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Teaching genetics with multimedia results in better acquisition of knowledge and improvement in comprehension

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Abstract

The main goal of this study was to explore whether the use of multimedia in genetics instruction contributes more to students' knowledge and comprehension than other instructional modes. We were also concerned with the influence of different instructional modes on the retention of knowledge and comprehension. In a quasi-experimental design, four comparable groups of 3rd and 4th grade high school students were taught the process of protein synthesis: group 1 was taught in the traditional lecture format ($n = 112$ students), group 2 only by reading text ($n = 124$ students), group 3 through multimedia that integrated two short computer animations ($n = 115$ students) and group 4 by text supplemented with illustrations ($n = 117$ students). All students received one pre-test in order to estimate their prior knowledge, and two post-tests in order to assess knowledge and comprehension immediately after learning and again after 5 weeks. Results showed that students comprising groups 3 and 4 acquired better knowledge and improved comprehension skills than the other two groups. Similar results were observed for retention of acquired knowledge and improved comprehension. These findings lead to the conclusion that better learning outcomes can be obtained by the use of animations or at least illustrations when learning genetics.

Keywords

acquired knowledge, computer animation, improvement in comprehension, learning of protein synthesis, multimedia learning, retention of knowledge and comprehension.

Introduction

Genetics and related topics, such as molecular biology, cell biology and biotechnology, are closely connected with our everyday life and are related to medicine, agriculture, industry, technology as well as ethics. Though genetics is interesting, it is an analytical and even abstract discipline. That is why it is complex to teach and to learn at high school level. According to students, genetics is the greatest challenge that they have encountered in their study (Marbach-Ad 2001; Ruiyong 2004; Tsui & Treagust 2007). Many teachers share the same opinion and regard genetics as an exact subject that is conceptually and linguistically difficult to teach (Fink 1990; Rode 1995; Malacinski & Zell 1996; Marbach-Ad 2001; Tsui & Treagust 2004, 2007). In order to facilitate the conceptualization of structures and processes in genetics, new and updated technologies in teaching and education, such as multimedia are being introduced into the teaching process. The rapidly growing use of personal computers in almost all

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domains of life has also influenced science education. Today, strong claims are being made for the potential of multimedia learning environments (Najjar 1998; Ainsworth 1999; Sweller 1999; Mayer 2003). But are they really so beneficial in education? A number of science educators believe that computer animation has a great potential in teaching and learning science concepts (Marbach-Ad *et al.* 2008). However, there have been few experimental-based reports about the effect of the use of computer animation on student achievement in learning genetics. In this paper, we briefly review recent research in this and other fields and present the results of our research project.

In the last two decades, there has been an increase in the amount of research on the use of multimedia in different areas, including education, but mostly in teaching mathematics, chemistry or subjects from technical domains (Tabbers *et al.* 2004). One of the major contributors on the research of multimedia in past several years is Richard Mayer. The promise of multimedia learning according to Mayer (2003) is that students can learn more deeply from well-designed multimedia messages consisting of words and pictures than from more traditional modes of communication involving words alone. This is because they learn more because of the ability of integrating different modes of information (visual and verbal), and so they integrate their knowledge in a more meaningful and successful way.

Mayer's cognitive theory of multimedia learning (Mayer 1997) draws on Paivio's dual coding theory (Paivio 1986), Sweller's cognitive load theory (Chandler & Sweller 1991; Sweller 1999), Baddeley's model of working memory (Baddeley 1986, 1992) and the constructivist learning theory (Mayer 1996). From the dual coding theory (Paivio 1986; Clark & Paivio 1991) Mayer and his colleagues base their approach on the learner having separate visual and verbal information possessing systems. From the cognitive load theory and the working memory model they take the idea that the processing capacities of visual and verbal working memories are limited (Chandler & Sweller 1991; Baddeley 1992; Sweller 1999). They draw on the constructivist learning theory to assume that meaningful learning occurs when students actively select relevant information, organize it into coherent representations and integrate it with other knowledge (Mayer 1996).

Mayer's model is based on three basic assumptions (Mayer 2001): (1) visual and auditory information is processed through separate and distinct information processing channels; (2) each information processing channel is limited in its ability to process information; and (3) processing information in channels is an active cognitive process designed to construct coherent mental representation. These three assumptions form the basis of the model that has been used to generate a series of experiments yielding seven major principles of how to use multimedia to help students understand a scientific explanation (Mayer & Moreno 2002).

