The Influence of Mind Mapping on Eighth Graders' Science Achievement

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This study assessed the influence of using mind maps as a learning tool on eighth graders' science achievement, whether such influence was mediated by students' prior scholastic achievement, and the relationship between students' mind maps and their conceptual understandings. Sixty-two students enrolled in four intact sections of a grade 8 science classroom were randomly assigned to experimental and comparison conditions. Participants in the experimental group received training in, and constructed, mind maps throughout a science unit. Engagement with mind mapping was counterbalanced with involving the comparison group participants with note summarization to control for time on task as a confounding variable. Otherwise, the intervention was similar for both groups in all respects. A multiple choice test was used to measure student gains across two categories and three levels of achievement. Data analyses indicated that the experimental group participants achieved statistically significant and substantially higher gains than students in the comparison group. The gains were not mediated by participants' prior scholastic achievement. Analyses also indicated that iconography was not as central to participants' mind maps as often theorized. Depicting accurate links between central themes and major and minor concepts, and using colors to represent concepts were the major aspects that differentiated the mind maps built by students who achieved higher levels of conceptual understanding.

An essential component of meaningful learning is the integration of new or target concepts into the learner's framework of relevant concepts (Ausubel, 1968). Building non-arbitrary and coordinated links between a learner's knowledge structures and a target concept or set of concepts could be facilitated by, among other things, the use of visual organizers (Novak & Gowin, 1984). Among the latter, mind mapping could serve as a particularly useful tool for helping younger students with the process of building conceptual understandings of disciplinary content and, consequently, promoting their achievement. Mind mapping is a historical forerunner in the development of dynamic visual tools and organizers. Similar to these latter tools, mind mapping promotes conceptual links between and among ideas in mostly non-linear, holistic ways and inspires the use of personal connections, experiences, and creativity as foundations for meaningful learning (Farrand, Hussain, & Hennessy, 2002; Grant & Shank, 1993; Margulies, 1995; Rega, 1993). However, unlike other visual tools, mind maps emphasize student-created representations of knowledge as compared to those representations being imposed by the visual tool itself (e.g., the hierarchy, branches, links, and cross-links in concept mapping). The approach involves brainstorming ideas, which are then diagrammed in a weblike structure rather than linear, uni-directional, two-dimensional (and sometimes hierarchical) sequential buildup of ideas based on a specified format (Davies, 1990; Farrand et al.; Hyerle, 1996; Nast, 2006). Various icons and other non-symbolic representations coupled with coloring are often used to further individualize mind maps in ways that enhance their utility and meaningfulness to learners who construct them.

Research supports the use of mind mapping in teaching and learning because it facilitates the essential processes of visual coordination and integration with other cognitive operations, which are essential to knowledge construction (Buzan, 1976; Creswell, Gifford, & Huffman, 1988; Nast, 2006). Also, the idiosyncratic nature of mind maps works in their favor because individualized perceptions play a significant role in assimilating, organizing, accommodating, and retaining information (Ornstein, 1986, 1991). The dynamic nature of mind maps, which allows for three dimensional representations of knowledge structures, adds to their versatility and responsiveness to individual differences (Nast; Sperry, 1993). Finally, mind mapping can greatly facilitate linking visual and verbal intelligences—in the context of Gardner's (1993) theory of multiple intelligences and Kline's (1988) notion of integrative learning, and help in the assimilation and long-term retention of information (Rega, 1993). Surprisingly, despite its promise and potential, the use of mind maps in science teaching and learning has been the subject of very limited empirical research. Thus, the purpose of this study was to assess the influence of using mind maps on middle school students' achievement in science.

Background and Review of the Literature

Hyerle (1996) organized visual tools under three categories, each with subcategories: (a) Brainstorming webs, which include mind mapping, clustering, and webbing, (b) task-specific organizers, which include life cycles, text structures, flow maps, and decision trees, and (c) thinking process maps, which include concept maps, thinking maps, and Vee maps. Visual tools, as their proponents argue, are deeply rooted in constructivist theory (Eastman, 1977; Jones, 1977; Novak & Gowin, 1984). In essence, such tools can be thought of as forms of metacognition: They support strategies that enable students to process information through building conceptual links, discern patterns among concepts, develop the capacity for viewing situations from multiple perspectives, and reflect on and modify understandings in response to feedback from others (Buzan, 2000; Hyerle, 1996; Wycoff, 1991). Much empirical research on visual tools has been directed toward the use of concept maps, Vee maps, and flow maps. Hardly any research on the impact of mind mapping has been undertaken despite their having additional advantages over those documented for other visual tools, especially that mind maps are somewhat unique in not imposing structures on students as they represent their knowledge and understandings (Anderson & Demetrius, 1993; Farrand et al., 2002; Heinze-Fry & Novak, 1990; Horton, McConney, Gallo, Woods, Senn, & Hamelin, 1993; Novak, Gowin, & Johansen, 1983; Westbrook, 1998).

Concept Maps, Vee Maps, and Flow Maps

Concept mapping has its origins in Ausubel's (1968) learning theory, which placed special emphasis on the influence of prior knowledge and the importance of fostering meaningful learning. Much of this learning occurs when students consciously and explicitly connect new knowledge to existing conceptual structures. Concept maps attempt to render a concrete representation of the structural knowledge of an individual and the ways in which these concepts are perceived to be connected to one another and to existing structures (Champagne, Klopfer, Desena, & Squires, 1981; Novak et al., 1983; Schaefer, 1979; West & Pines, 1985).

