# Computer Generated Dynamic Graphic Organizer's Effect on Learning Outcomes

## Theoretical Framework for the Research

Graphic displays of information have long been critically examined for their ability to improve students' learning and retention of new information. Traditionally, graphic displays of information include concept maps, flow charts, semantic maps, tree diagrams, and other organizers dealing with the display of information graphically in a meaningful way (Horton, Lovitt, & Bergerud, 1990). Graphic displays of information can be used as advance organizers to give students a road map before learning new and potentially challenging material (Ausubel, 1968).

The intervention used in this study is closely related to author-provided graphic organizers discussed by Stull and Mayer (2007). Previous work on similar tools have all been linked to cognitive theory in one way or another. Advance organizers allow students to link previous knowledge to new knowledge following knowledge schemas (Ausubel, 1968). Indeed, there is evidence that when introduced to the material beforehand, students learn more from lectures covering difficult concepts (Schwartz & Bransford, 1998; Stelzer, Gladding, Mestre, & Brookes, 2008). Concept maps reduce cognitive load by demonstrating the connections between ideas (Hill, 2005; Novak, 1998). In fact, graphic organizers provided to students have been shown to reduce cognitive load allowing for better processing of new information (Stull & Mayer, 2007). Underlying this study is the idea that students learn better by making and visualizing connections between knowledge.

Having the ability to access, apply, and connect various mathematical equations is useful in helping individuals understand the topics that these equations describe. Equations are a way of writing and making sense of formal mathematical concepts (Wang & Liu, 2017b). Across many subjects, graphic organizers have been used to assist students in making sense of new, formal concepts. Graphic organizers have the potential to improve learning and retention by making new, abstract material more concrete and by making connections between prior knowledge and new information (Ausubel, 1968; Dexter & Hughes, 2011; Mayer, 1979). The complexity of new mathematical knowledge in mathematical expressions (ME) could create a cognitive load burden. To help students learn mathematical ideas, a team of computer science engineering researchers developed the Dynamic Interactive Mathematical Expressions (DIME) map system (Wang, Liu, Lin, & Vrecenar, 2018). This DIME map system provides a road map of interconnected topics and equations in order to reduce the cognitive load inherent in learning new material.

This "road map" of interconnected topics manifests itself through the DIME map, which uses links, arrows, and spatial arrangement to highlight both key concepts and structural relationships. The DIME system removes redundant elaborations found in the text and covers only the fundamental concepts expressed in equations bounded with words. In other words, the DIME system finds mathematical equations and expressions and identifies them using the surrounding text, even when there are many other unrelated words in the surrounding sentences. It also uses the semantics established throughout the document to accurately identify and connect elements of the expressions and equations, creating a smooth continuity of meaning across presentations.

The DIME system differs from the existing manually constructed, static cognitive mappings. The system links key concepts presented in words and equations within a text and then automatically creates a map of the interconnection of mathematical equations and expressions from this information. Users can then customize their maps interactively to meet their own conceptual needs. The most innovative element of the DIME system is its elastic container that allows users to see the DIME map displayed side-by-side with the original PDF text document. It is an elastics map that can hold large amounts of content, while providing a convenient way to move the display through pan and zoom in/out operations. The placement of the ME nodes follows the principle of spatial affinity for connected concepts, which is in accordance with humans' spatial perception. The density of the nodes can be adjusted to make best usage of the space and avoid overlapping and linked back to the text. Further, a user can customize the spatial arrangement of partial nodes to meet her own conceptual understanding. One can also "hide" a node from the DIME map that one regards as less important.

1) One could search the words and mathematical expressions directly to locate certain pieces of information, and the matched information will be highlighted in both the DIME map and textbook through resizing and the changing of colors. 2) When studying the building components and the usage of certain MEs, one could simply click to focus on the ME. After the click, only related MEs will be highlighted and the others will fade out using transparency. The in/out relationship is indicated by the arrows. 3) The DIME map is synchronized with the original material side by side through the color coding. One could navigate to the original materials on the left by clicking on the ME in the DIME map. On the other sides, the MEs in the current view of the left PDF viewer will be highlighted blue in the DIME map. Finally, a snapshot of the user-made arrangement could be taken for record or for sharing with others. Given the input limitation for the small screen, the PDF and the DIME map could be hidden to make the best use of the space. Redundancy input options such as buttons are provided for the user using touch screen or touch pad. The dynamic and interactive features of the DIME map make it potentially more engaging, and therefore educationally significant, than traditional graphic organizers.

**Methods**

This study focused on two research questions:

(1) Does use of the DIME map improve ability to connect knowledge?

(2) Does use of the DIME map improve attitude toward learning physics?

There were 31 high school participants who signed up to take a physics class during a summer camp designed for STEM-oriented students. These students were randomly assigned to one of two groups: 15 were assigned to the control group (5 females and 10 males) and 16 were assigned to the experimental group (5 females and 11 males). None of the students had taken a physics class in school. Detailed demographics for the participants in this study were as follows: 10 (32%) females and 21 (68%) males; 9 (29%) Hispanic or Latino and 22 (71%) White; 10 (32%) 9th graders, 7 (23%) 10th graders, 11 (35%) 11th graders, and 3 (10%) 12th graders. Both the experimental and the control groups engaged in four 1.5-hour sessions exploring the physics involved in fixed axis rotation and their relations to the popular toy, fidget spinners.

