Yang, C., Jen, C.-H., Chang, C.-Y., & Yeh, T.-K. (2018). Comparison of Animation and Static-picture based Instruction: Effects on Performance and Cognitive Load for Learning Genetics. *Educational Technology & Society, 21* (4), 1–11.

Comparison of Animation and Static-picture based Instruction: Effects on Performance and Cognitive Load for Learning Genetics

Chi Yang[1], Chun-Hui Jen[1], Chun-Yen Chang[1,2*] and Ting-Kuang Yeh[1,2,3*]
[1]Science Education Center and Graduate Institute of Science Education, National Taiwan Normal University, Taiwan // [2]Department of Earth Sciences, National Taiwan Normal University, Taiwan // [3]Institute of Marine Environmental Science and Technology, National Taiwan Normal University, Taiwan // chyi51757@gmail.com // jen.chunhui@gmail.com // changcy@ntnu.edu.tw // tkyeh@ntnu.edu.tw
[*]Corresponding authors

(Submitted November 30, 2016; Revised March 4, 2017; Accepted April 28, 2017)

ABSTRACT

This study aimed to examine the relative effectiveness of using an animation versus static pictures in terms of supporting the learning of genetics. To provide a methodologically sound comparison, the two sessions were constructed to be equivalent and were designed based on principles provided by the cognitive theory of multimedia learning and the cognitive load theory. Genetics was chosen as the instructional content, which included learning about the processes of cell division, mitosis, and meiosis. The results indicate that students in the animation group perceived less extraneous cognitive load and achieved a better learning outcome than those in the static pictures group. Therefore, this study supports the superiority of the animation over static picture instruction when learning micro-scientific phenomena.

Keywords

Multimedia learning, Genetics learning, Computer animation, Cognitive load, Static pictures

Introduction

The integration of multimedia technologies to promote learners' cognitive development is considered one of the most important objectives for science education (Mayer & Moreno, 2003; Yeh et al., 2012). Several studies have provided evidence that multimedia instructional environments can help students learn more effectively than traditional strategies (Jereb & Smitek, 2006; Najjar, 1996). However, the application of appropriate instruments to the design of effective multimedia-based educational tools has not been studied sufficiently (Mayer, 2008; Tabbers, Martens, & van Merrienboer, 2004). One important long-debated issue is the effectiveness of using computer animation and static pictures to support students' learning (Höffler & Leutner, 2007).

It is often assumed that animation can help learners mentally visualize a dynamic process compared to static pictures; however, this assumption is still controversial. Researchers have believed that animation visualization offers a realistic representation of the to-be-explained processes, facilitates a deeper comprehension of dynamic systems and inspires greater motivation to learn (Höffler & Leutner, 2007; Mayer, Hegarty, Mayer, & Campbell, 2005). In contrast, it is also believed that some possible cognitive advantages are associated with learning from static picture instruction. For example, (1) static pictures reduce cognitive processes because learners see only frames that represent key steps in the process, helping them focus on the most relevant information, and (2) learners are encouraged to explain the changes from one frame to the next, thereby enhancing active information processing (Mayer et al., 2005).

There are no consistent findings regarding the superiority of animation or static picture instruction in learning processes. A number of studies have reported that animated graphics can be used more effectively than static graphics to illustrate difficult abstract concepts and to visualize dynamic processes (Bodemer, Ploetzner, Feuerlein, & Spada, 2004; Williamson & Abraham, 1995). However, animation-based approaches are not always advantageous over static pictures. In a study conducted by Starbek, Starčič Erjavec, and Peklaj (2010), four groups of high-school students were taught the process of protein synthesis through a traditional lecture, text only, animation, and static pictures. In this study, Starbek and colleagues (2010) found that the animation group and the static picture group acquired better knowledge and improved their comprehension skills compared to the other two groups. However, the animation group, and the static picture group did not differ from each other, which failed to confirm the superior impact of animation. A similar finding was also reported by Rieber (1989) in a sample of 192 high school students; no significant differences in learning achievement were found between the graphic and animation groups.

To clarify the superiority of animation over the static pictures approach, in the following paragraphs, we discuss two crucial points that should be taken into account but were usually overlooked in previous studies. The first point concerns the methodology issue, which focuses on the equivalent design between animations and static picture instruction; the second point concerns the instructional design, emphasizing the application of learning theories to reduce learners' cognitive load.