Schnotz and Lowe (2003) have also developed a theory of multimedia learning. They argued that Mayer's model is too simple to explain how the multimedia affects a student's cognition and understanding. Their model consists of a descriptive and a depictive branch of representation (Schnotz & Bannert 2003). In their study, Schnotz and Lowe (2003) found that dual coding theory does not take into account the fact that the subject matter can be visualized in different ways and that this affects the structure of the mental representation. Furthermore, dual coding theory neglects the fact that pictures can also have negative effects on understanding because of the interference between a picture and a mental model construction (Chandler & Sweller 1991). This negative effect was greater in students with high prior knowledge than in those with low prior knowledge. For the latter, constructing a mental representation from words and pictures was easier than constructing it from words alone. Thus, multimedia can have three different effects on cognitive load (Schnotz (2008): an enabling effect (impossible effects become possible); a facilitating effect (possible but difficult processes become easier); and an inhibiting effect because of increase of cognitive load caused by multimedia instruction.

Schnotz and Lowe (2003) reported also that use of animation incorporating a high degree of user control, does not always function as an effective tool for learning. That is because domain novices tend to neglect thematically relevant aspects, because of the lack of the necessary domain-specific background knowledge and to the design of the animation itself. Tversky *et al.* (2002) argued that only carefully designed and appropriate animation is beneficial to learning. According to them, animations are often too complex or too fast to be accurately perceived and comprehended. Moreover Ploetzner and Lowe (2004) argued that learners are likely to need some form of external support or ancillary activity in order to make best use of animation. Lowe (2003) refers to a problem of animation as being overwhelming for students, because of the speed at which events are displayed and the number of animated elements that have to be taken into account. Schnotz (2002) found that students failed to process the animated pictorial material deeply. Therefore, despite the benefits that, according to Mayer, animation can have on learning, it can also result in specific processing difficulties.

The benefits of animation on learning have also been investigated by other researchers. Among them, Neo and Neo (2001) presented the use of multimedia in a problem-based learning environment. Integrating multimedia into teaching and learning enables students to exercise their creative and critical thinking skills and to face the real-life situation of problem solving. Ward and Walker (2008) concluded that students who processed the material deeply, using multiple sources to construct their understanding, had both better grades and recall than students who were preoccupied with a surface-processing mode of exactly re-stating the course content from a single source.

Other researchers tested Mayer's principles of use of multimedia. Leahy *et al*. (2003) searched the Redundancy Principle. They reported that the effectiveness of multimedia instruction depends very much on how and when auditory information is used. Mayer (2001) investigated the Redundancy and Coherent Principles and concluded that adding on-screen text or interesting but irrelevant details can overload the visual information processing channel, causing lower transfer performance. Another study of the effectiveness of multimedia concentrated on the Modality Principle and cueing effect. In this study Tabbers *et al*. (2004) came to the conclusion that adding visual cues to the pictures resulted in higher retention scores, while replacing visual text with spoken text resulted in lower retention and transfer scores. Kalyuga *et al*. (1999) investigated alternatives to split-attention instructional designs, presenting text in an auditory form and using colour coding to highlight the salient. Both alternatives were effective because of reduction in cognitive load.

In several studies, the difference between illustration (static picture) and animation (motion picture) has been investigated. Lewalter (2003) studied the difference between animation and static illustration with respect to their effect on learning. She found that when presenting dynamic processes, animation appeared to be more beneficial, but when learning facts, no difference between this two learning conditions were observed. On the other hand, Lowe (2003) argued that if animations simply display processes without providing further instructional enrichment, their educational potential may be compromised. In another study, despite the advantage of multimedia over text- and picture-only conditions, participants often misremembered multimedia presentations as picture-based ones (Brunye *et al.* 2006). This suggests that individuals may feel intuitively that pictures are more important than text. In contrast to these findings, Schnotz and Bannert (2003) found that students with higher prior knowledge processed text more intensively because of the presence of pictures. But students with lower prior knowledge concentrated more on the pictures. The results of an experiment performed by Michas and Berry (2000), showed that the effectiveness of media or their combinations was influenced by the extent to which they conveyed action information. That can happen through the appropriate combination of verbal and visual media, or by a single medium enhanced with appropriate symbols or features. Hidrio and Jamet (2008), found that animation did improve comprehension, also in contrast to learning conditions in which one or more static illustrations were added to the spoken text. Ainsworth *et al*. (1996) investigated the use of more animations and found that student performance was influenced by the demands of translating between representations. In another paper, Ainsworth (1999) argued that multi-representational learning environments have three main functions: to support complementary cognitive processes, to constrain possible interpretation and to encourage learners to construct deeper understanding. Therefore, an open question under which conditions animated pictures really enhance comprehension and learning remains.

