Animated Presentation of Pictorial and Concept Map Media in Biology

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Abstract. Intelligent tutoring systems are beginning to include more varied forms of media, but little is known about how to choose the appropriate media and whether or not it should be animated. This study used a 2 (animated/static) x 2 (picture/concept map) factorial design in order to evaluate the effect of animation and media type on conceptual knowledge, relational knowledge, and free recall. Learners on Mechanical Turk (N = 208) were exposed to one of four conditions in which they viewed a modified Khan Academy video on cell parts. We found that animation induced higher learning gains when it comes to relational knowledge. For conceptual knowledge, animated concept maps outperformed animated pictures while static pictures produced slightly more learning than static concept maps. Our results indicate that using animations to slowly build complexity in visual displays is particularly important when the displays have a rich structure as in concept maps.

Keywords: picture, concept map, animated media, static display, Khan Academy, Biology, link, node.

1 Introduction

As intelligent tutoring systems (ITSs) become more and more sophisticated, the types of media that can be included in such systems have become increasingly varied. In order to support the students' learning, ITSs have included static images (e.g. AutoTutor [1]), diagrams (e.g. Andes [2]), animated illustrations (e.g. Guru [3]), concept maps (e.g. Guru [3], Betty's Brain [4]), videos (e.g. Operation Aries! [5]), and other media. However, there are at this time very few rules in place to guide which media type to select and how to present it given a myriad of parameters such as the student's prior knowledge, student's spatial ability, and task demands [6]. More work is needed to understand what types of media work best under certain conditions.

Recently, the tension between static and animated images has been of particular interest. The literature on animated images demonstrates a strong division between results, where animations sometimes contribute significantly to students' learning and, at other times, they have no impact on learning whatsoever. For instance, in the document explanation literature, images animated using a technique called "sequential display"

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(where an image starts out blank and segments of an image appear when they become relevant in the narration) often result in better memory for the information on the image [7]. In a recent meta-analysis, animations were shown to have a $d = .37$ advantage over static images when it comes to learning [8]. However, the authors caution that this effect is not as strong under all conditions (for instance, animations had a weaker effect in Biology than they did in Chemistry), and may in fact disappear in some circumstances (such as when the animations are purely decorational). For instance, [9] found that students who viewed an ordered series of static images outperformed those who viewed an animated visual of the same dynamic process, which is one of the conditions under which animations are meant to operate best. Therefore, it seems that additional investigations must be done to discover the strengths and limitations of image animation.

However, it is not only animated pictures and illustrations that have been investigated for their efficacy. Researchers focused on concept maps, an educational device that is growing in popularity and has been incorporated into multiple ITSs, have also examined how animation can add to student learning. One of the limitations of concept maps is that they often contain no cues to guide specifically how they should be read. Eye tracking research bears this out, as gaze patterns vary largely between participants examining a concept map [10]. Therefore, animations are seen as a method of directing student attention and imposing a specified processing order. There have been two substantial investigations into concept map animation, but the results of these studies have been mixed, indicating that there may be conditions and best practice rules that guide the animation of concept maps as well. [11] found that animated concept maps resulted in better recall of the information 48 hours later over static maps or even animated text, but that animation had no effect on the ability to recall lower-level details. Recently, [12] also compared static and dynamic text and concept maps but found that animation provided no advantage for either text or concept maps. These opposing results may be due to at least one of two key differences in the experimental designs of the aforementioned studies: concept map complexity/size, where [12]'s map was more complex than [11]'s, and the use of accompanied narration, which [12] claimed counteracted the effects of animation in their study by providing too much scaffolded guidance.

While there seems to be indications that both animated concept maps and pictures can be advantageous to learning under the right conditions, very little is known about how they compare to each other. It seems intuitive to suppose that both have their own time and place in educational multimedia environments, but there are currently no rules to guide the selection of one over the other for ITS designers, and further still, there is no research to suggest whether the presence or absence of animation for either of these media forms should inform this selection decision. Currently, both the concept map animation literature and the picture animation literature focus primarily on how each media type stacks up to its own static version, as well as how it compares to and/or works alongside text (e.g. [11], [13]). How concept maps and pictures compare to each other in terms of learning, as well as how animation affects this comparison, is still an open question.