It is vital to reduce potential non-equivalence problems by controlling variables other than the presentation format when comparing the relative effectiveness of animation/static pictures. By doing so, the argument can be made that the differences in the outcomes result from inherent differences between the formats (animation versus static pictures) rather than the poor design of either of these. However, after reviewing the literature, we found that there are at least three sources of non-equivalence between instructions that will lead to incomparability and render conclusions difficult. The first one is the amount of information provided by instructions. For example, to compare the relative effectiveness of different instructions, Starbek et al. (2010) provided participants with static illustrations and text to summarize protein synthesis in one experimental condition, and provided two animations showing the transcription and translation processes of protein synthesis, which were supplemented with English text in another condition. In this case, the two conditions not only differed in the dynamics of the materials but also in the graphic and the text information the materials provided. The second possible source of non-equivalence is the interface of the instructions. For example, in Mayer et al. (2005), the authors compared the relative effectiveness between computer-based animation and paper-based static diagrams, and found that static picture instruction led to better learning compared with animation. Although Mayer et al. attempted to maintain the informational equivalence between the two instructions, the difference in the interface between the two conditions (i.e., computer-based vs. paper-based) still confouned the results. The third possible source of non-equivalences is interactivity. Computer-based instructions are generally designed with functions that allow learners to interact with the instructions. However, in some studies, interactivity was not treated as a controlling variable when comparing the relative effectiveness between animations and static pictures. For example, in Watson, Butterfield, Curran, and Craig (2010), animations included self-pacing functions that were compared with static instructions, which presented no interaction. On the contrary, in Ayres, Marcus, Chan, and Qian (2009), learners had to use the scroll function to observe the information they needed in static picture instruction, but this function was not included in the animation presentations. Although Watson et al. and Ayres et al. both found that the animation condition was superior to the static picture condition since the interactivity of the instructions also varied with the presenting format in their studies, the influence of presentation format on learning outcomes is ambiguous.

It has been indicated that the design of multimedia instructions should follow principles that help to lower learners' cognitive load. For example, Aryes and Paas (2007) argued that many animated instructional environments are not as effective as expected because they create an unnecessarily large cognitive load. Similarly, Tversky, Morrison, and Betrancourt (2002) have indicated that dynamic visualization is no more effective than static visualization if the animation is too complex or the material is presented too quickly. Therefore, Aryes and Pass (2007) as well as Tversky et al. (2002) suggested that the design of multimedia instructions must be based on well-established principles that help to reduce learners' cognitive load through careful control of the manner of presentation and by attracting learners' attention in a more appropriate way. Although researchers acknowledge the importance of applying well-established principles in the design of effective multimedia instruction, not all studies have clearly mentioned on what principles or theories the design was based.

To look more carefully into the superiority of animation in comparison with the static picture approach, in this study, we took the equivalence issue into account and applied well-established principles in the design of instructions. To keep the design equivalent, both animation and the static picture instruction (1) provided identical information for learners to learn, (2) were designed as computer-based instructions, and (3) were designed with interactive functions (i.e., self-pacing). To ensure that the instructions were well-designed to reduce learner's cognitive load, both instructions were designed based on principles suggested by the cognitive load theory (CLT; Sweller, Ayres, & Kalyuga, 2011; Sweller, Chandler, Tierney, & Cooper, 1990; Sweller, Van Merrienboer, & Paas, 1998) and the cognitive theory of multimedia learning (CLMT; Mayer, 2001; Mayer, 2003; Mayer & Moreno, 2002). Both CLT and CTML propose minimizing unnecessary cognitive load, which is the central consideration in the design of multimedia materials, and provide research-based principles that could be applied in the design of multimedia materials to reduce learners' cognitive load. By applying principles suggested by CLT and CLTM, the instructions used in this study were designed to reduce the processing of extraneous materials and to allow learners to deeply study the materials.

This study specifically focused on comparing an animation of invisible infinitesimal phenomena with an equivalent static picture instruction. Hegarty (2004) has argued that researchers must go beyond making a simple distinction between static and dynamic displays because the latter could be further categorized as (1) animations of visible phenomena (e.g., a machine in motion), (2) animations of invisible phenomena (e.g., changes in temperature on a weather map), and (3) animations of abstract information (e.g., statistical concepts). Therefore, the results from studies with one type of dynamic display may not inevitably generalize to others. To respond to what Hegarty (2004) asserted, we have paid attention to the superiority of animations of invisible infinitesimal phenomena since it has been suggested that animations may be more effective when they are utilized to visualize invisible phenomena in the real world (Narayanan & Hegarty, 2002).

Genetics was chosen as the learning topic in this study. With recent advances in gene technology and the rapid progress on the Human Genome Project, genetics is becoming an important learning prerequisite in high school curricula. However, since the principles of genetics are abstract and the phenomena of genetics are infinitesimal and cannot be observed by the naked eye, students often develop misconceptions and become disorientated while studying this topic. Studies have found that students are weak in learning genetic terminology (Albaladejo & Lucas, 1988; Banet & Ayuso, 2003) and the invisible infinitesimal processes of cell division or meiosis (Brown, 1990; Stewart, Hafner, & Dale, 1990). The difficulty in learning genetics not only puzzles students but also poses a large challenge to most genetics teachers (Johnstone & Mahmoud, 1980). In Taiwan, the topic of genetics is covered extensively in the subjects of Science and Life Technology Curriculum Standards (Grades 1–9) and Life Science Curriculum Guidelines (Grades 10–12). Given that the understanding of genetics is an integral component of science education, it is crucial to design appropriate instructional tools to facilitate learning.