Research has shown that concept mapping, whether teacher or student initiated, tend to enhance science achievement through promoting integrated learning (e.g., Westbrook, 1998; Willerman & MacHarg, 1991), enhancing meaningful learning (e.g., Heinze-Fry & Novak, 1990; Novak et al., 1983), increasing comprehension of text (e.g., Slotte & Lonka, 1999), building hierarchical relationships among concepts (Horton et al., 1993), and acting as a social "glue" in collaborative groups (Esiobu & Soyibo, 1995; Roth & Roychoudhury, 1993). However, other researchers have identified several shortcomings with hierarchical concept maps (e.g., Safayeni, Derbentseva, & Cañas, 2005) and/or found that concept mapping had no significant effects on student achievement (e.g., Lehman, Carter, & Kahle, 1985; Markow & Lonning, 1998).

The Vee heuristic was derived from Gowin's interest in the structure of knowledge (Gowin, 1979). The purpose of the Vee map is to assist students in unpacking the relationship between the conceptual and procedural aspects of science-based activities. As they construct the Vee, students give explicit consideration to the research question, the events, and objects under investigation; the conceptual structure that underlies the inquiry; the data recording and transforming procedures; and the knowledge and value claims that derive from the investigation (Novak, 1990; Novak et al., 1983). Vee maps can help students organize their thought patterns and reflect on the processes of learning science (Roth & Roychoudhury, 1992).

While some studies have linked the use of Vee maps to enhanced student achievement, others pointed out the difficulties inherent in using them (Esiobu & Soyibo, 1995). Novak et al. (1983) found that students often need a long time to understand the procedure for constructing and become accustomed to using Vee maps efficiently. Such a limitation might mitigate the effectiveness of Vee maps as a practical classroom tool (Eisobu & Soyibo, 1995).

Flow maps are hierarchical organizational charts that reflect learners' organizational structures when interpreting a certain topic or domain. Unlike concept maps, flow maps do not feature linking terms or phrases between the mapped concepts (Anderson & Demetrius, 1993; Bischoff, 2002). Anderson and Demetrius found that cross-relational links in flow maps produced by junior high school students increased with enhanced recall of relationships among science concepts. Flow map interconnectedness was correlated with middle school students' recall of biological information (Demetrius, 1998) and enhanced laboratory performance (Anderson, Randle, & Covotsos, 2001). Tsai (1998) correlated flow map linkages with eighth graders' science achievement. Bischoff (1999) found significant correlation between elementary teachers' knowledge interconnectedness as represented in flow maps and their ability to apply ecological knowledge to novel environments. However, flow maps are somewhat limited to a linear organization of the knowledge domain being studied (Anderson & Demetrius).

Mind Maps

Mind mapping emphasizes visual imagery. Several studies on memory show the significance of visual imagery in information retention. For example, Haber (1970) showed his participants an original group of 2560 photos. Later, participants were shown 2560 pairs of photos and asked in each case to identify which photo was in the original group. The success rate for this test averaged around 90% showing drastically improved retention ability among learners when the target information is visualized. Building on such studies, Buzan (1976) developed mind mapping as a method for note-taking based on the idea of making notes as brief as possible and as "interesting to the eye" as possible by using visual effects.

Although little research has been conducted on the use of mind maps, some researchers have hypothesized that mind maps could be effective in improving study skills and recall of information, which can lead to higher achievement (e.g., Ornstein, 1986; Sperry, 1993; Sylwester, 2000). Buzan and Buzan (1993) argued that patterns in mind maps allow students to represent and *see* connections more easily than outlines or flowcharts. Also, Regina (1993) noted that because mind maps facilitate making rapid connections between ideas, students can easily add information, concepts, and linkages to better grasp the "whole picture" and relationships among its parts. Wycoff (1991) argued that another advantage to the use of mind maps is the active engagement of various cognitive functions and processes, which has been shown to enhance learning (e.g. Russell, 1979). Despite such promise and potential derived from theoretical work, there are virtually no empirical studies on using mind mapping as a learning tool in science teaching, even though connection-building and individual sense-making have been emphasized as key to improved understanding of abstract science concepts (e.g., Roth & Roychoudhury, 1992).

The individualized, student-created structure and nature of mind maps might also have an additional advantage. Research has indicated that the impact of instruction in metacognitive tools on learning is often mediated by student achievement level (Gage & Berliner, 1998). In general, medium achievers accrue more benefits from instruction in and using metacognitive tools than low and high achieving students. This differential impact is often explained on the basis that high achievers have already developed their own effective strategies, while low achieving students either lack the motivation or prerequisite skills to make effective use of the target strategies, and, thus, both groups do not benefit as much from instruction in or using metacognitive strategies as would "average" students (Gage & Berliner). Being of the metacognitive variety, some recent evidence suggests that such differential effect applies in the case of visual tools, such as concept maps (e.g., Stoyanova & Kommers, 2001; Rao, 2004). Such results could be attributed to the fact that some visual tools embody metacognitive models with certain structures and restrictions (e.g., hierarchical nature of concept maps, need for relational abstraction in Vee maps) that might compromise their effectiveness in relation to students' achievement levels. In comparison, it could be hypothesized that the highly individualized nature of mind maps and their relative lack of structural restrictions might render this metacognitive tool effective in promoting learning irrespective of students' achievement level. Such hypothesis was tested in this study.