It may also be the case that it is not a simple matter of determining which media type is most effective, but rather, which type aids specific kinds of learning. For instance, one of the strengths of concept maps is that they explicitly model the relationships between concepts, which have been theoretically linked to creativity, understanding, and deep knowledge of the material [14,15]. However, both pictures and concept maps can convey conceptual knowledge, or information pertaining to the topic's main concepts, such as through picture labels or labeled nodes. To date, none of the concept mapping literature has tried to differentiate between these different knowledge types; therefore, little is known about how concept maps, especially animated concept maps, may influence memory for these kinds of information. Picture animation research has revealed that animation can have an effect on memory for different types of knowledge. [8] found that animation had the largest effect on procedural motor knowledge, followed by declarative knowledge. Others have found that the method chosen for animation, such as displaying objects that are thematically related versus spatially related, can deeply impact how the information is later recalled [16]. It may be instructive to investigate how images, animated or not, impact conceptual and relational knowledge as well, as this would allow for a direct comparison between the performance of students exposed to either concept maps or pictures.

Likewise, there also remains an open question as to how narration impacts animated concept maps. Narration is the preferred mode of information delivery when pictures, animated or not, are available, so that the student's attention is not split between the text and the picture [17]. Narration presented with animated images is also not uncommon (e.g. [13]). However, questions have been raised about whether narration washes out the effects of animation in concept maps [12]. Narration may therefore be one parameter for deciding whether or not to use an animated image or concept map, but a replication of this "washing out" should be observed before deeply exploring this parameter.

In this study, we will look at how pictures and concept maps, both animated and static, effect students' relational and conceptual knowledge learning in Biology, as well as their free recall of information. This will allow for a direct comparison between pictures and concept map media types in terms of their learning efficacy, which may help guide selection principles for their inclusion in educational multimedia environments. The visual in every condition will also be accompanied by spoken narration in order to further test [12]'s hypothesis that spoken narration removes the animation effect that had been observed by [11]. Although no advantage was found for animation in Biology visuals [8], this domain relies heavily on visual aids, and so discovering the best practices for displaying these visuals is to the advantage of both educators and ITS designers within the field of Biology.

This experiment used a Khan Academy Biology video as the basis for the educational intervention. Khan Academy is a popular online company dedicated to making short, freely available video lectures that students find easy to understand. Khan Academy videos always feature audio narration of a lesson played in synchrony with screen capture of the narrator drawing pictures or working out problems that support the lesson. Therefore, the videos produced by Khan Academy are ideal for this kind of investigation because they are ecologically valid learning videos that natively feature picture animation and spoken narration. Khan Academy is also at the forefront of online, self-paced education, and features the kind of media which could be in ITSs due to their low production costs. This experiment seeks to use and modify these materials, which already exist in the educational world, in order to compare the learning produced by animated pictures and concept maps.

2 Methods

A 2 x 2, between-subjects experiment was conducted in order to examine the interactive effects of media animation (*animated* vs. *static*) and media type (*picture* vs. *concept map*). Participants were randomly assigned to one of these four conditions.

Participants were recruited through Mechanical Turk (MTurk), an online service offered through Amazon. MTurk allows "requesters" to put up short tasks ("HITs") to be completed by their "workers," who are then paid a small wage for satisfactorily completing the task. Requesters can also place restrictions, called "qualifications," on who can participate in their study. To ensure quality results, participants who wished to participate in the current study had to have previously completed 50 HITs and had to have at least 95% of those HITs approved by the requesters, meaning that they had done an adequate job on the task and had been paid for it. Additionally, participants in this study had to certify that they were above 18 years of age (an MTurk standard), were a native English speaker, were a United States or Canadian citizen (implemented to increase the odds of recruiting native English speakers and enforced via IP checks), had adequate hardware to complete the experiment, and did not have significant hearing impairments. Those who failed to meet these criteria were disqualified from proceeding to the experiment. Participants who completed the study were paid $1.00.