In the last few years, there has been some research on the principles of learning genetics. Rotbain *et al*. (2006) studied the relative effectiveness of models and illustrations when used as teaching tools in molecular genetics. According to them, the students who used either a bead model or an illustration model extended their knowledge in genetics more than the control group, who were taught in the traditional lecture format. They also revealed that the bead model activity was significantly more effective than illustration activity. The same conclusion was made by Ferk (2003), who tested the effectiveness of computer pseudo-3-D models over stereo-chemical formulas. Students reported that they could more easily visualize molecular structure on the basis of a static computer image than from abstract notation used in stereo-chemical formulas.

Tsui and Treagust (2007), who studied reasoning in learning Mendelian genetics, found that the multiple representations of genes increased students' understanding of the concept of the gene. In another study, the same authors (Tsui & Treagust 2003) had found that the use of multiple representation contributed to students' reasoning in genetics, but only in easier reasoning types and if students had been mindful in their learning.

Marbach-Ad *et al*. (2008) reported that computer animation is significantly more effective than illustration in molecular genetics, especially when teaching about dynamic processes. Stopping, starting and replaying an animation can allow re-inspection, focusing on specific parts and actions. The same conclusion was made by Tversky *et al*. (2002), who claimed that if learners are in control of the speed of animation and can view and review, stop and start, zoom in and out, and change the orientation of the whole and parts of the animation at will, the problems of actual perception can be alleviated. However, according to Marbach-Ad *et al*. (2008) engaging students in illustration activities can still improve their achievement over traditional instruction.

Given the rather inconsistent findings in different fields to date and because little has been done on the effectiveness of using animations in genetics education, the main purpose of our research was to evaluate the effectiveness of animations compared with other modes of teaching protein synthesis. We further sought to determine how such presentations influence students' knowledge and their comprehension of learned concepts (these are the first two categories within cognitive domain of educational activities raised by Bloom 1956). Furthermore, the additional issue to be addressed in our research was the influence of animation on the retention of students' knowledge and comprehension after 5 weeks.

Methods

Participants

In the present study, 468 students, grades 12 and 13 from four different high schools in Ljubljana, Slovenia were included: Secondary School of Nursing, Secondary School for Pharmacy, Cosmetics and Health Care, and two grammar schools. There were 193 (41.2%) males and 275 (58.8%) females, mean age was 18.04 years. They all participated voluntarily and for students who were not 18 years old at that time, we obtained permission from their parents. The proportions of male and female students are similar to the male – female ratio in secondary school population. The investigation was conducted in the school year 2007–2008.

Study material

Four different sets of materials on protein synthesis were developed, all in Slovene language with exception of two animations that were supplemented with English text. The first approach was a text only summary on protein synthesis from different handbooks (text only group). The second was made by adding illustrations with remarks to the previous text (text and illustration group). The third set was prepared for traditional lecture format – spoken text and pictures, which were drawn in front of the students during the explanation (traditional study group). The fourth was a multimedia presentation of protein synthesis with two short animations showing transcription (http://www.stolaf.edu/people/giannini/flashanimat/molgenetics/transcription.swf) and translation (http://www.biostudio.com/demo_freeman_protein_synthesis.htm) (multimedia group). In contrast to text and illustration conditions, in multimedia conditions students learnt with a stand-alone program, which was designed by a computer engineer and the first author of this article, and was customized to the class and curriculum, like all other materials we made for and used in our study. The most important differences from all other instructional conditions were two animations (downloaded from internet), which were inserted in the multimedia presentation in order to facilitate comprehension of transcription and translation as two main processes of protein synthesis. These animations could be stopped and reviewed as many times as desired any time during multimedia presentation.