Purpose and Research Questions

This study aimed to assess the influence of using mind maps as a learning tool on grade 8 students' achievement in science and whether such influence was mediated by students' prior achievement. The study was guided by the following research questions: (1) What is the effect of using mind mapping on the science achievement of grade 8 students? (2) Does the impact of using mind mapping, if any, interact with students' prior achievement levels? (3) What is the relationship between different elements of participants' mind maps (geography, central themes, major concepts/links, and minor concepts/links) and gains in their science achievement?

Method

The study had a 2x3 factorial posttest only comparison group design. The first factor (the independent variable) was use of mind mapping as a learning tool with two levels (use and no use). The second factor (the moderator variable) was prior scholastic achievement (PSA) with three levels (high, medium, and low). Post-instruction student achievement served as the dependent variable. Two of the four sections of the targeted classroom, were randomly chosen as experimental and two were chosen as comparison groups. One month prior to data collection, participants in the experimental and comparison group received systematic instruction in using mind mapping and note summarization respectively. Students in the experimental group developed expertise in mindmap construction by following a procedure for systematic writing of mindmaps adapted from Buzan (1976). Next, the science achievement of the two groups was compared following a month-long intervention in which students in the experimental group used mind maps on a daily basis while those in the comparison group used note summarization. Student post-instruction achievement was measured on a multiple-choice item test developed by the researchers.

In addition to being part of the instructional intervention, participants' mind maps also served as a source of data to address the research question about the relationship between different aspects of students' mind maps and their science achievement. Two mind maps for each participant in the experimental group—one produced early during the study and the other toward its end—were collected and systematically analyzed. "Early" and exit mind map analyses for each participant were compared and contrasted. Exit mind maps were also compared and contrasted after being clustered according to participants' level of achievement.

Participants

Participants were 62 students (13 to 14 years old) enrolled in four intact sections of a grade 8 science classroom. The sections were randomly assigned to the experimental and comparison groups. The experimental group comprised 31 students (13 female, 18 male) and so did the comparison group (15 female, 16 male). The study was undertaken in a K-12, private, American school in a Middle Eastern country. The school is an independent, non-sectarian, co-educational, college preparatory school, serving the international and local communities in that country. English is the language of instruction. The school's science curriculum is aligned with the *National Science Education Standards* (National Research Council, 1996).

Intervention

To ensure instructional consistency across treatments, the primary researcher prepared and followed detailed lesson plans during the entire course of the study. The plans were reviewed by the other researcher at the beginning of each instructional week.

Mind mapping instruction. Experimental group students were taught to construct mind maps as part of their regular classroom instruction over a period of one month using techniques adopted from Buzan and Buzan (1993) and Margulies (1995). Instruction began with an individual in-class assignment requiring each student to read specific pages in their science textbook and extract a list of important words (concepts). Then, the primary researcher introduced mind maps and detailed the procedures for their construction. Next, students were provided colored crayons and asked to mind map the set of concepts they extracted from their reading. Students shared their maps with the whole class. For the following four weeks, while working on a unit on hereditary traits, students were given 10 minutes at the end of each session to build mind maps.

At the end of the month, student feedback on the process was collected using an open ended questionnaire. As a result, a strategy for constructing mind maps was discussed and agreed upon with students: They were allowed to add to previously constructed mind maps if, during a session, *they* perceived that the ideas, concepts, or information discussed did not warrant building a totally new map. However, it was agreed that added structures would be distinguished by using a different color and identified with an entry date using the same color. Otherwise, if students perceived that, by the end of a session, new ideas, concepts, or information warranted a major reconstruction, they would turn in their previous mind map and build a new one. It was up to each student to determine which concepts, ideas, or information end up being represented in their maps.

Note summarization instruction. Students in the comparison group were provided with a special procedure to organize their notes. One month prior to data collection, the primary researcher discussed and distributed a handout on the format. After that, students began to use this format to produce their own note summarizations at the end of each session. The process included student recording of an entry date, entry number, what was learned during the specific session, what questions were asked and a summary of the answers, and any additional inquisitive comments. The purpose of engaging students with this procedure was to counterbalance the time spent by the experimental group participants interacting with target science concepts as they built their mind maps. Thus, by providing the comparison group participants with the same amount of time to engage with the science content, time-on-task would not confound the results of the study.

While working on a unit on "Matter" during the next month, 10 minutes at the end of each session were dedicated to build mind maps in the experimental group and to note summarization in the control group. The researchers collected maps and summaries at the end of each session, and copied and returned them to students at the beginning of the next session. This procedure was undertaken not only to collect data, but also to convey to students a sense of the importance of, and to ensure they made serious efforts toward, building mind maps and taking notes.