This study thus aimed to examine the relative effectiveness of using animation versus static pictures in terms of supporting the learning of invisible infinitesimal scientific phenomena. In this article, “relative effectiveness” refers to an instruction (1) that has less cognitive load and/or (2) that helps learners to reach higher achievement compared to the other instruction. Therefore, the investigation was guided by answering the following questions:

- Whether animations of invisible infinitesimal phenomena require less cognitive load than equivalent static picture instruction.
- Whether animations of invisible infinitesimal phenomena help learners to reach higher achievement than equivalent static picture instruction.

Methods

Participants

A total of 181, 7th grade students from six classes at a public junior high school were recruited and were assigned to one of two groups based on their class. Three of the six classes were assigned to the static pictures group (n = 89), and the remaining three classes were assigned to the animation group (n = 92). According to the data collected from the Intelligence Test for Junior High School--Revised Edition (Chen, 2004), these two groups did not differ from each other in their verbal reasoning, mathematics reasoning, and figural reasoning abilities.

Procedure

The study procedure consisted of a prior knowledge estimation phase, a learning phase, and a testing phase in sequence. In the prior knowledge estimation phase, students’ prior knowledge about genetics concepts was assessed. In the learning phase, students attended two 50-minute class-periods with multimedia instruction followed by an immediate evaluation of the extent of cognitive load they perceived during the curriculum. The content of the instruction was identical in both groups, but different media (i.e., static pictures versus animation) were used. In the testing phase, students were asked to complete an achievement test to evaluate their learning outcomes.

Designs of the multimedia instructions for learning genetics

The instructions were designed to promote an understanding of abstract concepts and invisible infinitesimal phenomena in genetics by applying principles of multimedia design suggested by CLT and CTML. Both animation and static picture instruction presented important concepts and phenomena in genetics, including (1) genetic material, (2) the process of cell division, (3) the process of mitosis, and (4) the process of meiosis. These four topics were sequentially presented in four segments. Animation instruction and static picture instruction were both computer-based, designed with self-pacing functions, and provided identical information for learners to learn, except that the animation was transitional in nature whereas the static pictures were not. To generate the content of the two sessions, we listed the main stages of the dynamic process to be learned (e.g., the process of mitosis) first, and then created corresponding diagrams and text to illustrate each stage. Static picture instruction thus was composed of a series of frames that presented the illustrations we created on each. Animation instruction was generated based on the frames used in the static picture instruction, but was designed to present continuously the minute changes occurring in the process.

The instructions were designed to reduce the processing of extraneous materials. The materials were presented as animation/static pictures and text together. Text was placed next to target images to reduce the split-attention effect (Sweller et al., 2011; see Figure 1). We avoided presenting materials irrelevant to basic concepts or essential elements (i.e., the coherence principle; Mayer & Moreno, 2003). Moreover, we highlighted key words and important concepts to help learners extract the main concepts and organize the information efficiently (i.e., the signaling principle; see Figure 2) (Mayer & Moreno, 2003).

