International Conference NEW PERSPECTIVES in SCIENCE EDUCATION

On Assessing Effectivity and Design of Multimedia Environments

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Abstract

Cognitive Theory of Multimedia Learning yields evidence that in demanding fields of science learning with dynamic multimedia can be more beneficial than learning with static monomedia [1]. With the ability to depict movements on the atomic level dynamic multimedia has emerged as a promising tool to teach chemistry [2]. To investigate this projection for higher organic chemistry a study was conducted with the aim to identify potential differences between learning with videos and learning with textbooks on the other hand. Named study surveyed transfer ability via post-test as well as the approaches to the tasks set in short group interviews. Furthermore, the students were asked about their attitudes towards the respective learning materials with a questionnaire. The aldol reaction was deliberately chosen as learning content for it requires a good understanding of the reaction from nucleophile and electrophile and is relatively demanding in regard to spatial ability. All 14 participants were randomly assigned to either the multimedia or the monomedia treatment which did not differ in content. They all were undergraduate students and had no prior knowledge of the aldol reaction.

Based on classical test theory this paper firstly presents the results of an item analysis providing discrimination-index, difficulty-index and Cronbach's alpha for the questionnaire. In addition to that the paper presents the results of the post-test to investigate whether there were differences in transfer ability between control and experimental group. In conclusion the results of both analyses shall be taken in consideration for the design of the main study on this topic.

1. Introduction

Numerous studies provide evidence that many students during their studies perceive organic chemistry as a difficult subject [3]. The reason for that might be the way in which information is exchanged: The almost exclusively used skeletal formula reduces the information of chemical compounds to a bare minimum which puts high demands to the prior knowledge of the recipients [4]. Especially for novices, this makes it difficult to follow reaction mechanisms and extract all relevant information from them. WATTS et al. could show that although students are usually able to make a suggestion for a reaction, they are rarely able to give elaborate reasons for the reaction steps in terms of providing suitable structure-property relationships [5].

In response to this finding, dynamic multimedia, often labelled as "learning videos", moved to the centre of attention of chemistry education research. Being able to facilitate the processing of information, it has emerged as a promising tool to counteract the difficulties mentioned above [2]. This paper briefly outlines possibilities of dynamic multimedia design. It then presents the results of a pilot study in which the design was compared to a static monomedial learning environment.

2. Design

Previous studies in this field used reaction mechanisms such as nucleophilic substitution for their investigations, which can be described as comparatively short with 1 to 2 reaction steps [6]. For this paper, the aldol reaction was chosen as the learning content, which has a medium scope with 4 reaction steps. This reaction can still be carried out with small molecules and thus be appropriately transferred into the multimedia format. Another reason was that the aldol reaction is part of the curriculum of teacher training at the University of Jena and that the study could be integrated into the teaching program. Another methodological benefit lies in the second reaction step: The nucleophilic attack can be seen as relatively demanding, which, according to GRAULICH, offers the advantage that students are less likely to falsify the performance in the power test by guessing [7]. The mechanism of the aldol reaction can be seen in Figure 1.

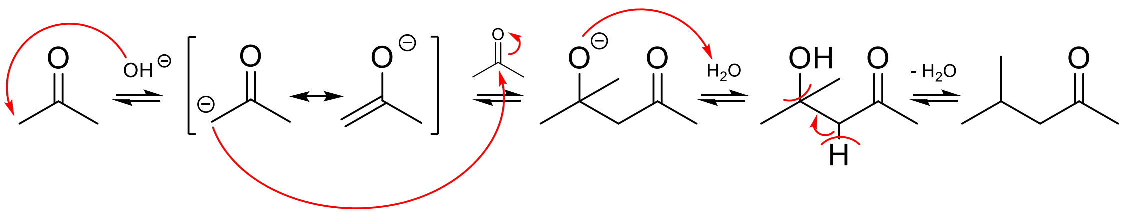


Figure 1: Mechanism of the aldol reaction

MAYER's Cognitive Theory of Multimedia Learning (CTML) was mainly used for the design of the instructional material [8]. Applications to topics, such as the occurrence of a thunderstorm, could show that the theory originating from psychology can be transferred to scientific contexts [8]. For the application to reaction mechanisms in organic chemistry, however, some design criteria of the CTML require modification:

- The **Multimedia Principle** states that the amount of information to be conveyed in the instructional material should be evenly distributed between image and speech [1]. For information on the structure of molecules, however, it is not necessarily advantageous to convey it in the form of speech. Such information should therefore always be given in picture form, while information about the resulting properties as well as information about the reaction process can then form the counterweight in the form of speech.