Variables

Independent variable. Building mind maps served as the independent variable. These were operationally defined as colorful web-like representations of a central theme or concept. A map has six basic elements: (a) Central theme: The major idea/topic underlying the target science content. It is represented by one or a few words and often located in the center of the map; (b) Major concepts: The ideas most relevant to the central theme and represented by one or a few words; (c) Minor concepts: The ideas that follow from the major concepts and are implicitly related to the central theme, often represented by a phrase; (d) Links: Structures (e.g., lines or arrows) that show direction and links among the major concepts, minor concepts, and central theme; (e) Icons or designs: Symbols, drawings, doodles, patterns, and/or geometric shapes that represent certain ideas; and (f) Legend: A key that identifies any icons or designs in the map.

Dependant variable. A test measured student achievement of goals consistent with the National Assessment of Educational Progress [NAEP] (1999) standards. Specifically, the test targeted the NAEP "knowing and doing science" domain of knowledge across two categories (conceptual understanding and practical reasoning) and three levels (basic, proficient, and advanced). The NAEP framework was used because the participant school followed an American-based science curriculum. Under the "knowing and doing science" domain, the NAEP framework defines "conceptual understanding" as the ability to understand basic concepts in relation to the tools used in the process of scientific investigation. "Practical reasoning" is defined as providing effective solutions to everyday problems by applying scientific knowledge, skills, and habits of mind. Additionally, "basic" achievement denotes partial mastery of prerequisite knowledge and skills fundamental for proficient work in a certain grade level and content area. "Proficient" achievement represents solid academic performance, including competency in tackling demanding subject matter, including subject-matter knowledge, application of such knowledge to real-world situations, and relevant analytical skills. The "advanced" level of achievement refers to superior performance in all aforementioned aspects of proficiency (see NAEP, 1999, especially chapter 2).

Moderator variable. Students' academic records were used to determine their PSA, which served as a moderator variable with three levels: High, medium, and low. High achievers (n for both groups = 19) were participants with overall science scores of 85% or higher. The overall scores for medium (n for both groups = 31) achievers ranged from 75 to 84%, and those for low achievers (n for both groups = 11) were equal to or lower than 74%.

Control variables. These included the teacher, teaching method, science content, classroom environment, and student time on task. Instruction in all four participant classroom sections was facilitated by the same teacher, the primary researcher. The science content (a unit on matter including the particulate nature of matter, atomic structure, and states of matter), instructional method and activities, classroom environment, and time dedicated to the various activities were the same for both experimental and control groups. In a nutshell,

Table 1
Distribution of Test-Items Across Target Categories and Levels

Category	Level			N items (%)
	Basic	Proficient	Advanced	
Conceptual understanding	8	5	4	17 (57)
Practical reasoning	5	5	3	13 (43)
N items (%)	13 (43)	10 (34)	7 (23)	30 (100)

during the intervention, the primary researcher went about teaching his classes as he usually would with the exception that 10 minutes in each instructional session was dedicated to building mind maps in the experimental sections and to note summarizations in the comparison sections.

Instrument

Post-instruction student achievement was measured using a test developed by the researchers. The test comprised 30 multiple-choice items, which targeted the NAEP (1999) "knowing and doing science" domain across two categories (conceptual understanding and practical reasoning) and three levels of achievement (basic, proficient, and advanced). Table 1 presents the number and percentage of items targeting each category and level.

A team of four secondary science teachers examined the items to ensure the test's content validity. The teachers were provided with the following materials: (a) A detailed outline of the science content addressed during the time of the study, including specific student learning objectives along with copies of corresponding textbook pages, handouts, worksheets, and descriptions of instructional activities; (b) operational definitions of the target test categories and levels; and (c) an initial pool of test items specifying the category, level, and instructional objective targeted by each item. They were asked independently to check whether the test items were aligned with the target objectives, categories, and levels and provide suggestions for revision and improvement. The teachers' feedback was collated and used to make several revisions to the test items ranging from minor edits to completely discarding some items. Newly added items were checked again by the teachers before being included in the final version of the test.

Data Analysis

Analyzing achievement test scores. Correct responses to test items were scored as "1" and incorrect responses were given a score of "0." Thus, test scores ranged from 0 to 30 points. Two multivariate analyses of variance (MANOVA) were conducted to compare mean test scores where mindmapping (use *vs.* no use) served as the independent variable and student PSA (high, medium, and low) as moderator variable (Tuckman, 1994). One analysis used the three levels of achievement (basic, proficient, and advanced) as dependent variables and the second used the two categories of achievement (conceptual understanding and practical reasoning) as dependent variables. When statistically significant, a MANOVA was followed with a univariate analysis.

Analyzing mind maps. The researchers developed a coding scheme to analyze students' mind maps. The scheme, which was derived from operational definitions of the elements of a mind map and ideas on assessing visual tools drawn from Ruiz-Primo and Shavelson (1996), targeted making judgments about four aspects of a mind map. These included map geography, central theme, links to major concepts, and links to minor concepts: (1) Map geography: The extent to which the map was web-like as compared to being linear; whether a legend was used; and the number of different icons used; (2) Central theme: The extent to which the theme was actually central to the concepts or ideas represented in a mind map; and whether the central theme was represented by an icon; (3) Links to major concepts (or ideas): Whether the major concepts were conceptually related to the central theme; the number of links to major concepts; whether the number of links was adequate as compared to indicating that the student had missed several significant links; and whether major concepts were represented by icons, symbols, and/or colors; and (4) Links to minor concepts (or ideas): Whether the minor concepts were conceptually related to the major concepts (or ideas) from which they derive; the number of links to minor concepts as determined by the average number of links directed toward each major concept; and whether minor concepts were represented by icons, symbols, and/or colors.