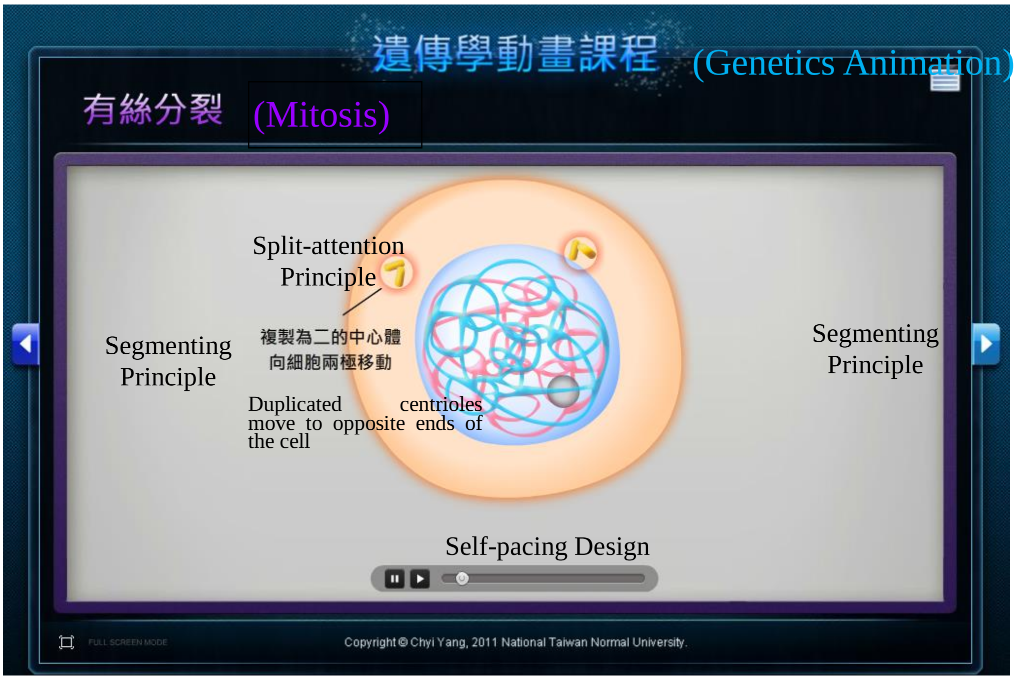

Figure 1. An example of the instructional section in animation instruction

The instructions were designed to allow learners to consider the materials deeply. To help learners to process the multimedia materials more efficiently, we produced a pre-training section for each topic and presented it before the illustrations, in which we briefly introduced glossaries and important concepts (i.e., pre-training principle; see Figure 2) (Mayer & Moreno, 2003). Since learners usually do not have sufficient time and capacity to handle animation material, especially when the content is rich and complex or the speed of the presentation is too fast to realize the context, the instructions were divided into meaningful segments, and learners could decide to watch the next or previous segment by clicking arrowhead indicators on the screen (i.e., segmentation principle; Mayer & Moreno, 2003; see Figure 1). Two levels of segments were constructed in the instructions. The first-level segments were the four topics to be learnt; each first-level segment was composed of a pre-training segment and an illustration segment. Moreover, the instructions were designed to allow learners to control the pace of the presentation. For example, in animation instruction, learners could decide the pace of the presentation by dragging a scrollbar back and forth or clicking a pause or play button (Figure 1). Similarly, the presentation of static pictures allowed learners to determine whether to go to the next stage, the previous stage, or back to the first stage by choosing the corresponding button (Figure 3).

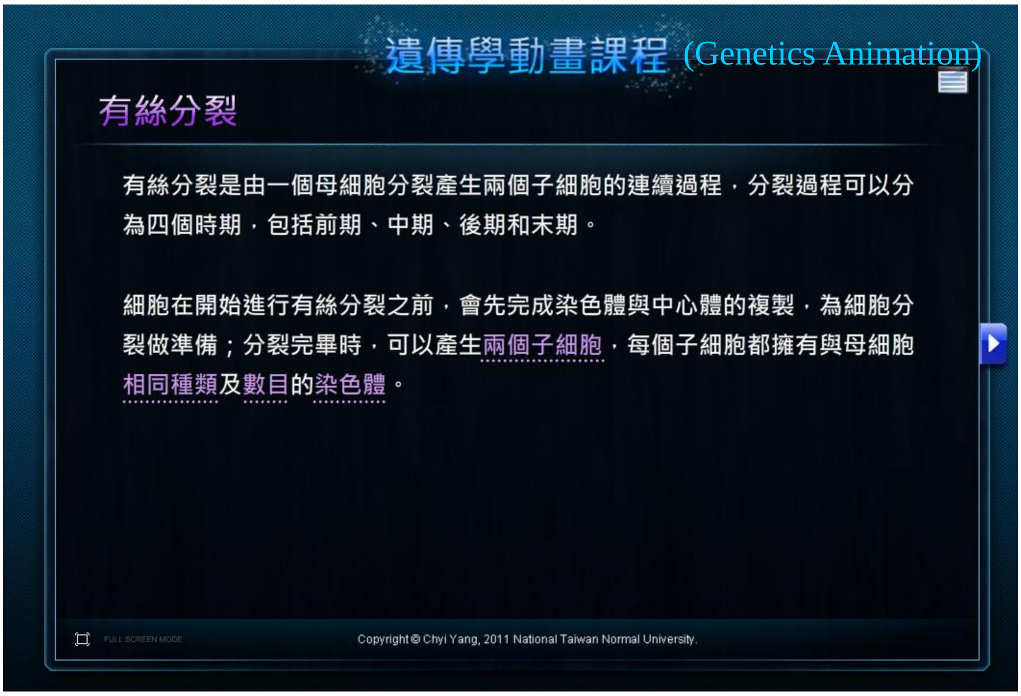

Figure 2. An example of the instructional section

Note. Translated content: Mitosis Overview: Mitosis is a process of cell division that results in two identical daughter cells. Mitosis is divided into four stages: prophase, metaphase, anaphase and telophase. Each stage has its own process. Before mitosis, to prepare for the process of cell division, centrioles and chromosomes are duplicated. After mitosis, each daughter cell will have the same number of chromosomes as the parent cell.

Figure 3. An example of the instructional section in the static picture instruction

Instruments

Three instruments were used in this study to assess students’ prior knowledge, to evaluate a subjective index of the cognitive load of the genetics curriculum and to assess students’ achievements regarding genetic concepts. Sample instrument questions are shown in Table 1.