- The **Signalling Principle** states that highlighting should be used to indicate information that needs to be related to each other for understanding [9]. In reaction mechanisms this is traditionally realised by curved arrows, which indicate the movement of electron pairs, but can be further enhanced by colour-coding or encircling. Since electrophile and nucleophile play a prominent role in the mechanism of the aldol reaction, both species were marked by the colours blue and red. Further on, the parts of the molecules that were important for the following reaction step were highlighted by encircling.

Other criteria however fit well into the typical form of presentation and can be readily applied to a reaction mechanism:

- The **Segmenting Principle** states that the entire learning content should be divided into small, self-contained segments [10]. This design criterion can be applied well to reaction mechanisms, since the mechanism is already divided into small segments by the individual reaction steps. For the instructional material the aldol reaction was divided into 3 segments: the deprotonation at the alpha-carbon, the aldol addition and the aldol condensation.

For the further design of the learning environment, the Four-Components Instructional Design Model (4C/ID) by MERRIENBOER and KESTER was used [11]. This theory further subdivides the individual segments, focusing on practice tasks.

3. Method

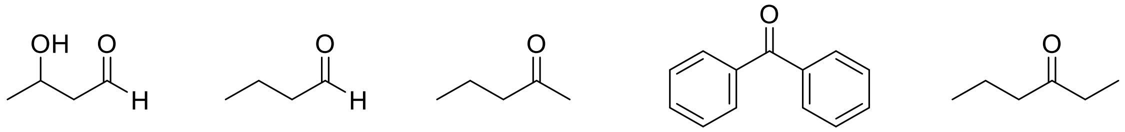
A control group design study was conducted at the university of Jena with all participants (N = 14) being voluntarily recruited. All of them were undergraduate chemistry teacher students with no prior knowledge of the aldol reaction. The participants were randomly assigned to either the control group (static monomedia) or the experimental group (dynamic multimedia) and received the respective treatment over a course of 60 minutes. The treatment for the control group did not differ in content and did use the exact same images. Accordingly, all the design criteria mentioned above were applied to the static monomedial treatment as far as it was possible.
At the end of the treatment, the participants were given a two-part questionnaire. In the first part, the participants were asked about the implementation of the design criteria mentioned above. For each design criterion, two items were formulated, which the participants could agree to on a 4-point Likert scale. The items with item codes are given in Table 1.

Design Principle	Item	Code
Multimedia Principle *(Meaningful distribution of image and speech)*	I always knew to which image the Text referred to.	**[Mu1]**
	I found it difficult to follow the video/text.	**[Mu2]**
Signalling Principle *(Connecting related information)*	The usage of colour has contributed to understanding.	**[Si1]**
	I could easily understand the movements of electron pairs.	**[Si2]**
Segmenting Principle *(Dividing the learning environ-ment into meaningful small units)*	I found it easy to navigate within the videos/material.	**[Se1]**
	I took the opportunity to take breaks.	**[Se2]**

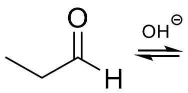
Table 1: Items derived from the design principles

To measure possible differences in the transfer ability of both groups, a post-test with 4 tasks on the aldol reaction was conducted. In the first task, participants were asked to rank 5 carbonyl compounds in order of increasing CH acidity. The other tasks were mechanistic problems on the aldol reaction, which gradually increased in difficulty. All tasks can be seen in Table 2.

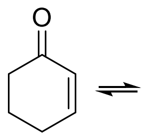
[TA1] Rank the following carbonyls starting with the highest CH-acidity.



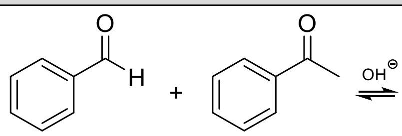
[TA2] Develop a reaction mechanism for the base-catalysed aldol reaction of the compound below. Using arrows, indicate the movement of electron pairs within the mechanism.



[TA3] State the carbonyl compound from which the compound below can be prepared via an aldol reaction.



[TA4] Benzaldehyde and acetophenone are reacted with a catalytic amount of KOH. Develop reactions mechanisms for all possible reaction products. Then make a reasoned statement about which product of the reaction is formed preferentially.



Benzaldehyd Acetophenon

Table 2: Tasks for the post-test

4. Results and Discussion

Table 3 shows the results of the item analysis for the first part of the questionnaire. Only the discrimination-index of the items Mu1, Mu2 and Si1 are greater than +0.30, which means that the other items do not correlate sufficiently with the overall result of the test. Similarly, the item difficulty is too high for most of the items. Cronbach's alpha is at the lower limit for the Multimedia Principle and the Segmenting Principle. This means that the ability to distinguish between features of the participants is limited.