In each set, the content and extent of the learning material was the same, only the ways the material was presented differed. Students in all four groups had the same time to learn the subject-matter.

Questionnaires

For the purposes of the research, pre- and post-tests were designed.

A pre-test for assessing students' prior knowledge about the structure of DNA and its duplication (it is a very similar process to transcription during protein synthesis) contained 14 questions (e.g. Which kind of nucleic acid makes up a bacterial genome?). The Cronbach α reliability coefficient of the pre-test is 0.79.

The post-test contained 35 questions. They measured knowledge and comprehension of protein synthesis – the structure of different RNAs, the course of transcription and translation, and the main role of these processes in a bacterial or eukaryotic cell. Three independent biology teachers helped us to determine which questions were related to assessing acquired knowledge and which to improving of comprehension skills. Knowledge (e.g. Name the process in bacterial cell by which mRNA is synthesized.) was measured by 23 questions and comprehension (e.g. What is the codon corresponding to the anticodon CAU?) by 12 questions. Cronbach α coefficient for the whole test was 0.92, for knowledge 0.87 and for comprehension 0.84.

All three teachers also tested both the pre-test and the post-test on their students beforehand, in order to ensure the validity of tests.

Procedure

A quasi-experimental design was used in this study. In each of the four high schools, four different classes were included and randomly assigned to one of the experimental conditions.

All students were subjected to the research procedure three times. The first meeting was dedicated to introduce the aims of the study. In order to estimate their prior knowledge the students then wrote a 20-minute pre-test. On the second occasion, after one week, the students learned for 45 min about protein synthesis in one of the four experimental conditions. Immediately afterwards they wrote a 35-min post-test (post-test 1). The third occasion took place after five weeks, when they were re-tested with the same 35-min test (post-test 2).

Statistical analysis

Data were analysed with SPSS 16 program (SPSS Inc, Chicago, IL, USA). First One-way analysis of variance (ANOVA) was used to investigate the differences between the four experimental groups in their prior knowledge. Analysis of the pre-test showed the differences between multimedia and traditional study groups on the one hand, and the text and illustration and text only groups on the other [F (3, 464) = 7.86, $P < 0.001$]. Students in the multimedia and the traditional study groups had higher scores. In order to resolve the problem of unequal means at the beginning of experiment, we took scores from pre-test as a covariant and applied Univariat analysis of covariance (ANCOVA). After this the repeated measures ANCOVA were calculated to find the main differences between groups with different instructional modes and between measurements (post-test 1 and post-test 2). Then the comparisons of the scores of students in four experimental conditions with Univariat ANCOVA on post-test 1 and post-test 2 with Bonferroni *post hoc* tests for each measurement were calculated. Further *post hoc* analyses for main effects within subjects for each instructional mode in different measurements were done with paired sample *t*-test.

Results

Students' overall achievement

Our results in Table 1 show the statistical significance between experimental groups considering scores of the whole post-tests [F (3, 464) = 63.50, $P < 0.001$] as well as scores of acquired knowledge [F (3, 464) = 79.66, $P < 0.001$] and improved comprehension [F (3, 464) = 34.48, $P < 0.001$] separately on both post-tests. The significance exists when considering different time of measuring achievement on the whole test [F (1, 464) = 19.54, $P < 0.001$], acquired knowledge [F (1, 464) = 10.52, $P < 0.01$] and improved comprehension [F (1, 464) = 17.34, $P < 0.001$], as well as considering both instructional modes and different time of measuring achievement together on the whole post-test [F (1, 3) = 105.62, $P < 0.001$], acquired knowledge [F (1, 3) = 58.69, $P < 0.001$] and improved comprehension [F (1, 3) = 110.31, $P < 0.001$].

Acquired knowledge and improved comprehension

Statistically significant differences were found in scores of the post-test 1 [F (3, 464) = 131.76, $P < 0.001$] as well as in the separate scores of acquired knowledge [F (3, 464) = 136.09, $P < 0.001$] and improved

Table 1. Results of repeated measures analysis of covariance (means, SD's, *F*-ratios) for achievement on the whole test, of acquired knowledge and improved comprehension for four instructional modes on first and second measurement.