Table 1. Sample items of instruments used in this study

Instrument	Sample items	Type
GFT	• Which one is a characteristic of the nucleus? (a) There is chloroplast in the nucleus for photosynthesis; (b) It contains hereditary (genetic) information and is the life center of a cell; (c) It supports the cell skeleton, preventing the cell from becoming deformed; (d) It is a place for energy production and nutrient oxidation.	Multiple-choice
CLQ	• Substantial mental effort was required to understand the course content of mitosis. *(overall cognitive load)* • The text font, size and color presented took substantial mental effort to read. *(extraneous cognitive load)* • Substantial mental effort was required to operate the computer. *(extraneous cognitive load)*	7-point scale
GCT	• Please describe what you know about chromosomes, DNA, and genes and the relationship among them.	Open-ended
	• A creature has 10 pairs of chromosomes in its cells. After five successive mitotic divisions, how many pairs of chromosomes does each daughter cell have? (a) 50 pairs; (b) 2 pairs; (c) 10 pairs; (d) 5 pairs.	Multiple-choice

Cognitive abilities assessment

The subjects' cognitive abilities were assessed via the second edition of the Intelligence Test for Junior High School (Chen, 2004), which is a commonly used in Taiwan, and thoroughly standardized test that suitably assesses the diversity of cognitive abilities in adolescents. The Intelligence Test for Junior High School-II consists of three inventories: verbal reasoning, mathematics reasoning, and figural reasoning, and each of these inventories contains 39, 32, and 32 items respectively. The internal consistency of the Intelligence Test for Junior High School-II range from 0.79 ~ 0.88.

Genetic Foundation Test (GFT)

The GFT was utilized to assess students' prior knowledge about genetics concepts before presenting the curriculum. The GFT consisted of 15 multiple-choice questions. These questions covered cell biology and basic genetic concepts that they had been taught in school. The test scores ranged from zero to 15. The content validity of the GFT was verified by two university professors of genetics and two experienced biology high school teachers. The internal reliability was calculated at 0.69 (Cronbach's alpha) in the current study.

Cognitive Load Questionnaire (CLQ)

The extent of the cognitive load that the instructions presented was evaluated via subjective measures in the current study. Using a post-treatment questionnaire, participants were asked to report the amount of mental effort they devoted to learning the genetics materials. This strategy has been frequently utilized in cognitive load studies and found to be highly reliable (Paas, 1992; Paas & Van Merriënboer, 1994; Paas, Van Merriënboer, & Adam, 1994). Chang and Yang (2010) also suggested that the subjective assessment of cognitive loads is convenient for administration; thus, it is appropriate for use in science classrooms.

According to CLT (Sweller et al., 1998), intrinsic cognitive load refers to the inherent nature of the materials to be learned, which is fixed and innate to the instruction; extraneous cognitive load results from the instructional design itself, which may vary between different methods of presenting the learning content. The overall load reflects the experienced load based on the entire working procedure. Because the difference between animation and static picture instruction is the presentation format, if animation does help to reduce the cognitive load, it is reasonable to anticipate that participants in the animation condition would report a lower level of extraneous load.

The CLQ has 13 items, including the extraneous and overall cognitive load of the curriculum. To evaluate the extent of the extraneous cognitive load, students had to indicate how much mental effort they perceived related to the multimedia instructions. The extraneous cognitive load may be attributed to the design of the instructional materials, such as the manner in which the curriculum was presented and the user-interface operation (as shown in Table 1). To evaluate the extent of the overall cognitive load, students had to indicate the amount of the mental effort required for learning (e.g., "It required substantial mental effort to understand the course content relating to mitosis"). Each item was rated on a scale ranging from 1 to 7 (1: strongly disagree; 7: strongly agree). A higher CLQ score indicated that a greater cognitive load was perceived by students. The content validity of the CLQ was verified by two university professors in the science education research field. The internal reliability in this study was shown to be adequate, with the Cronbach's alpha calculated to be 0.94.

The Genetics Concepts Test (GCT)

To assess students' achievement on genetics learning, the GCT was administered after the curriculum. Table 1 includes examples of questions from the GCT. The GCT consisted of two sections that evaluated different aspects of achievement. The first section had three open-ended questions designed to assess students' understanding of their genetics learning. Two experienced biology teachers were asked to grade students' answers following the standard answers and scoring criteria provided. The second section contained 20 multiple-choice questions that aimed to evaluate students' knowledge of the genetics they learned in the curriculum. Students received one point if they correctly answered each question in this section. The content validity of the GCT was verified by two university professors and two junior high school teachers in the field. The internal reliability (Cronbach's alpha) was calculated to be .81 in the present study.

Data analysis

Since the assumption of normal distribution was not fulfilled for all dependent variables, the Mann–Whitney U-tests were conducted to evaluate differences in prior knowledge, perceived cognitive load, and learning outcomes between the animation and static pictures groups. The statistical tests were performed with SPSS version 18.0.

Results

Perceived cognitive load

The results revealed that the animation instruction required less cognitive load than the static picture instruction. As shown in Table 2, one of the major findings in this study was that students in the animation group perceived significantly lower extraneous cognitive loads than students in the static pictures group (U = 3358.5, p = .037). However, perceived overall cognitive load of the animation group was not significantly lower than the static pictures group (U = 3592.00, p = .151).