The reliability of the scheme was established through blind, double coding of 18 out of 62 analyzed mind maps (29%). The researchers trained a third coder, a chemistry middle school teacher, to assist with this process. Training consisted of a 60 minute session where the coder was introduced to the content of instruction, the elements of a mind map coupled with examples, and the coding scheme, and provided with a chance to practice coding some mind maps. Next, one researcher and the teacher independently coded 18 randomly selected mind maps. For each map, an inter-rater reliability coefficient was determined by dividing the total number of agreements by the total number of coding decisions (Miles & Huberman, 1984). This process resulted in a high level of agreement as indicated with an average inter-rater reliability coefficient of 0.96.

To further ascertain whether achievement gains, if any, were related to mind mapping, two mind maps for participants in the experimental group were analyzed. The first was an early map completed toward the beginning of data collection and the second was an "exit" map completed toward the end of the study. For each participant, analyzed aspects of the early and exit maps were compared and contrasted to document changes in the nature of maps that were evident over time.

To answer the question on the relationship between different elements of participants' mind maps and science achievement gains, analyses for "exit" mind maps were compared and contrasted across three sub-groups. These sub-groups were generated based on the experimental group participants' post-instruction test scores on the "conceptual understanding" category (17 of the 30 test items). Participants who achieved a score of 85% or higher on this category were considered to have good conceptual understanding (GCU; n=9), participants with scores ranging from 71 to 84% were included in the moderate conceptual understanding (MCU; n=12) group, and those with scores equal to or less than 70% were included in the poor conceptual understanding (PCU; n=10) group. Exit mind map codings were then organized by conceptual achievement level (GCU, MCU, and PCU) into frequency tables and graphs in order to discern patterns in the relationship between the nature of these mind maps and participants' conceptual understanding in science.

Results

Influence of Mind Mapping on Science Achievement

Table 2 presents the mean posttest scores for the experimental and comparison group participants across achievement categories (conceptual understanding and practical reasoning) and achievement levels (basic, proficient, and advanced), as well as the corresponding overall means. It should be noted that in Table 2 raw mean scores were converted to percentages to allow for easier interpretation of the results. Table 3 presents a summary for a MANOVA with treatment (T) (mind mapping *vs.* no mapping) as the independent variable, achievement categories (conceptual understanding and practical reasoning) as dependent variables, and PSA (high, medium, and low) as moderator variable. The test was significant for T ($p < .001$) and PSA ($p < .05$), and non-significant for the interaction between T and PSA ($p > .05$). These results indicate that the experimental group participants' scores were significantly different from those of students in the comparison group. Indeed, the univariate ANOVA indicated that students in the mind mapping group scored significantly higher both on the conceptual understanding ($M_{exp} = 72.90$, $M_{comp} = 57.53$, $p < .001$) and practical reasoning ($M_{exp} = 76.31$, $M_{comp} = 61.00$, $p < .001$) categories.

Table 4 presents a summary for a MANOVA with T as independent variable, levels of achievement (basic, proficient, and advanced) as dependent variables, and PSA (high, medium, and low) as moderator variable. The test was significant for T ($p < .001$) and non-significant for PSA ($p > .05$) and the interaction between

Table 2
Mean Test Scores for Experimental and Comparison Group Participants

Category	Level						Total	
	Basic		Proficient		Advanced			
	M_E	M_C	M_E	M_C	M_E	M_C	M_E	M_C
Conceptual understanding	81.25	72.38	42.00	34.00	94.75	57.25	72.90	57.53
Practical reasoning	97.40	83.40	44.20	33.80	95.00	69.00	76.31	61.00
Total	87.46	76.62	43.10	33.90	94.71	62.30	74.34	59.03

Table 3
Multivariate Analysis of Variance for Treatment (T) by PSA on Achievement Categories

Multivariate ANOVA			Univariate ANOVA			
			Conceptual understanding		Practical reasoning	
Source	*F*	*p*	*F*	*p*	*F*	*p*
T	14.11	.000	34.27	.000	17.07	.000
PSA	2.98	.010				
T x PSA	.724	.631				

Table 4
Multivariate Analysis of Variance for Treatment (T) by PSA on Achievement Levels

	Multivariate ANOVA		Univariate ANOVA					
			Basic		Proficient		Advanced	
Source	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
T	11.91	.000	11.75	.001	5.56	.022	22.56	.000
PSA	2.06	0.64						
T x PSA	.40	.879						