In this experiment, 214 participants completed the study, but six were disqualified due to their failure to meet the participation criteria. The average age of the participants was 35.91, with a minimum age of 18, a maximum of 72, and a median of 32.5. One hundred fourteen of the participants (54.8%) were female. Previous examinations of the Mechanical Turk workers found that workers are, on average, 31 years old, with ages ranging from 18 to 71, and 55% of workers are female [18], making our sample typical of the MTurk population with the exception that workers outside of the United States and Canada were excluded. Studies have shown that the MTurk population appears to function similarly (i.e., produce qualitatively and quantitatively similar results) to university populations and other online populations [19,20,21].

The materials for this study consisted of four edited videos which made up the stimuli, two interchangeable knowledge measures, and a brief demographics survey (portions of which are reported above). The interventions for this study are based on the "Parts of a Cell" video produced by Khan Academy. In Parts of a Cell, the narrator discusses various cellular components while drawing and labeling them on screen. The Parts of the Cell video was selected due to its straightforward nature and its popularity, as it is one of the most highly viewed videos from their Biology series. The original Parts of the Cell video was edited to shorten the overall video length from 21 minutes to 15 and to remove segments of the video where the narrator scrolls away from the main image to illustrate some point in an aside. This edited video comprised the *animated picture* stimulus. The *animated concept map* stimulus replaced the visual portion of the edited video with an animated concept map. In the concept map version, the nodes correspond to the same labeled and drawn cell parts that appeared in the pictorial version. The concept map is composed of 18 key propositions (facts in node-link-node format) arranged in a hierarchical layout, with much of the arrangement of the map determined by the order in which information is delivered in the narration. In the *animated concept map*, propositions are added to the map generally when the proposition has been stated for the first time. Once added to the map, propositions are not removed, and the map builds in complexity until it reaches its completed state near the end of the lesson. This is the traditional method of animating concept maps [11,12]. The *static* stimuli, both *pictorial* and *concept map*, were created by taking the final, complete version of the cell picture and concept map, respectively, and using that static image as the visual for the entire video while preserving the same audio narration.

While the "smooth drawing" of the picture and the chunked "sequential display" of the concept map are not visually equivalent forms of animation, both represent the ecologically valid and traditional display methods associated with their respective media types; concept maps have long been considered "animated" if displayed one proposition at a time, while pictures lend themselves to being drawn as a form of drawing attention to and elaborating certain areas of the image (as would be seen in, for instance, expert human tutoring [22]). This experiment considers both styles of animation as roughly functionally equivalent, as both are intended to guide the student's attention to specific parts of the media.

The knowledge measures were created by first extracting the propositional facts of the ensuing lesson (e.g. "Vesicles transport proteins"). These propositions were then made into multiple choice questions by removing either the equivalent of a proposition's node (e.g. "Vesicles transport ______") or its linking phrase ("Vesicles ______ proteins."). There were 18 key propositions in the Biology lesson videos, and therefore 18 node and 18 link questions were created for the knowledge measures. The questions were then randomly sorted into Form A and Form B such that each proposition is represented only once per form, resulting in 9 node question and 9 link questions per form. Participants experienced either Form A or Form B as their pretest, and received the opposite test for their posttest (counterbalanced).

To participate, MTurk workers had to first accept the assignment on MTurk, and were then transferred to the actual experiment, which took place in Qualtrics. Once the worker consented to participate and had made the necessary certifications, he or she first took a pretest to assess his/her prior knowledge on cell parts in Biology. After completing the pretest, participants then experienced one of the four conditions (animated picture video, animated concept map video, static picture video, static concept map video). Controls were removed from the video in order to help prevent starting and stopping the lesson, and participants were instructed merely to listen attentively while the video plays without taking notes. Once the video completed, participants performed a free recall task, where they were asked to write down as much information as they could remember from the material they just saw and heard.

After the free recall task, participants took the posttest (the opposite test form from the pretest), and then filled out a brief demographics form. They were then given a password to enter into Mechanical Turk as proof of completion, for which they were then paid.

3 Results

This research seeks to investigate the effects of animation (animated versus static) and media type (picture versus concept map) on various types of learning, specifically conceptual learning, relational learning, and the general free recall of facts. This was accomplished by examining different types of questions: those questions querying the student's memory of node information (conceptual), link information (relational), and their free recall responses. Each of these research questions has been analyzed and considered separately below.

