An Exploratory Study on Inclusion of Visual Representations of Thermodynamics-related Problems

Adetoun O. Yeaman, Karis Boyd-Sinkler, Diana Bairaktarova, PhD
Department of Engineering Education
Virginia Tech
Blacksburg, U.S.A.

Abstract—**Engineering students conceptualize problems in diverse ways depending how the problems are presented. In this study, we investigate how different representations of problems, such as with images and sketches versus traditional word description of problems, allow students to recall information. Some students experience difficulties visualizing a concept when given a word problem while others do not have the same difficulty. A plausible explanation is that students who have less difficulties may be more creative problem solvers or have a better understanding of the material. Data for this study was taken from 132 students enrolled in an introductory thermodynamics course in a large Midwestern university. Half of the participants (n=65) were asked to recognize applications of Laws of Thermodynamics in comparison to the other half (n=67) who were presented with images and asked to identify which Law of Thermodynamics was being depicted. We hypothesized that a higher percentage of students presented with only the images would answer correctly questions of the Laws of Thermodynamics compared to the students who were presented with a standard text description of the problems and asked to answer the questions. The results did not corroborate with our hypothesis. Findings revealed nearly identical performance. In this exploratory study, we discuss outcomes in terms of the underlying links between students' abilities to recall information and the potential of visual representations to enhance learning of thermodynamics-related concepts.**

Keywords—multimedia learning, visualization, thermodynamics, visual thinking, problem solving

I. Introduction

Multimedia learning, which deals with materials presented in multiple modes such as text and images, has been found to enhance learning [1]. Literature reveals that when words and images are incorporated into communication targeted towards promoting learning, people learn better than when only words are presented [1]. Thermodynamics, one of the foundational engineering courses in several engineering disciplines, has been considered as one of the most difficult subjects for students in developing a conceptual understanding, which has presented a need for better ways of enhancing learning in this area [2]. The purpose of this study is to investigate how different representations of problems, such as with images and text versus traditional only worded problems, influence the ability of students to recall information, specifically related to Laws of Thermodynamics.

II. Background

The use of multimedia to enhance learning has been studied for many years and discussed in different forms. Nevertheless, the majority of research surrounding the use of visual representations is presented as a supplemental component for the enhancement of conceptual understanding and how visualization can be used to help solve mathematical and scientific problems [3]. In this section, we review existing literature that attempts to look at visualization from various perspectives. We believe that although several researchers have looked at the role of visualization, there are still missing gaps in research on its relevance in engineering education.

From an educational standpoint, there has been extensive research on how the transfer of learned material and conceptual understanding should ideally take place. Several researchers have attempted to justify transfer of knowledge using a technique called concrete fading [4]. During this technique, concrete examples slowly fade to abstract examples, promoting accurate and adequate transfer. Goldstone and Son, further encouraged this adaptation of concrete fading through the notion of progressive idealization (2005). There has been some resistance to the use of concrete fading as it works under the premise that all superficial similarities will promote universal transfer of material (Goldstone et al. 2003). Other researchers have utilized technology to promote visualization. A study focused on teaching complex adaptive systems using computer based systems emphasized idealized graphics over concrete graphics as it provides a broader range of learning and transfer [6]. Some researchers have focused on visualization through computational and mental models to create understanding, generalization, and transfer of material [7].

Furthermore, other researchers have looked at problems regarding transfer of content material using a number of theories including the Generic Tokens Theory and the "rigged-up perceptual systems" [8], [9]. Several of the theories surrounding visualization drew from the notion of associative

978-1-5090-5920-1/17/$31.00 ©2017 IEEE

recognition which comes from the field of cognitive psychology. In associative recognition, individuals are able to better recall items that are encoded as visual images than verbal labels alone [10]. There are several studies that have looked further into the concept of associative recognition including Dual-Coding Theory and the Visual Imagery Hypothesis [11]–[16]. A recognized strength of using visualizations is the possibility of reduced cognitive load on the individual. By providing a visual-recall cue, the user removes material that may be perceived as irrelevant to the problem (Beveridge & Parkins, 1987).

Phillips et al (2010) note that rather than a single theory that perfectly models visualization, there are multiple partial models and suggest that "current educators and researchers should use the available results in contexts like those in which they were found, because we do not have theories adequate to the task of determining their generalizability to other situations." Heeding this advice, it is important that we expand on and conduct research in the specific area of the influence of visualizations regarding recall in engineering educational settings.

We used the information from the studies above to guide our study, particularly associative recognition. Our study is based on the hypothesis that on a given test on Laws of Thermodynamics, a higher percentage of students presented with pictorial questions would answer questions correctly in comparison to students who were asked to recall knowledge on the Laws in the form of worded problems.