Learning outcomes

As the data in Table 2 shows, the animation group outperformed the static pictures group on the open-ended questions (U = 2985.00, p = .002). However, a statistically significant difference was found between the two groups on the multiple-choice questions (U = 3795.00, p = .395). It is worth noting that the animation group did not significantly differ from the static pictures group in terms of the GFT scores (U = 4046.50, p = .892), thus we can believe that the difference found in the open-ended questions was not due to different levels of prior knowledge.

Table 2. Comparisons of students' perceived cognitive load in learning, prior knowledge, and genetic conception learning outcomes between the animation and static pictures group

	Mean (*SD*)	*U*	*p*
Cognitive Load Questionnaire (CLQ)			
Extraneous cognitive load			
Animation Group (n = 92)	3.66 (*1.13*)	3358.80	.037*
Static Pictures Group (n = 89)	4.11 (*1.35*)		
Overall cognitive load			
Animation Group (n = 92)	4.37 (*1.62*)	3592.00	.151
Static Pictures Group (n = 89)	4.72 (*1.61*)		
Genetic Foundation Test (GFT)			
Animation Group (n = 92)	11.28 (*3.05*)	4046.50	.892
Static Pictures Group (n = 89)	11.43 (*2.79*)		
Genetic Concept Test (GCT)			
Open-ended			
Animation Group (n = 92)	15.28 (*5.28*)	2985.00	.002**
Static Pictures Group (n = 89)	13.46 (*4.50*)		
Multiple-choice			
Animation Group (n = 92)	10.83 (*4.41*)	3795.00	.395
Static Pictures Group (n = 89)	11.44 (*4.23*)		

Note. $^{*}p < .05$; $^{**}p < .01$.

Discussion

The present study aimed to compare the relative effectiveness of animation- and static picture-based multimedia instruction in invisible infinitesimal phenomena (i.e., genetics). Previous studies that compared the relative effectiveness of different multimedia platforms did not focus on the design equivalence of the multimedia platforms and the application of learning theory, which makes it hard to interpret the results. To refine previous studies, we attempted to design the animation and static picture instruction to be equivalent based on the principles suggested by CTL and CTML.

The first major finding of this study was that the animation group outperformed the static pictures group in the open-ended questions. A number of studies have indicated that multiple-choice formats may be appropriate for questions that assess the memorization of key points, facts, dates, and definitions. In contrast, open-ended questions that elicit students' constructed responses and give students higher degrees of freedom in reasoning may serve as a better foundation for the evaluation of students' higher-order reasoning and qualitative understanding (Chang, Yeh, & Barufaldi, 2010; Wang, Chang, & Li, 2008). Previous studies also showed that it is difficult to develop multiple-choice test items that assess higher cognitive skills or conceptual structures (Chang et al., 2010; Wang et al., 2008). The better performance of the students in the animation group on the open-ended question may be attributed to the finding that animation helps learners visualize the invisible infinitesimal process of genetics. This finding is in accord with viewpoints provided by several researchers. For example, Marbach-Ad, Rotbain, and Stavy (2008) suggested that animation can be used more effectively than static pictures to illustrate difficult abstract concepts and to visualize dynamic processes. Similarly, Russell, Netherwood and Robinson (2004) also suggested that animation in multimedia for the teaching of biology helps students to integrate and understand abstract concepts.

This study also provided evidence that students in the animation group perceived a lower extraneous cognitive load than students in the static picture group. As mentioned previously, animation is often considered too complex or too fast to be accurately perceived (Tversky et al., 2002). In other words, learners may perceive a larger cognitive load in animation-based learning. However, recent researchers in the area of cognitive psychology have reported a fascinating insight: the cognitive load imposed by instructional animation can be ameliorated by an appropriate instructional design (Hasler, Kersten, & Sweller, 2007; Mayer & Moreno, 2003; Moreno & Mayer, 1999). Our results provided empirical support that a well-designed animation instruction could generate a smaller extraneous cognitive load than a static pictures instruction. Since the two instructions were designed to be equivalent, except that the animation was dynamic, the difference could not come from the non-equivalence of the design. A possible explanation for why students in the animation group perceived a lower extraneous cognitive load than those in the static pictures group in the current study is that the transitional nature of the animation can guide learners' attention, helping them focus on important information in the instructions. We are hopeful that future research will examine this possibility.

One should note that, we cannot conclude that lower perceptions of extraneous cognitive load gave rise to better learning performances in this study. We did not manipulate perceived extraneous cognitive load to investigate whether it consequently brings changes in students' learning performances, the causal relationship between them therefore was not established. Although according to our data, after controlling the influence of prior knowledge, lower perceptions of extraneous cognitive load did predict higher scores of open-end questions in the GCT (β = -0.133, p = .049), which implies that these two variables were associated with each other, future studies are still needed to confirm the causal relationship.

