that provide crucial information to the course of chemical reactions, so students often make erroneous mechanistic predictions. The high workload of the cognitive system also results in fewer resources available for constructing and modifying mental models, which impairs learning and performance [1]. Based on a cognitive psychology approach, the following will explain how learning organic chemistry reaction mechanisms can be facilitated by incorporating dynamic multimedia in learning environments.

2. Theoretical Framework

Since the term (dynamic) multimedia has a variety of definitions, a clarification of terms shall be given first. Media can be distinguished by the senses through which they are perceived. This property of media is called modality. Though information can be received through all five senses, this article focusses on the sense of hearing and the sense of sight. Media that convey information through the sense of hearing are referred to as *auditory*. Media that convey information via the sense of sight are referred to as *visual*. Media can also be assigned different forms of codality according to the symbol system which is encoding the presented information [6]. Media that convey information encoded in the form of images are called *pictorial* while media that encode information in the form of speech are called *verbal*. These distinctions result in four possible modality-codality combinations (Fig. 1). Due to the low relevance of the auditory/pictorial combination, only the three combinations voice, text, and picture will be considered in the following.

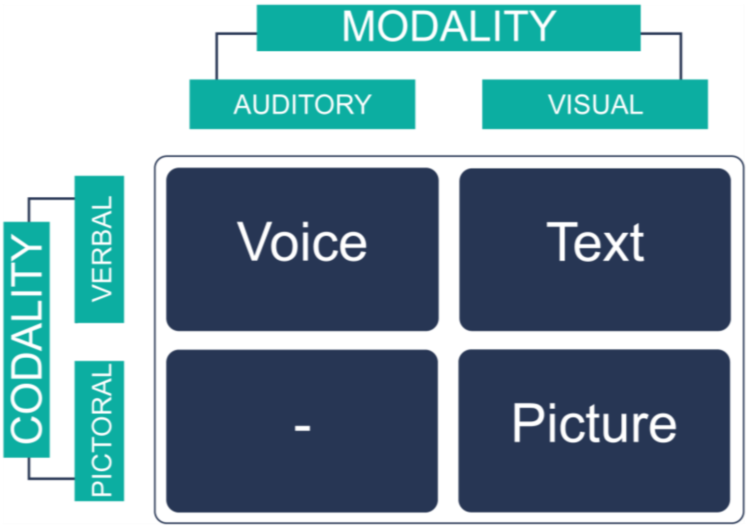

Fig. 1. *Possible Combination for modality and codality*

In consideration of that multimedia can be defined as media that combine the characteristics of multimodality and multicodality [7]. Thus, they must (1) convey information using the sense of sight as well as the sense of hearing and (2) use language and images as symbol systems.
Dynamic multimedia are of particular interest for chemical education research because they can adequately depict dynamics at the sub-microscopic level, whereas their static equivalents can only indicate such dynamics by reaction arrows and dashed lines.
This clarification of terms allows to scientifically frame oftentimes indistinct terms such as “learning videos” as dynamic multimedia and thus make them accessible for research. Mayers Cognitive Theory of Multimedia Learning [2] provides a valid model for learning in multimedia learning environments. (Fig. 2) According to the theory the human cognitive system is divided into long-term memory and working memory, with the working memory being the core of the model. It is considered to be strongly limited in its capacity and thus represents the limiting factor in the learning process. An overload of the working memory results in the so-called cognitive overload, which results in an immediate termination of the learning process. Consequently, all design principles to be derived from the Cognitive Theory of Multimedia Learning aim at reducing the cognitive load in the working memory.
Furthermore, the theory assumes a division of the working memory into two autonomously working subsystems. Both channels process information according to their modality and codality, however they can be simplistically assumed as a language channel and a picture channel [2]. Due to the use of extensive symbolic language, conventional teaching formats in organic chemistry overuse the picture channel of the working memory, leaving valuable resources of the language channel unused.