We first investigated how animation and the media type affected "link" questions, which tap into relationship knowledge. The nine multiple choice link questions from both the pre- and posttests were first scored for correctness, and then each participant's proportional learning gains score was calculated. Proportional learning gains, formulated as (Proportionalized Posttest – Proportionalized Pretest) / (1 – Proportionalized Pretest), are a useful learning gains metric because they control for prior knowledge. These were then analyzed using a 2 x 2 between-subjects analysis of variance (ANOVA). While there was not a significant main effect for media type (p = .39) or a significant animation x media type interaction (p = .645), there was a significant main effect for animation, $F(1, 204) = 4.041$, $p = .046$. We see that, when the media was animated (M = .542, SD = .377), participants scored significantly higher on the link questions than those in the static media conditions (M = .405, SD = .577; d = .281).

The analysis of the node questions was given a similar treatment; the scores from the nine node questions in the pre- and posttests were used to calculate a proportional learning gains score, which was then examined using a 2 x 2 between-subjects ANOVA. There was no significant main effect for animation (p = .741), but there was a marginally significant main effect for the media type, $F(1, 204) = 3.402$, $p = .067$, where those in the concept map condition (M = .427, SD = .39) scored higher on node questions than those in the picture condition (M = .319, SD = .452; d = .254). However, the results may be best explained by the significant animation x media type interaction, $F(1,204) = 9.021$, $p = .003$. When the media was animated, those in the concept map condition (M = .501, SD = .282) outperformed those in the picture condition (M = .222, SD = .537) on the conceptual node questions (d = .65). When the image was static, however, those in the picture condition (M = .414, SD = .347) learned more about concepts (nodes) than did those in the concept map condition (M = .347, SD = .468; d = .165).

The free recall was scored automatically by comparing the responses to a list of keywords created from the transcript of the audio narration. One point was awarded for each of the keywords mentioned in the free recall response (although not for repeated mentions), and a coverage score for each person was then calculated by dividing the number of keywords mentioned by the total number of keywords on the list. This allowed us to examine their memory for technical vocabulary particular to the topic. The coverage scores were then analyzed using a 2 x 2 ANOVA to investigate the impact of animation and media type on the participants' memory for vocabulary. A covariate of the combined pretest scores for both link and node questions was also included in order to control for prior knowledge. There was no main effect for media type (p = .374), but there was a marginally significant main effect for animation, $F(1,202) = 3.524$, p = .062, where those who experienced an animated visual (M = .349, SD = .2) had better coverage of key vocabulary terms than those in the static visual conditions (M = .318, SD = .19; d = .195).

4 Discussion

In order to aid common ITS design decisions, this study sought to examine how animation, combined with picture representations and concept maps, affects memory for different types of information. The interpretation of the results is clearest when separately considering how relationships and concepts are best learned.

When it comes to knowledge of relationships, this experiment provides evidence that animation can contribute significantly to learning gains, indiscriminate of whether the image is a picture or a concept map. It seems that the action of animation, therefore, is better at guiding attention to the relationships between concepts, which included relationships such as part-of relations, properties, typology, and functional connections ("Vesicles – *transport* – proteins"). While this finding is not explicitly supported by the picture animation literature, there are some indications that it is in line with previous work. Animation has been shown to be somewhat effective in supporting declarative knowledge learning (d = .44), which would contain both concept and relationship knowledge, but it is especially effective in teaching procedural motor knowledge (d = 1.06; [8]). While procedural motor knowledge is undoubtedly also a combination of conceptual and relationship knowledge, it is mostly focused on the relational "how to" information. Therefore, it is somewhat expected that animations would aid more in teaching relationship knowledge. For concept maps, however, this is entirely new information; most recently, animation had been found to have no effect on learning [12], and there has not been an investigation on how animation would impact the learning of links or nodes. Therefore, the discovery that animation does in fact support learning with concept maps provides evidence that animated concept maps may need to be more deeply explored to understand the conditions under which they do or do not aid learners. Interestingly, although it seems intuitive that concept maps would be superior at teaching relational knowledge, no such link was found in this study, perhaps partially due to the topic (where many of the relationship are "part-of" relations, which are equivalently conveyed pictorially).