		Scores on post-test1	Scores on post-test2	Within groups	Between groups	Interaction
		Mean (SD)	Mean (SD)	*F* (df = 1)	*F* (df = 3)	*F* (df = 3)
Whole post-test	Text only group	12.26 (6.10)	15.27 (7.66)	19.54***	63.50***	105.62***
	Text and illustration group	24.94 (4.41)	18.60 (7.73)			
	Traditional study group	21.13 (5.77)	17.85 (5.21)			
	Multimedia group	25.37 (7.26)	23.97 (7.87)			
Knowledge acquisition	Text only group	9.40 (4.51)	10.69 (5.30)	10.52**	79.66***	58.69***
	Text and illustration group	17.20 (2.65)	13.40 (5.14)			
	Traditional study group	14.09 (3.56)	12.80 (2.76)			
	Multimedia group	17.81 (4.30)	16.99 (4.65)			
Improved comprehension	Text only group	2.85 (1.96)	4.58 (2.83)	17.34***	34.48***	110.31***
	Text and illustration group	7.74 (2.06)	5.20 (2.91)			
	Traditional study group	7.04 (2.72)	5.04 (2.83)			
	Multimedia group	7.57 (3.26)	6.98 (3.41)			

$^{**}P < 0.01$; $^{***}P < 0.001$
F, *F*-value; *P*, significance; SD, standard deviation.

Table 2. Results of Bonferroni *post hoc* test – in table are shown only significant differences.

	Experimental groups	MD (SE)		Experimental groups	MD (SE)
Post-test 1	MU – TS	4.45 (0.74)***	Knowledge acquisition	MU – TS	3.85 (0.47)***
	MU – TO	11.80 (0.74)***		MU – TO	7.84 (0.46)***
	TI – TS	5.43 (0.76)***		TI – TS	3.90 (0.48)***
	TI – TO	12.79 (0.72)***		TI – TO	7.89 (0.46)***
	TS – TO	7.35 (0.75)***		TS – TO	3.99 (0.47)***
Improved comprehension	TI – TS	1.20 (0.35)**	Post-test 2	MU – TI	3.85 (0.92)***
	TI – TO	4.89 (0.32)***		MU – TS	6.34 (0.91)***
	MU – TO	4.26 (0.34)***		MU – TO	7.29 (0.91)***
	TS – TO	3.69 (0.35)***		TI – TS	2.49 (0.93)*
				TI – TO	3.44 (0.88)***
Retention of acquired knowledge	MU – TI	2.89 (0.58)***	Retention of improved comprehension	MU – TI	1.38 (0.41)**
	MU – TS	4.32 (0.58)***		MU – TS	1.98 (0.40)***
	MU – TO	5.71 (0.57)***		MU – TO	2.00 (0.41)***
	TI – TO	2.82 (0.56)***			

$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$
MD, mean difference; *P*, significance; SE, standard error; MU, multimedia group; TS, traditional study group; TO, text only group; TI, text and illustration group.

comprehension [$F\ (3, 464) = 91.11$, $P < 0.001$] when comparing students learning in different instructional modes.

Achievement on the whole post-test 1

The highest scores of the whole post-test 1 were found in the multimedia and the text and illustration groups, followed by the traditional study group and the lowest scores were found in the text only group. The differences were further analysed with Bonferroni *post hoc* test, which are shown in Table 2.

Acquired knowledge

The separate analysis of post-test 1 questions related to knowledge gave results similar to those for the whole post-test 1. The highest scores were found in the multimedia and the text and illustration groups, followed by the traditional study group and the lowest scores were found in the text only group. Significant differences calculated with Bonferroni *post hoc* test are shown in Table 2.

Improved comprehension

The separate analysis of post-test 1 questions related to improved comprehension gave results similar to those for the whole post-test 1 and for acquired knowledge. The greatest improvement was shown in the text and illustration and in the multimedia groups, followed by the traditional study group. The lowest improvement in comprehension was shown in the text only group. Significant differences between experimental groups are shown in Table 2.