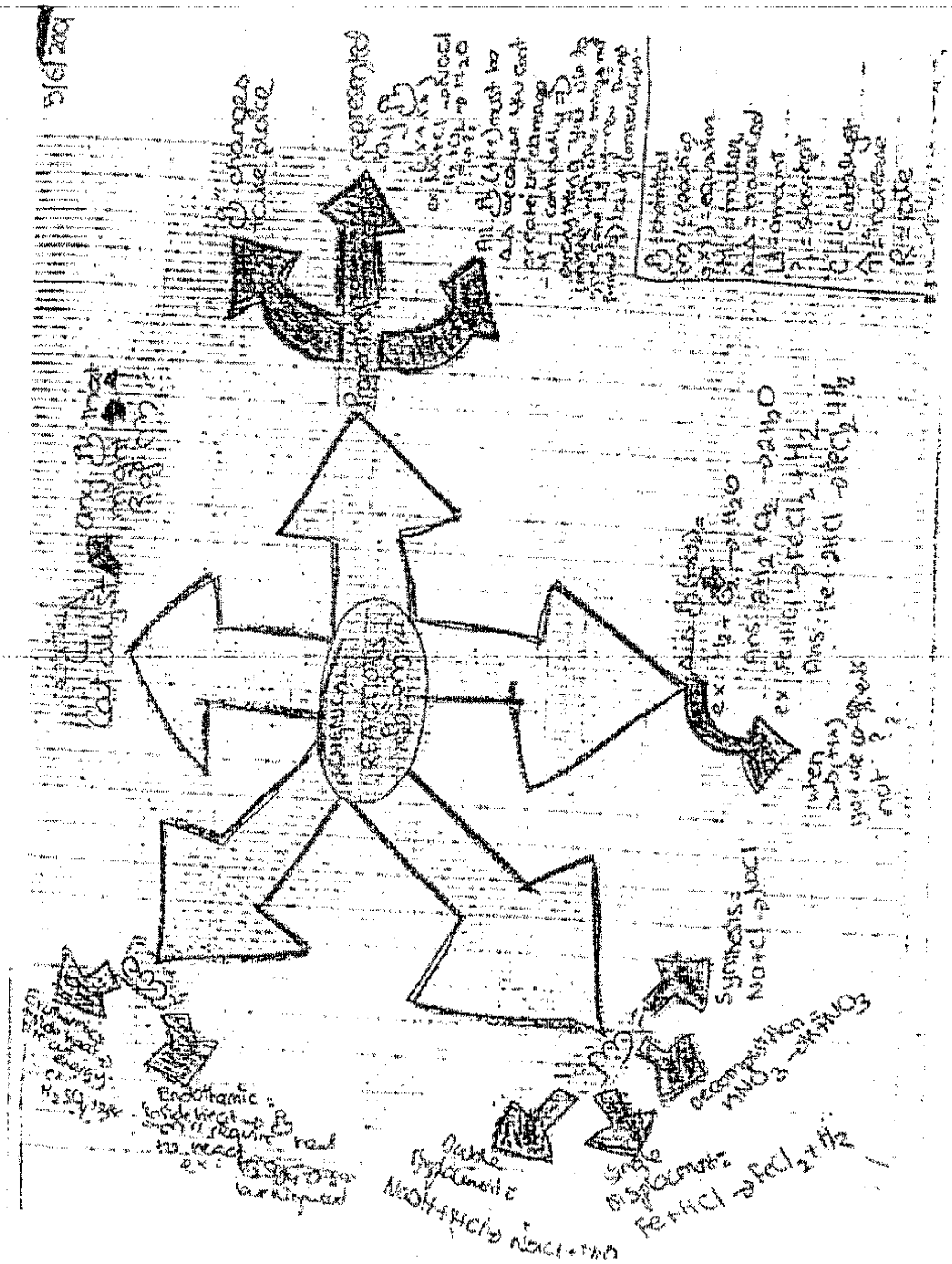

Figure 1. An illustrative example of the mindmaps constructed by the experimental group participants.

T and PSA ($p > .05$). Thus, the science achievement levels for the experimental group participants were significantly different from those of their comparison group counterparts. Univariate analyses indicated that students in the experimental group scored significantly higher on the basic ($M_{exp} = 87.46$, $M_{comp} = 76.62$, $p < .01$), proficient ($M_{exp} = 43.10$, $M_{comp} = 33.90$, $p < .05$), and advanced ($M_{exp} = 94.71$, $M_{comp} = 62.30$, $p = < .001$) components of the achievement test. Additionally, as Tables 3 and 4 indicate, the lack of significant interaction between the treatment and participants' PSA for categories of achievement ($p = .879$) and levels of achievement ($p = .631$) indicate that the observed achievement gains for students who used mind mapping was not mediated by their scholastic achievement. In other words, there were no differential impacts for students' prior achievement on learning gains they derived from using mind maps across the target categories and levels of achievement.

Nature of Participants' Mind Maps and Relationship to Gains in Conceptual Understandings

Figure 1 presents an illustrative example of the mind maps constructed by participants toward the end of the study. The experimental group participants' early and exit maps were analyzed in terms of their geography, central theme, and links to major and minor concepts. Early and late analyses were compared to explore changes in the nature of participants' mind maps over time. Next, analyses of exit mindmaps for three subgroups of the experimental group participants were compared and contrasted to assess any relationship between aspects of the mind maps and students' conceptual understandings. As noted above, these three groups corresponded to experimental group students with good (GCU), medium (MCU), and poor (PCU) conceptual understandings as indicated by their posttest scores.

Geography of the mind maps. All student maps, both early and exit, featured web-like representations. In terms of geography, the main difference between these maps was in the use of legends. By and large, students did not make much use of legends in their early maps. As they revised/expanded existing maps or built new ones, students made more use of legends. Compared to only 15% of the early mindmaps, 82% of the exit maps had legends most of which aimed at explicating symbols and abbreviated words rather than icons.