**Data Sources**

Students chose four of eight possible 1.5-hour activities. They were then immersed in the activity each day (4 or 5 days) for the 1.5 hours. Students who selected the physics activity were then randomly assigned to either the control or experimental group. The course was taught by a single instructor who was observed by at least two, but on some days three, researchers whose primary focus was to ensure that lessons were presented to the two groups in exactly the same fashion, with the same pacing, and using the same pedagogical strategies. The notes made by these additional researchers were kept as observation data to ensure that the only exception in the instructional content administered between the two groups was when the DIME map was used with the experimental group. The purpose of using the same instructor was to avoid scripting to reduce the cognitive load on the instructor and to afford a more uniform implementation. The instructor was trained to use the DIME map by the development team and the instruction for teaching students about the DIME map was co-developed by the instructor and the research team.

In addition to the observation data collected, one pre/posttest for each Knowledge, Connections, and Attitude was administered. The instruments were first vetted by research faculty in the colleges of Science and Education who evaluated their validity and their alignment to the lesson content and objectives. The Cronbach's alpha across items was .705, while Attitude was .849, Connections was .301, and Knowledge was unable to be calculated because it was almost uniformly zero at pretest and maximum at posttest. Attitude was robust yielding a strong positive internal consistency estimate. Both Connections and Knowledge tended toward the upper end of the possible scores resulting in little variation, which limited the use of internal consistency estimation of reliability. Our data were analyzed using *t*-tests because we met all the assumptions and did not violate multiple estimates of the same dependent variable; therefore, it was not necessary to use a Bonferroni correction. We also reported effect sizes because they are often referred to as the single best reporting strategy for quantitative methods and need not be reserved for when reporting a statistically significant result.

**Results**

The primary interest of this exploratory study was to determine if the DIME map in some way mediated learning for the experimental group as compared to the control group. After the data were collected and analyzed preliminarily, it also became interesting to examine the effects of the DIME map by gender.

There were no statistically significant differences in pretest scores across Attitude, Connections, and Knowledge between the two groups or between the females of each group (see Table 1). The Wilks lambda was not statistically significant so the MANOVA was a suitable choice for the data analysis. The adjusted $R^2$ effect sizes were small and relatively unimportant. Therefore, the random assignment and the pretest allowed us to conclude to with reasonable certainty that any obtained effects were due to the intervention and the DIME map. Although the sample sizes were small, which meant there was increased likelihood of a Type II error, the a priori power analysis with an estimated effect size of .45 indicated that 5 participants per estimated parameter was sufficient.

Table 1

**MANOVA of Pretest Control and Experimental Groups Across Tested Variables**

| | Variable | Wilks Lambda | | MANOVA | | | Effect |
|---|---|---|---|---|---|---|---|
| | | Value | *F* | *Type III SS* | *F* | *p* | Adj $R^2$ |
| Group CE (Experimental-Control) | Connections | .912 | .872 | .659 | 1.460 | .273 | .015 |
| | Knowledge | | | 2.450 | 1.779 | .193 | .025 |
| | Attitude | | | 6.804 | .495 | .487 | .017 |
| Group CE, Females Only (Experimental-Control) | Connections | .764 | .617 | .400 | .800 | .397 | .023 |
| | Knowledge | | | .000 | .000 | .999 | .000 |
| | Attitude | | | 6.40 | 1.347 | .279 | .037 |

The standardized effects were computed using Cohen's *d* for all variables including those that were not of primary interest to provide study information for future meta-analyses. Because no significant differences were found between groups and subgroups on the pretest, all reported effect sizes are experimental group/subgroup versus control group/subgroup. The largest obtained effects were for Attitude (*d*= .322) and Connections (*d*=.653). In particular, Females who used the DIME map had better attitudes toward the content (*d*=.761) and scored better on Connections within the physics content (*d*=1.618). That is, females in the experimental group were better able to make connections to tangential but closely related concepts than females in the control group.

More modest results were found when calculating the effect for females' Knowledge (*d*= .338). A third standard deviation indicated substantial differences between females who used the DIME map and those who did not for Knowledge. The test for Knowledge tested a student's lowest level of understanding of the mathematics and was aligned with Bloom's Taxonomy (knowledge). While females in both the control and experimental groups increased their scores on the Knowledge pre/posttest, the experimental group experienced a much greater increase.

**Educational Importance of the Research**

This work extends the research in three broader areas. First, it addresses important issues with the development of mathematical or symbolic language (cf. Esteve, 2008; Goldin & Kaput, 1996; Silver, 2017). Second it addresses the broad research agenda of reading in the mathematics content area (cf. Moschkovich, 2007), and finally it addresses how students learn to make connections between the text intended to teach mathematics and symbolic representations used to express those mathematical representations (Godino, Batanero, & Font, 2007; Hiebert, 1988). Historically, concept maps and graphic organizers have been limited in how students can make use of them to meet their own individual academic needs. It is common to find concepts maps and graphic organizers that are predesigned for students as an advance organizer or that are co-developed with a group of students as a classroom instructional strategy. The limitation in these forms of concept maps and graphic organizers lies in the lack of self-agency and customizability: these organizers are singular constructions designed for the class and are therefore not customizable to any particular student's needs. Such types of organizers are static and fully dependent on who designed the instruction or led the development. While there is nothing wrong with this method, it is a proxy measure aimed at understanding how students learn from or whether maps improve student learning. Only now has technology afforded the ability for students to interactively work with a textbook chapter to build dynamic and customizable maps of the content they are learning.

Because mathematics becomes more complex and the syntax and semantics of algebra (cf. Capraro, Capraro, & Rupley, 2010; Rupley, Capraro, & Capraro, 2011) often integrate aspects of other formulae, students using a DIME map can easily track a complex formula back through its development. For example, angular momentum is equal to moment of inertia multiplied by angular velocity. This relationship may sound simple; however, this relationship is comprised of several mathematical relationships that students must already know and understand. By using the DIME software, students are able to visualize and interact with the connections between concepts and meet immediate personal learning needs. Through future research analyzing the effects of the DIME map on larger groups and across more variables, the DIME map may prove to effectively improve retention, understanding, and attitude for high school students.

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