The retention of acquired knowledge and improved comprehension

Statistically significant differences were found in scores of the post-test 2 [F (3.464) = 26.20, $P < 0.001$] and in the separate scores of retained knowledge [F (3.464) = 37.17, $P < 0.001$] and retained comprehension [F (3.464) = 11.16, $P < 0.001$] when comparing students learning in different instructional modes.

Retention on the whole post-test 2

With respect to the measure of the retention of acquired knowledge and improved comprehension, the highest overall scores were found in the multimedia group, followed by the text and illustration group, the traditional study group and the text only group. The Bonferroni *post hoc* test showed significant differences between some groups, which are shown in Table 2.

Retention of acquired knowledge

The Bonferroni *post hoc* test showed the same differences between groups of students when taking the retention of acquired knowledge into account. The multimedia group showed the highest retention of knowledge, then the text and illustration group, followed by the traditional study group and the text only group. Significant differences in retention of acquired knowledge are shown in Table 2.

Retention of improved comprehension

The multimedia group showed the highest retention of improved comprehension, followed by text and illustration group, traditional study group and the text only group. Significant differences in retention of improved comprehension are shown in Table 2.

Differences in achievement on the post-test 1 and post-test 2 on the same instructional mode

In order to compare the differences in achievement in the two measurements on the same instructional mode, *post hoc* t-tests were performed. Average overall scores in each instructional mode are shown in Fig 1, scores of retained acquired knowledge in Fig 2 and of improved

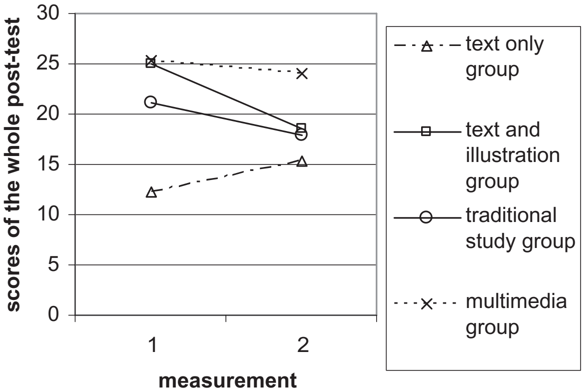

Fig 1 Mean differences under four instructional modes between first measurement and second measurement of the whole post-test achievement.

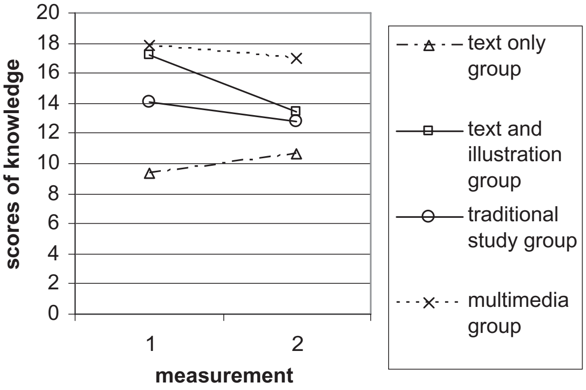

Fig 2 Mean differences under four instructional modes between first measurement and second measurement of acquired knowledge.

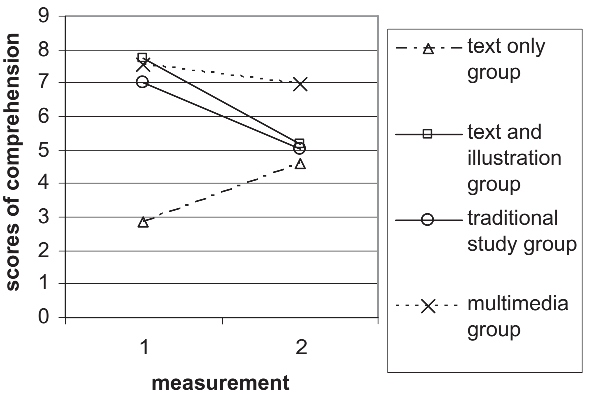

Fig 3 Mean differences under four instructional modes between first measurement and second measurement of improved comprehension.

comprehension in Fig 3. The figures also show the possible source of interaction.