Icons are artistic representations of concepts included in a mind map, usually in the form of simple drawings. Icons were rare both in early and exit student mind maps. The few students (20%) who made use of icons had an average of four per early mind map, which dropped to an average of only two icons for their exit maps. It seems that icons were not very useful to students. This could be either because drawing the icons placed demands on students' creative abilities, or because students found the time and effort needed to come up with and draw icons did not pay off in terms of representing their ideas, or making sense and remembering the target content. By comparison, the web-like structure of mind maps (as compared, for instance, to linear or hierarchical structures) was either easier or more helpful to students when attempting to represent or map their ideas about such content. Finally, analyses showed that the exit mind maps for the GCU, MCU, and PCU groups did not differ in terms of geography.

Central theme. The central theme of a student map was analyzed in terms of whether it was similar to or different from what the teacher suggested to be central for the session at hand, and if different, whether the difference was merely semantic (using alternate wording) or both semantic and conceptual, and whether the theme was represented by an icon. First, in the case of both early and exit mind maps, almost all central themes were represented by words rather than icons. Such icons were used only in about 8% of the early and 4% of the exit mind maps.

During any given session and according to the detailed lesson plans, the teacher (primary researcher) made a single reference to what he thought the central theme for that session's mind map could be. In early mind maps, 62.5% of participants used the same central theme as that suggested by the teacher. This percentage dropped substantially in exit mind maps to 37.5%. An examination of exit mind maps with different themes (62.5%) showed that they were semantically different from but conceptually similar to the themes judged by the teacher as being central to the session at hand. Though conceptually similar, students characterized these central themes using more specific wording, and, in some cases, concepts were replaced by abbreviated definitions or a relevant attribute or attributes. Thus, as they gained more experience with building mind maps, a majority of participants seemed to produce more individualized representations of their understandings. Toward the end of the study, about two thirds of participants in the experimental group were depicting central themes on their maps in terms that helped *them* understand the target content as compared

Table 5
Analyses of Links to Major Concepts

Major concepts	Characteristic	Mindmap		Sub-group exit maps		
		Early	Exit	GCU	MCU	PCU
Nunber of links from central theme to major concepts	0-3	64.4%	49.4%	60.0%	40.0%	44.4%
	4-6	27.4%	47.0%	40.0%	40.0%	55.6%
	>6	8.2%	3.6%	0.0%	20.0%	0.0%
Number of scientifically accurate links	Appropriate	75.0%	66.7%	100%	50.0%	66.7%
	Too few	12.5%	12.5%	0.0%	30.0%	11.1%
Represented by icons	All/most	12.5%	0.0%	0.0%	0.0%	0.0%
	Less than half	8.3%	12.5%	20.0%	10.0%	22.2%
	None	79.2%	87.5%	80.0%	90.0%	77.8%
Labeled with color(s)	All/most	66.7%	62.5%	80.0%	60.0%	55.6%
	Less than half	4.2%	4.2%	0.0%	10.0%	0.0%
	None	29.1%	33.3%	20.0%	30.0%	44.4%
Meaningfully related to central theme	All/most	95.8%	100%	100%	100%	100%
	Less than half	4.17%	0.0%	0.0%	0.0%	0.0%
	None	0.0%	0.0%	0.0%	0.0%	0.0%

to building maps centered on a term suggested by their teacher.

What is more, mind map analyses indicated that toward the end of the study *all* participants in the GCU group were using central themes that were conceptually equivalent but semantically very different (e.g., explicated in idiosyncratic but accurate ways) from those suggested by the teacher. By comparison, about 80% of participants in the MCU and PCU groups were using such central themes.

Links to major concepts. These links represent lines or directional arrows from a mind map's central theme to the major concepts depicted in the map. Table 5 presents analyses of this aspect in early and exit maps, as well as in the exit mind maps of the three experimental participants' sub-groups. Five characteristics of this aspect of students' mind maps appear in Table 5: (a) the number of links from the central theme to major concepts, (b) the number of links that were scientifically accurate, (c) whether the major concepts were represented by icons, (d) whether the major concepts were labeled with colors, and (e) whether the major concepts were meaningfully or conceptually related to the central theme.

The major difference between early and exit mind maps was that the percentage of exit maps with 4-6 links to major concepts increased substantially from 27% to 47%. There were small decreases in the number of scientifically accurate links (from 75 to 67%) and use of colors to label major concepts (68 to 63%), as well as a small increase in terms of meaningful links between the major concepts and central themes (96 to 100%). Icons continued to be scarcely used in both early and exit mind maps with at least 80% of participants using no icons to depict major concepts.

As far as the exit maps were concerned, participants in the GCU group had substantially more scientifically accurate links to major concepts (100%) when compared to those in the MCU (50%) and PCU (67%) groups. The same pattern was evident for using colors to label major concepts: 80% of students in the GCU group used colors as compared to 60% and 56% among students in the MCU and PCU groups respectively. Also, it is noteworthy that students in the GCU group used fewer links (60% of their mind maps had three or fewer links) than those used by students in MCU and PCU groups (40 and 45% respectively). However, compared to 50% and 67% in the other two groups, almost all links depicted by GCU students were scientifically accurate.