III. Methods

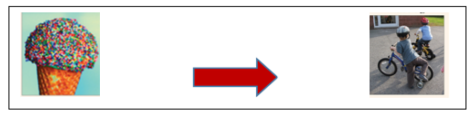
This exploratory study serves as a pilot and specifically aims at engaging the mechanical engineering education community in a meaningful discussion of inclusion of multimedia learning in teaching fundamental subjects, including Thermodynamics. In this line of thought, we present below an instructional approach done in an introductory classroom by one of the authors of this paper. As such, the study does not utilize any specific method but rather suggests research design and potential hypotheses to steer the conversation around multimedia learning and to utilize feedback of the community into a new study design. The setting of this pilot study was an introductory thermodynamics classroom in a Midwestern university during a mid-term exam. The study involved two groups. As our study does not utilize an experimental design, in this paper, we will call the groups A and B. Group A was provided with images to go along with brief questions and group B was provided with the questions in only text form. An example of questions from both groups is presented in Figure 1. Students were not permitted to use their text books but could reference class notes on the exam. Students were also allowed to use the basic equation sheet, property tables, a pen/pencil and a simple calculator. Some of the problems on the test were not relevant and subsequently excluded from this study. On these questions, students were required to show their work clearly and follow the standard problem solving procedure. Each problem on the exam was worth 5 points. Answers needed to be placed in a box provided and there was no partial credit awarded.

A. Study Hypothesis

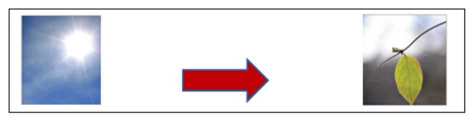
Hypothesis 1: Group A (image group) will perform better than group B (text) on Laws of thermodynamics questions.

Ho1: A=B
Student achievement on the test questions with images will be the same as the achievement on the text questions with only text.

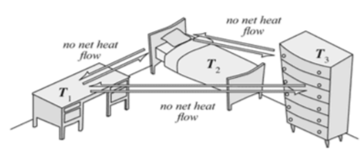
Q1A. Which law of Thermodynamics does the picture below represent?



Q2A. Which law of Thermodynamics does the picture below represent?



Q3A. Which law of Thermodynamics does the picture below represent?



Q4A. Which law of Thermodynamics does the picture below represent?

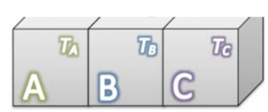


Figure 1. Test questions for group A (0^{th} and 1^{st} Law of Thermodynamics)

Q1B. You have been asked to do a metabolism (energy) analysis of a person. How would you define the system for this purpose? Which Law of Thermodynamics is applicable in this case?

Q2B. If an object A is in thermal equilibrium with an object B, and object B is in thermal equilibrium with object C, then object C will be in thermal equilibrium with object A. Which Law of Thermodynamics does this statement represent?

Figure 2. Test questions for group B (0^{th} and 1^{st} Law of Thermodynamics)

B. Data collection

On the midterm exam, students were provided with test questions including a section of questions relevant to the Laws of thermodynamics (see sample questions above). This section was the focus of our study. The two groups, A and B represent students in two classes of a thermodynamics course who received their tests separately in two different semesters. Group A received problem questions with images. On the other hand, group B received questions with only text. Sample questions are shown in Figures 1 and 2 above. Notably, questions Q1B is equivalent to Q1A and Q2A, while Q2B is equivalent to Q3A and Q4A in terms of content covered.

C. Participants

Participants in this study were sophomore students at a Midwestern university. Two sections of the course taught by the same instructor in two separate semesters were included in this study. One section consisted of sixty-five students while the other consisted of sixty-seven students. Students in the course from two different sections were the participants in this study.

IV. RESULTS

We are in a process of analyzing the data and plan on presenting the completed results in the final version of this paper. Preliminary results reveal that students' grades on the two types of problems were nearly identical. Comparing the answers for both, the 0^{th} and the 1^{st} Law of Thermodynamics, there were 13 students from each section answered their respective questions incorrectly (Table 1). We base the following discussion and future work on these preliminary results.

TABLE I. STUDENTS GRADES DISTRIBUTION

Image Questions (Group A)	**Correct**	**Incorrect**	**Text Questions (Group B)**	**Correct**	**Incorrect**
0^{th} and 1^{st} Law Q1A, 2A	54	13	0^{th} and 1^{st} Law Q1B, 2B	52	13

V. DISCUSSION AND FUTURE WORK

In this study, outcomes are discussed in terms of the underlying links between students' abilities to recall information and the enhancement of learning thermodynamics concepts. The results of this exploratory study can be interpreted in diverse ways.

Many people can recall information more efficiently using cues from pictures than from words alone [18]. In addition, people tend to process pictures faster than words [10]. However, considering that students who were given pictures did not have a significant difference in grades from the students who were not given pictures, there is a need to understand the results better. The time on the test might have given both groups of students a sufficient opportunity to process information and answer the questions correctly given the preparation allowed through the structure of the course.

Many aspects of the structure of the course not accounted for in this study may have influenced the results as well. Firstly, the class was structured as a flipped classroom in which students came to class haven read and prepared for active discussion and engagement with course content during class time. This active learning pedagogy has the capacity to enhance learning however, was not the focus of this study. Also during the course, the instructor provided an open-education resource to students along with a textbook and students could choose which resources to utilize in familiarizing themselves with the course material. The textbook recommended for the class also had many pictures in it that could have improved students' ability to recall content relevant to the exam. Considering that this variety of helpful leaning resources were available to the students over the course of time leading up to the test, they might have been influence by a variety of helpful factors not accounted. Subsequently, students could have been able to recall information about the 0^{th} and 1^{st} Law of thermodynamics easily and the difference in mode of presenting test questions did not have any significant difference on their understanding and subsequent performance.