Design Principle	**Item**	r_{it}	***P***	**α**	***M (SD)***	
					Control Group	Experimental Group
Multimedia Principle	**[Mu1]**	*0,59*	*80.95*	*0.61*	*3.48 (0.69)*	*3.38 (0.36)*
	[Mu2]	*0.43*	*80.16*		*3.29 (0.45)*	*3.52 (0.60)*
Signalling Principle	**[Si1]**	*0.30*	*81.75*	*0.55*	*3.48 (0.42)*	*3.43 (0.53)*
	[Si2]	*0.24*	*76.98*		*2.90 (0.98)*	*3.71 (0.41)*
Segmenting Principle	**[Se1]**	*0.11*	*85.71*	*0.65*	*3.64 (0.48)*	*3.50 (0.50)*
	[Se2]	*-0.27*	*43.65*		*2.52 (0.54)*	*2.10 (0.53)*

Table 3: Results of the item analysis

For every design criterium a two-sample t-test was performed to see if the control group and the experimental group differed in how much they considered the design criteria to be implemented in their treatment. Means and standard deviation for both control group and experimental group can be seen in table 4. For the multimedia principle no significant difference could be found for the control group treatment (M = 3.38, SD = 0.51) and the experimental group treatment (M = 3.45, SD = 0.42); $t(12)$ = -0.288, p = 0.778. Similarly, for the Signalling Principle, no difference could be found between the control group treatment (M = 3.19, SD = 0.66) and the experimental group treatment (M = 3.57, SD = 0.41); $t(12)$ = -1.306, p = 0.216. And also for the Segmenting Principle no significant difference could be measured between control group treatment (M = 3.08, SD = 0.14) and the experimental group treatment (M = 2.80, SD = 0.51); $t(12)$ = 1.216, p = 0.247. So that the conclusion can be drawn that the outlined design criteria für dynamic multimedia to some extend can also be applied to monomedia.

Design Principle		***M (SD)***	
		Control Group (N = 7)	Experimental Group (N = 7)
Multimedia Principle	**[Mu1]**	*3.48 (0.69)*	*3.38 (0.36)*
	[Mu2]	*3.29 (0.45)*	*3.52 (0.60)*
Signalling Principle	**[Si1]**	*3.48 (0.42)*	*3.43 (0.53)*
	[Si2]	*2.90 (0.98)*	*3.71 (0.41)*
Segmenting Principle	**[Se1]**	*3.64 (0.48)*	*3.50 (0.50)*
	[Se2]	*2.52 (0.54)*	*2.10 (0.53)*

Table 4: Means and standard deviations for control and experimental group

Table 5 shows the results of the post-test for control and experimental group. For each of the 4 tasks there are differences in the means of both groups. These are slightly in favour of the control group for the items TA1 and TA2, and slightly more clearly in favour of the experimental group for the items TA3 and TA4. The experimental group scored higher in total, although this can also be attributed to the fact that more points could be scored in TA4. However apart from TA3 none of these differences were statistically significant, as can be seen in Table 5. Despite a discernible trend, it cannot be safely concluded that the control group performed better on simple tasks that can be solved by recalling information and the experimental group performed better on difficult tasks that require transfer. Although this would be well in line with the hypothesis mentioned above, according to which the experimental group, through better information processing, could achieve better transfer performance [8]. However, according to this hypothesis, they should also have scored better in the easier tasks TA1 and TA2. Another interesting finding is that the standard deviations of the experimental group for each item are higher than those of the control group. One explanation for this could be that the effectiveness of the dynamic multimedia learning environment is dependent on person characteristics, which were heterogeneously distributed within the experimental group.

Post-test item	M (SD)		t(12)	p
	Control Group	Experimental Group		
[TA1]	*3.86 (1.46)*	*3.71 (1.60)*	0.174	*0.432*
[TA2]	*2.14 (0.69)*	*2,00 (1.63)*	*0.213*	*0.417*
[TA3]	*0.29 (0.49)*	*1.43 (1.51)*	*-1.903*	*0.041*
[TA4]	*1,71 (1.50)*	*3.14 (2.97)*	*-1.137*	*0.139*
Total score	*8.00 (2.58)*	*10.29 (6.21)*	*0.899*	*0.193*

Table 5: Results of the two-sample t-test for the post test

5. Outlook

This paper presented the adaptation of three design principles derived from CTML to an organic chemistry mechanism. To assess the effectivity of the implementation as well as potential differences in the transfer ability a control group design study was conducted. For the control group a static monomedial pendant was designed which did not differ in content. The study showed that there were no significant differences between the groups in how effective the participants found the implementation of any of the design principles. The post-test yielded differences in the scores of both groups, in that the control group performed better on average on the easy tasks and the experimental group on the hard tasks. The experimental group also scored better overall. However, this difference was only statistically significant for TA3.
However, the validity of both tests is limited by the fact that some of the parameters of the item analysis are outside the recommended range. For further studies, corresponding items should therefore be reformulated and further items added to the scales. A central task will also be to acquire a larger sample size.

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