Conceptual learning is a more complex story. When the media is animated, concept maps provide superior support in teaching conceptual knowledge (operationalized by node questions). This is particularly interesting because it is not merely a case of concept maps explicitly spelling out the concepts while the picture merely represents them pictorially. The image on the picture drawn by the narrator is also labeled, and the labels of the picture and nodes of the concept map share a high overlap (93%, with the remainder being words jotted down on the picture in an aside). Therefore, the concepts are both equally visually represented in verbal form, but the concept map has the added advantage of removing extraneous detail, which may be the key to its success. Although animated pictures have been shown to aid in teaching declarative knowledge [8], which is at least partly conceptual, this study indicates that animated concept maps may be even better for creating gains in conceptual knowledge. For the static media, the picture fared slightly better than the concept map in terms of conceptual learning, although the difference is not great. This may be because, in the absence of animation, the more detailed picture has more unique cues to encode, and so more attention is paid to the labels and concepts. Further investigation is needed to determine if there is a true advantage of static pictures over static concept maps. However, both static conditions produced higher learning gains for concepts than did the animated picture, possibly due to its overwhelming volume of information and action.

The results from the free recall analysis show a more general (albeit slighter) trend, where animation affected participants' recall of technical vocabulary, which included both conceptual and relationship knowledge (e.g. terms such as "cytosol" and "transcribe"). This effect in and of itself is not surprising given that the literature shows that animation tends to improve learning [8], but what is interesting is the lack of effect for media type. Previous analyses of free recall responses in experiments with animated or static concept maps or text have found that concept maps produce better free recalls than text [11,12]. Here, when comparing two image-based media, this effect disappears; it is possible then that animated image-based media may produce more recalled information than text, although additional research would need to be done to make this direct comparison. While the present free recall analysis is not as thorough as those typical of the concept map literature, where free recall responses are hand scored against a list of declarative knowledge statements, the free recall analysis done here does hint that animation may be useful in not just *recognition* of key terms, as may be demonstrated by the multiple choice questions, but in *recall* of information.

The pattern of results from this study implies that, generally speaking, there are conditions under which concept maps or pictures may be the preferred media, with animation being the main parameter considered in the present work. Animation in general seemed to contribute to relationship knowledge, while animated concept maps specifically were most efficacious in instilling conceptual knowledge. Although, if animation is not an option, static pictures were more effective for conceptual knowledge. This underlines two general findings. First, different types of media seem to have their own contexts in which they are most effective in improving learning, and the learning environment and knowledge goals should be addressed in order to decide on the media type. Second, animation can have different effects on different types of media and learning, and further exploration of this little studied effect is in order. There are also some other interesting implications of this study. This study demonstrated that animated concept maps are not redundant with spoken narration, which would lead to a washing out of learning differences, as [12] suggested. While the parameters under which animation is not useful for concept maps is not yet known, narration does not seem to be one of those parameters. Additionally, it is interesting that these effects were found in the domain of Biology, which was one of the least successful domains in demonstrating differences between animation and static images. It may be the case that other domains would produce a stronger effect.

While this work fills gaps in our current knowledge of animated media, there are some limitations to this study. First, the results of this study do not take into account the effects of domain (in this case, Biology). It may be the case that certain domains or even certain properties of specific lessons are better represented with other types of media or other forms of animation. Likewise, this study also examines very specific kinds of knowledge measures, those that measure conceptual and relational knowledge, but it may be true that for other types of knowledge, such as general declarative knowledge, deep knowledge, or procedural knowledge, the results may vary. It is not the purpose of the present work to claim that one media type is superior to another in general, but rather, to relate that under the established conditions, animation and animated concept maps seem to produce larger learning gains in relational and conceptual knowledge, respectively. This work also does not explore every method of animating an image; there remains a breadth of animation methods in the existing literature to explore using this paradigm.

With the growing use of concept maps and other forms of media in ITSs, it is important that we continue to investigate the conditions under which they can be effective so that informed design decisions can be made. This will allow us to select the most effective media to use in our systems while avoiding investing in unnecessary "bells and whistles" that do not contribute to the student's experience. Future work which explores the limitations and advantages of different types of media in varying degrees of animation are necessary to contribute to the field's development.

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