Notably, in this study, students were presented with only a few image and text comparable problems on their mid-term exam. In addition, this study has looked at only one level of complexity in the sense that the questions were all geared towards recalling the 0^{th} and 1^{st} Laws of thermodynamics. Perhaps, if multiple types of questions with varying levels of difficulty were presented to the students, the outcome may have been different. Future studies could incorporate more questions that are not only about the Laws of thermodynamics thereby allowing us to observe the impact of incorporating visual representations on the course more broadly. Future work could also explore further hypotheses. For example, on questions specific to the 0^{th} Law of thermodynamics, group A will perform better than group B. Examining this hypothesis would allow for a more controlled investigation on one content area. Another example is within group A, students' scores on the questions relevant to the 0^{th} Law of thermodynamics will be the same on the questions relevant to other Laws of thermodynamics. This would control for results that could be accounted for by differences in the level of difficulty of questions across thermodynamics laws.

Further study could also include repeating the same study in other courses relevant problem solving in which students often have difficulty and problem descriptions are typically presented in text. Further research will attempt to establish a relationship between students' abilities to recall information when presented with similar problems in different formats.

VI. CONCLUSIONS

Thermodynamics is an important subject in the core undergraduate curriculum of several engineering disciplines. Students struggle to grasp content in this course. This exploratory study sought to understand the impact of using images in the description of problems on an exam in students' ability to recall information. A group of students were provided with questions solely presented in textual format while another group of students had questions supported by pictures. The study was based on the hypothesis that the students who received images will have better scores on the test, however the results of the study did not show any significant difference between the two groups. Future work will control for several factors not accounted for in this study that may have impacted unexpected results such as helpful learning resources provided in the course that may have enhanced recall of information. Implications of the results of this study would not only impact the future of thermodynamics courses but may also provide insight on how to present information to students in another problem-solving type courses.

REFERENCES

[1] R. E. Mayer, Multimedia Learning, 2nd ed. Cambridge University Press: Cambridge University Press, 2009.

[2] Y. Liu, "Development of instructional courseware in thermodynamics education," Comput. Appl. Eng. Educ., vol. 19, no. 1, pp. 115–124, 2011.

[3] S. P. Norris, Reading for evidence and interpreting visualizations in mathematics and science education. Sense Publishers, 2012.

[4] E. R. Fyfe, N. M. Mcneil, J. Y. Son, and R. L. Goldstone, "Concreteness fading in mathematics and science instruction: a systematic review," Educ Psychol Rev, vol. 26, pp. 9–25, 2014.

[5] R. L. Goldstone and J. Y. Son, "The transfer of scientific principles using concrete and idealized simulations," Source J. Learn. Sci., vol. 14, no. 1, pp. 69–110, 2005.

[6] J. Y. Son and R. L. Goldstone, "Fostering general transfer with specific simulations," Pragmat. Cogn., vol. 17, no. 1, pp. 1–42, 2009.

[7] R. L. Goldstone, U. Wilensky, and R. Goldstone, "Promoting transfer by grounding complex systems principles," J. Learn. Sci., vol. 17, no. 4, pp. 465–516, 2008.

[8] J. Y. Son, L. A. A. Doumas, and R. L. Goldstone, "When do words promote analogical transfer?," J. Probl. Solving, vol. 3, no. 1, 2010.

[9] R. L. Goldstone, D. H. Landy, and J. Y. Son, "The education of perception," Top. Cogn. Sci., vol. 2, no. 2, pp. 265–284, Apr. 2010.

[10] W. E. Hockley, "The picture superiority effect in associative recognition," Mem. Cogn., vol. 36, no. 7, pp. 1351–1359, 2008.

[11] J. M. Clark and A. Paivio, "Dual coding theory and education," Source Educ. Psychol. Rev. Educ. Psychol. Rev., vol. 3, no. 3, pp. 149–210, 1991.

[12] A. Paivio, Mental representations: a dual coding approach, 9th ed. New York : Oxford University Press, 1986.

[13] M. Sadoski and A. Paivio, Imagery and Text : A Dual Coding Theory of Reading and Writing: EBSCOhost. Mahwah, NJ: Routledge, 2001.

[14] Z. W. Pylyshyn, Seeing and visualizing : it's not what you think. MIT Press, 2003.

[15] I. Vekiri, "What is the value of graphical displays in learning?," Educ. Psychol. Rev., vol. 14, no. 3, pp. 261–312, 2002.

[16] V. Bell and P. N. Johnson-Laird, "A model theory of modal reasoning," Cogn. Sci., vol. 22, no. 1, pp. 25–51, 1998.

[17] L. M. Phillips, S. P. Norris, and J. S. Macnab, Visualization in Mathematics, Reading, and Science Education. Springer, 2010.

[18] R. E. Mayer, Multimedia Learning, 2nd ed. Cambridge: Cambridge University Press, 2009.