Statistically significant differences in scores of the whole test in all four experimental groups between first and second measurement were found. The text only group showed significantly higher achievement on post-test 2 than on the post-test 1 [t (123) = –8.67; $P < 0.001$]. All other groups of students showed significantly lower achievement on post-test 2: the text and illustration group [t (116) = 10.77, $P < 0.001$], the traditional study group [t (111) = 11.36, $P < 0.001$] and the multimedia group [t (114) = 6.88, $P < 0.001$]. In the second measurement, the decline was found in all experimental groups but the text only group. Nevertheless, the text only group still had the lowest overall scores (Fig 1).

Further analysis of scores of acquired knowledge in all four instructional modes between the first and second measurements also showed significant differences. The text only group showed significantly higher knowledge on the post-test 2 than on the post-test 1 [t (123) = –5.21; $P < 0.001$]. All other groups of students showed significantly less knowledge on the post-test 2: the text and illustration group [t (116) = 9.41, $P < 0.001$], the traditional study group [t (111) = 5.46, $P < 0.001$] and the multimedia group [t (114) = 5.50, $P < 0.001$]. Nevertheless, the text only group achieved lower knowledge than other experimental groups (Fig 2).

Significant differences were also found between the first and second measurements of improved comprehension under all four instructional modes. The text only group showed significantly higher comprehension on the post-test 2 than on the post-test 1 [t (123) = –10.25; $P < 0.001$]. All other groups of students showed significantly lower comprehension on post-test 2: the text and illustration group [t (116) = 10.43, $P < 0.001$], the traditional study group [t (111) = 12.71, $P < 0.001$] and the multimedia group [t (114) = 4.23, $P < 0.001$]. The decline was found in all instructional modes except in the text only condition, where an increase was found. But the traditional study and the text only groups showed the lowest retention of comprehension (Fig 3).

Discussion

Genetics is an interesting but very hard discipline for students to conceptualize molecular structures and consequently to understand the structures and processes in this field. In order to clarify mixed reports considering the influence of multimedia on learning, we tested its effectiveness compared with the other teaching media while learning protein synthesis, which is an important topic in genetics education. Our research was aimed to investigate Mayer's first principle (Mayer & Moreno 2002) of how to use multimedia – the Multimedia Principle; that it is better to present an explanation in words and pictures than solely in words. The other six principles were considered when designing material in our multimedia representations: the Spatial Contiguity Principle (corresponding words and pictures are presented near each other on the page or screen), the Temporal Contiguity Principle (corresponding words and pictures are presented simultaneously), the Coherence Principle (extraneous words, pictures and sounds are excluded), the Redundancy Principle (an animation and on-screen text, without narration) and the Individual Difference Principle (the aforementioned strategies are most effective for novices – which the students in our study were). In our research, we were not able to consider the Modality Principle (animation with narration is better than animation with on-screen text), because of difficulties with equipment in the schools involved in the experiment.

Considering the overall test scores and acquired knowledge scores, our results showed the highest achievement in the text and illustration and the multimedia groups, then in the traditional study group. The text only group showed considerably lower scores. In tasks assessing improved comprehension, the highest achievement was again found in the text and illustration and multimedia groups. Very similar scores to the multimedia group were found in the traditional study group. Again, the text only group exhibited the lowest scores. Our results therefore do not confirm the superior impact of multimedia compared with the other instructional conditions, which was reported by many researchers (Michas & Berry 2000; Neo & Neo 2001; Tversky *et al*. 2002; Lewalter 2003; Tsui & Treagust 2007; Marbach-Ad *et al.* 2008; Ward & Walker 2008). Marbach-Ad *et al*. (2008) found that animation activity was significantly more effective than the illustration while learning genetics. On the other hand, Large (1994, 1996) argued that multimedia is more beneficial only for simple topics. However, according to Marbach-Ad *et al*. (2008) and Rotbain *et al*. (2006) engaging students in illustration activity is still better than the traditional lecture format. This was also found in our study. Nevertheless, our results showed the greater effectiveness of carefully designed material combining pictures and text, confirming the results of Tversky *et al*. (2002) and of Michas and Berry (2000). Thus, our results are in accordance also with Mayer's affirmation that students can learn more deeply from well-designed multimedia messages consisting of words and pictures, regardless whether learning takes place in a computer or a written learning environment, than from more traditional modes of communication involving words alone (Mayer 2003). This confirms the Multimedia Principle. Our results also support the conclusion of Schnotz and Lowe (2003) that only task-appropriate pictures are likely to support learning. In the present research, we laid great stress on the way in which appropriate illustrations were supplemented with corresponding words in the multimedia presentation as well as in the presentation for students who learnt with text and illustration.