Although this study supports the superiority of animation instruction, the findings should not be interpreted to mean that animations are relatively more effective in all situations. Since the instructions were designed to visualize processes that are not visible by the naked eye in the real word in this study, it is not appropriate to generalize the findings to instructions that are designed to visualize visible phenomena. Future studies are needed to examine the relative effectiveness of animations that are designed to visualize other types of phenomena compared to static picture instructions.

Moreover, this study should not be taken to controvert the value of the static pictures approach to aid students' learning. Instead, static picture instructions might also be useful to support students' learning in some aspects. Our findings indicated that the static picture instruction was not less effective for students' performance of multiple-choice questions, which indicates that the static pictures approach could be an alternative and convenient way to help students acquire basic concepts of a learning topic.

An interesting and valuable topic for future research into multimedia learning in genetics would consider individuals' working memory capacity (WMC). WMC is a frequently used index of an individual's cognitive capacity, which is known to play a crucial role in higher-order cognitive functions. It has been suggested that the impact of cognitive load on individuals with lower WMC exceeds the impact on individuals with higher WMC (De Neys, 2006). Thus, it is reasonable to expect that a well-designed animation instruction would benefit individuals with lower WMC more than those with higher WMC. A number of studies have examined the effect of WMC on multimedia learning (Austin, 2009; Lusk, et al., 2009; Seufert, Schütze, & Brünken, 2009); however, the results are inconsistent. Future studies examining the effect of animation instruction on WMC would contribute to a better understanding of the boundary conditions of the multimedia approach.

In conclusion, this study, with consideration of equivalent design between instructions and the application of learning theories, reveals that the animation approach is more effective in helping students to learn invisible infinitesimal phenomena than the static pictures approach because it helps to lower the perceived extraneous cognitive load and reach higher achievement. Although this study is not without restrictions, it provides a methodologically sound comparison between the animation and static pictures approaches, which could serve as a basis for future studies.

Acknowledgments

The work in this study was supported by the National Science Council of Taiwan under contracts NSC 105-2511-S-008 -002 -MY3 and 105-2511-S-003 -012 -MY3 and by the Aim for the Top University Project-NTNU.

References

Albaladejo, C., & Lucas, A. (1988). Pupils' meanings for "mutation." *Journal of Biological Education, 22*(3), 215-219.

Austin, K. A. (2009). Multimedia learning: Cognitive individual differences and display design techniques predict transfer learning with multimedia learning modules. *Computers & Education, 53*(4), 1339-1354.

Ayres, P., Marcus, N., Chan, C., & Qian, N. (2009). Learning hand manipulative tasks: When instructional animations are superior to equivalent static representations. *Computers in Human Behavior, 25*(2), 348-353.

Ayres, P., & Paas, F. (2007). Making instructional animations more effective: A Cognitive load approach. *Applied Cognitive Psychology, 21*(6), 695-700. doi:10.1002/acp.1343

Banet, E., & Ayuso, G. E. (2003). Teaching of biological inheritance and evolution of living beings in secondary school. *International Journal of Science Education, 25*(3), 373-407.

Bodemer, D., Ploetzner, R., Feuerlein, I., & Spada, H. (2004). The Active integration of information during learning with dynamic and interactive visualisations. *Learning and Instruction, 14*(3), 325-341.

Brown, C. (1990). Some misconceptions in meiosis shown by students responding to an advanced level practical examination question in biology. *Journal of Biological Education, 24*(3), 182-186.

Chang, C.-C., & Yang, F.-Y. (2010). Exploring the cognitive loads of high-school students as they learn concepts in web-based environments. *Computers & Education, 55*(2), 673-680.

Chang, C. Y., Yeh, T. K., & Barufaldi, J. P. (2010). The Positive and negative effects of science concept tests on student conceptual understanding. *International Journal of Science Education, 32*(2), 265-282. doi:10.1080/09500690802650055

Chen, R. H. (2004). *Intelligence Test for Junior High School--Revised Edition.* Taipei, Taiwan: Chinese Behavioral Science Corporation.

De Neys, W. (2006). Dual processing in reasoning two systems but one reasoner. *Psychological Science, 17*(5), 428-433.

Hegarty, M. (2004). Dynamic visualizations and learning: Getting to the difficult questions. *Learning and Instruction, 14*(3), 343-351.

Höffler, T. N., & Leutner, D. (2007). Instructional animation versus static pictures: A Meta-analysis. *Learning and Instruction, 17*(6), 722-738.

Hasler, B. S., Kersten, B., & Sweller, J. (2007). Learner control, cognitive load and instructional animation. *Applied Cognitive Psychology, 21*(6), 713-729. doi:10.1002/acp.1345

Jereb, E., & Smitek, B. (2006). Applying multimedia instruction in e-learning. *Innovations in Education and Teaching International, 43*(1), 15-27. doi:10.1080/14703290500467335

Johnstone, A., & Mahmoud, N. (1980). Isolating topics of high perceived difficulty school biology. *Journal of Biological Education, 14*(2), 163-166.