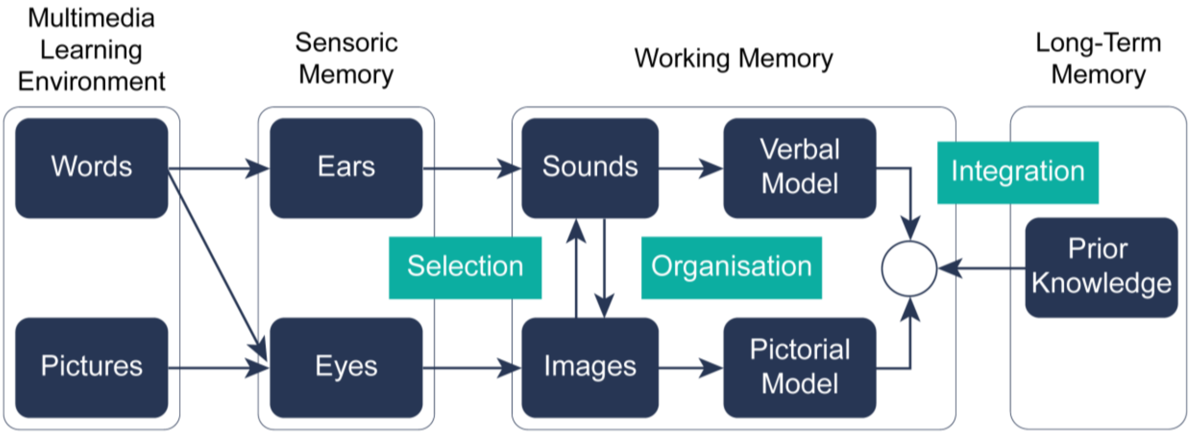

Fig. 2. *Cognitive Theory of Multimedia Learning*

When learning with dynamic multimedia however, both channels can be engaged equally. The cognitive resources saved are then available to students for performing other demanding cognitive tasks. Furthermore, the even load allows the exchange of information between both channels and results in the construction of a verbal model and a pictorial model which are equally valid. With this a more elaborate and more comprehensive mental model can be created in the step of integration (Fig. 2).
In Addition to that, dynamic multimedia can cognitively relieve students through supplantation [3]. In conventional teaching formats reaction mechanisms are often displayed as static representations and hence unable to depict dynamics on a sub-microscopic level appropriately. Consequently, students must emulate the dynamics through cognitive modelling which requires a large number of cognitive resources, especially for complex reaction mechanisms [8]. However, with dynamic multimedia's ability to depict dynamics, sophisticated cognitive modelling (e.g., intramolecular rearrangements) can be outsourced to the learning environment. The capacities saved this way can be used for the construction of elaborate mental models.

3. Preliminary Work

In the context of an examination thesis at the Friedrich Schiller University of Jena, it was investigated to which extend the approach outlined above could be used for the creation of dynamic multimedia in chemistry education. Based on the Cognitive Theory of Multimedia Learning [2], six design principles were used for the criteria-led construction of dynamic multimedia. Electrophilic aromatic substitution was chosen as the learning content because the underlying mechanism requires high visualization and, due to the mesomeric-stabilized complexes, benefits especially from the dynamic multimedia format [9].
In order to evaluate the material, student teachers in the 8th and 10th semesters were surveyed (N = 28). A questionnaire was used, which asked with an ordinally scaled, four-step Lickert scale whether the respondents considered the individual design principles as implemented or not implemented. This questionnaire provided a positive sentiment and was able to show that (1) student teachers evaluated the learning video series as positive without knowledge of the model and its design criteria and that (2) student teachers considered the elaborated design criteria as implemented with knowledge of the model and its design criteria. Therefore, it can be concluded that the Cognitive Theory of Multimedia Learning [2] is an elegibile cognitive psychological approach for creating dynamic multimedia in chemistry education.

4. Outlook

In further research, it will now be investigated whether and to what extent the expected differences in learning with dynamic multimedia and static monomedia can be measured. The learning content will also be a mechanistically demanding learning content of higher organic chemistry, which, just like electrophilic aromatic substitution, requires high visualization [9]. In this context, the questionnaire of the preliminary work shall serve as a starting point for the creation of measuring instruments for further work.
In a control group design, it will be investigated whether retention and transfer performance of both groups differ. In addition, the level of prior knowledge will be surveyed to investigate whether students with little or high prior knowledge benefit from the dynamic multimedia treatment. Another research in-

terest is the influence of the spatial ability on the constructs mentioned above. It is unclear whether, under the outlined conditions, learners with low spatial imagination (ability-as-compensator hypothesis) or learners with high spatial imagination (ability-as-enhancer hypothesis) benefit more from learning with dynamic multimedia [10]. To investigate this question, the spatial imagination will also be measured.

5. References

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