The same level of acquired knowledge as well as of improved comprehension shown in the multimedia and the text and illustration groups can be interpreted in different ways. One possibility is that students without any basic knowledge of the processes of transcription and translation neglected thematically relevant aspects in producing coherent and comprehensive knowledge structures while learning with multimedia and that this led to lower knowledge and comprehension. Similar results have been found in other studies (Large 1994, 1996; Lowe 2003; Schnotz & Lowe 2003) that showed the benefits of multimedia animation only while learning simple topics. Obviously, students who are not used to learning with animations and are novices in a given field, feel more comfortable learning with text and illustrations, and thus both show as much knowledge and comprehension as those in the multimedia group, but not more as we predicted. Also, Ainsworth (1999) claimed that translation between two representations influence a student's performance. In our study, students had to learn from two different animations (each describing one process of protein synthesis), but yet had to connect them to understand the whole process of protein synthesis. It could be that translation between the animations was the reason that they did not perform better than students learning with text and illustrations. A second possible reason for equal knowledge and comprehension gained while learning with multimedia and with text and illustration may lie in the fact that the short animations in multimedia condition were subtitled with English text and some students might have had problems understanding it. This could overload their verbal processing channel. According to Mayer (2003), a cognitive overload can happen while processing learned material and building connections between pictorial and verbal representation. That might impair learning relative to students' in the text and illustration group. Even though they could learn about transcription and translation on previous slides of multimedia presentation in Slovene language, the short animations by themselves (motion picture with foreign language remarks) evidently were not more effective than the illustrations with the supplementary Slovene text, which were supposed to be less effective. We can therefore conclude that in this research, students laid stress on text around illustrations or motion pictures (in animations), which is in contrast to claims stated by Brunye *et al*. (2006), who argued that individuals considered pictures as more important than text for understanding and completing procedural tasks.

Considering retention of acquired knowledge and improved comprehension together (results on the whole post-test 2), multimedia with two animations resulted in higher retention. The same results were found considering retention of knowledge alone as well as retention of comprehension. Again, Mayer (2003) claimed that illustrations or motion pictures do contribute to better learning and understanding of some themes even more when higher levels of thinking processes, such as understanding, analysis, synthesis or evaluation are being learnt. Our results also showed that the smallest drop in achievement from first to second post-test in tasks measuring the whole knowledge and comprehension alone (when considering knowledge alone, the drop is the second smallest) occurs with multimedia learning and confirms the results from Ward and Walker's research (Ward & Walker 2008), who concluded that students who process the material deeply have better recall of the learned material. From these results we can conclude that multimedia contributes to better retention of acquired knowledge and improved comprehension. We propose that the observation may be due to the motion visual presentation of transcription and translation observed by students during multimedia learning conditions, which stayed in students' memory longer than static illustrations. Furthermore, static illustrations can only describe, with difficulty, some processes or actions that take place during genetic processes. Therefore, motion pictures are more effective in describing dynamic phenomena and consequently more economical considering the time someone needs to learn a given processes.

We have to point out another rather unexpected result that was found in the text only group. Although overall scores in this experimental group were the lowest of all four groups, the achievement increases significantly from the first to the second post-test. Further qualitative analysis and interviews with teachers revealed that because of the very low basic knowledge, teachers in this group explained the subject matter again and repeated it more often than did teachers in other experimental groups. This happened because protein synthesis was part of their regular curriculum. In using experimental or quasi-experimental designs in real school situations, it is very hard to control all the possible environmental variables that can influence students' achievement. One possible solution could be to use content that is not an obligatory part of the curriculum, but an elective one, to avoid problems in measuring the retention of gained knowledge and comprehension.

Two main conclusions can be drawn from this study. First, the use of multimedia – animations or at least illustrations or motion pictures – as an addition to some text during learning contributes to acquiring knowledge as well as to improving comprehension. Secondly, multimedia also contributes to the retention of knowledge and comprehension. The question is whether multimedia would function as positively when learning just facts and data, and not dynamic processes. This issue will be addressed in future studies.

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