Lusk, D. L., Evans, A. D., Jeffrey, T. R., Palmer, K. R., Wikstrom, C. S., & Doolittle, P. E. (2009). Multimedia learning and individual differences: Mediating the effects of working memory capacity with segmentation. *British Journal of Educational Technology, 40*(4), 636-651.

Marbach-Ad, G., Rotbain, Y., & Stavy, R. (2008). Using computer animation and illustration activities to improve high school students' achievement in molecular genetics. *Journal of Research in Science Teaching, 45*(3), 273-292. doi:10.1002/tea.20222

Mayer, R. E. (2001). *Multimedia learning.* New York, NY: Cambridge University Press.

Mayer, R. E. (2003). The Promise of multimedia learning: Using the same instructional design methods across different media. *Learning and Instruction, 13*(2), 125-139.

Mayer, R. E. (2008). Applying the science of learning: Evidence-based principles for the design of multimedia instruction. *American Psychologist, 63*(8), 760-769.

Mayer, R. E., Hegarty, M., Mayer, S., & Campbell, J. (2005). When static media promote active learning: Annotated illustrations versus narrated animations in multimedia instruction. *Journal of Experimental Psychology: Applied, 11*(4), 256-265.

Mayer, R. E., & Moreno, R. (2002). Animation as an aid to multimedia learning. *Educational Psychology Review, 14*(1), 87-99.

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist, 38*(1), 43-52.

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The Role of modality and contiguity. *Journal of Educational Psychology, 91*(2), 358-368.

Najjar, L. J. (1996). Multimedia information and learning. *Journal of Educational Multimedia and Hypermedia, 5*(2), 129-150.

Narayanan, N. H., & Hegarty, M. (2002). Multimedia design for communication of dynamic information. *International Journal of Human-Computer Studies, 57*(4), 279-315.

Paas, F. G. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A Cognitive-load approach. *Journal of Educational Psychology, 84*(4), 429-434.

Paas, F. G., & Van Merriënboer, J. J. (1994). Instructional control of cognitive load in the training of complex cognitive tasks. *Educational Psychology Review, 6*(4), 351-371.

Paas, F. G., Van Merriënboer, J. J., & Adam, J. J. (1994). Measurement of cognitive load in instructional research. *Perceptual and Motor Skills, 79*(1), 419-430.

Rieber, L. P. (1989). The Effects of computer animated elaboration strategies and practice on factual and application learning in an elementary science lesson. *Journal of Educational Computing Research, 5*(4), 431-444. doi:10.2190/961x-qqeq-7pvk-uk9e

Russell, A. W., Netherwood, G. M. A., & Robinson, S. A. (2004). Photosynthesis in silico. Overcoming the challenges of photosynthesis education using a multimedia CD-ROM. *Bioscience Education, 3*(1), 1-14.

Seufert, T., Schütze, M., & Brünken, R. (2009). Memory characteristics and modality in multimedia learning: An Aptitude–treatment–interaction study. *Learning and Instruction, 19*(1), 28-42.

Starbek, P., Starčič Erjavec, M., & Peklaj, C. (2010). Teaching genetics with multimedia results in better acquisition of knowledge and improvement in comprehension. *Journal of Computer Assisted Learning, 26*(3), 214-224.

Stewart, J., Hafner, B., & Dale, M. (1990). Students' alternate views of meiosis. *The American Biology Teacher, 52*(4), 228-232.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory.* New York, NY: Springer.

Sweller, J., Chandler, P., Tierney, P., & Cooper, M. (1990). Cognitive load as a factor in the structuring of technical material. *Journal of Experimental Psychology: General, 119*(2), 176-192.

Sweller, J., Van Merrienboer, J. J., & Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.

Tabbers, H. K., Martens, R. L., & van Merrienboer, J. J. G. (2004). Multimedia instructions and cognitive load theory: Effects of modality and cueing. *British Journal of Educational Psychology, 74*(1), 71-81.

Tversky, B., Morrison, J. B., & Betrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human-Computer Studies, 57*(4), 247-262.

Wang, H. C., Chang, C. Y., & Li, T. Y. (2008). Assessing creative problem-solving with automated text grading. *Computers & Education, 51*(4), 1450-1466. doi:10.1016/j.compedu.2008.01.006

Watson, G., Butterfield, J., Curran, R., & Craig, C. (2010). Do dynamic work instructions provide an advantage over static instructions in a small scale assembly task? *Learning and Instruction, 20*(1), 84-93.

Williamson, V. M., & Abraham, M. R. (1995). The Effects of computer animation on the particulate mental models of college chemistry students. *Journal of Research in Science Teaching, 32*(5), 521-534.

Yeh, T. K., Tseng, K. Y., Cho, C. W., Barufaldi, J. P., Lin, M. S., & Chang, C. Y. (2012). Exploring the impact of prior knowledge and appropriate feedback on students' perceived cognitive load and learning outcomes: Animation-based earthquakes instruction. *International Journal of Science Education, 34*(10), 1555-1570. doi:10.1080/09500693.2011.579640