Table 6
Analyses of Links to Minor Concepts

Major concepts	Characteristic	Mindmap		Sub-group exit maps		
		Early	Exit	GCU	MCU	PCU
Average number of links to major concepts	0-2	80.3%	64.1%	40.0%	80.0%	44.4%
	3-4	12.0%	28.4%	60.0%	20.0%	44.4%
	>4	7.7%	7.5%	0.0%	0.0%	11.2%
Represented by icons	All/most	29.2%	16.7%	20.0%	10.0%	22.2%
	Less than half	12.5%	37.5%	20.0%	40.0%	33.3%
	None	58.3%	45.8%	60.0%	50.0%	44.5%
Labeled with color(s)	All/most	62.5%	45.8%	60.0%	40.0%	44.4%
	Less than half	0.0%	4.2%	0.0%	10.0%	0.0%
	None	37.5%	50.0%	40.0%	50.0%	55.6%
Accurately related to major concepts	All/most	79.2%	95.8%	100%	100%	88.0%
	Less than half	4.2%	0.0%	0.0%	0.0%	0.0%
	None	16.6%	4.2%	0.0%	0.0%	12.0%

Links to minor concepts. These links represent lines or directional arrows from major to minor concepts depicted in a map. Table 6 presents analyses of this aspect in early and exit maps, as well as in the exit mind maps of the three experimental participants' sub-groups. Four elements of this aspect of students' mind maps appear in Table 6: (a) the average number of links from the major to the minor concepts, (b) whether the minor concepts were represented by icons, (c) whether the minor concepts were labeled with colors, and (d) whether the minor concepts were meaningfully or conceptually related to the major concepts with which they are associated.

Table 6 indicates that the major differences with regard to this aspect were that (a) the percentage of students who used an average of 3–4 links from major to minor concepts more than doubled from early (12%) to exit (28%) mind maps, and (b) compared to about 80% of the early mind maps, 96% of the exit maps featured meaningful and conceptual connections between major and minor concepts, despite an increase in the average number of links. Such results are consistent with gains in the experimental group participants' meaningful learning and increased achievement scores. By comparison, the use of icons to represent minor concepts decreased as did the use of coloring to label these concepts. However, about half of the exit mind maps made extensive use of colors to represent minor concepts compared to only about 17% that made similar use of icons.

With regards to exit mind maps, substantially more participants in the GCU group (60%) had an average of 3–4 links from the major to the minor concepts as compared to students in the PCU (44.4%) and MCU (20%) group. Some students in the PCU group (11%) had many links between the major and minor concepts (> 6 links), but most of these links were conceptually inaccurate. Similarly, substantially more GCU students (60%) made use of coloring to label minor concepts (*versus* 40% for the MCU and 44% for the PCU group).

Discussion and Conclusions

The present results provide empirical support to theoretical assertions about the potential of mind mapping to positively impact student learning (e.g., Buzan & Buzan, 1993; Nast, 2006; Ornstein, 1986; Sperry, 1993; Sylwester, 2000) in the context of middle school science. Compared to students who did not use mind mapping, participants in the experimental group achieved statistically significant gains on all target categories (conceptual understanding and practical reasoning) and levels (basic, proficient, and advanced) of achievement. Moreover, the observed gains were not only statistically significant, but practically significant as well. On average, students who used mind mapping scored about 15 percentage points higher than participants in the comparison group on the conceptual understanding and practical reasoning components of the post-instruction achievement test. The smallest gains were evident in the case of test items targeting "proficient" levels of understanding (about 9 percentage points) and the largest were observed in the case of items targeting the "advanced" levels (about 32 percentage points). Gains in the case of the "basic" level test items averaged around 11 percentage points.

More importantly, the present results indicate that gains achieved from using mind maps as a learning tool were not mediated by students' prior achievement. The interaction between mind map use and PSA was not statistically significant in the case of both the target categories and levels of achievement. This is not true of several metacognitive strategies and some visual tools, such as concept maps (e.g., Rao, 2004; Stoyanova & Kommers, 2001), that seem to benefit low and high achieving students to lesser extents than average students (Gage & Berliner, 1998). As hypothesized in this study, the individualized, student-created structure and nature of mind maps seem to have provided students of varying achievement levels in the experimental group opportunities to utilize mind maps in ways that best fit the ways *they* recall information, make sense of concepts, and integrate their understandings of science content.

The inference above is supported by several observations. First, after having developed some facility with using mind maps, the majority of participants in the experimental group started to "personalize" the central themes in their mind maps. Compared to only 37% at the beginning of the study, toward the end of the intervention 62% of participants were using semantically different but conceptually equivalent central themes compared to those suggested by the teacher. Second, participants often replaced concept labels with brief descriptions or concept attributes in their bid to represent and/or bolster their recall and understanding of the target science content. Third, students made less use of icons and more use of colors, abbreviations, and other non-symbolic representations in building their maps despite the fact that all these components received equal attention during the mind mapping training sessions. In other words, students custom-used the components of mind maps that best fit their needs to represent their knowledge structures.

The results of this study do not lend empirical support to the theorized importance of iconography to mind mapping (e.g., Buzan, 1976, 2000; Buzan & Buzan, 1993). Icons were used by a minority of participants to represent central, major, and minor concepts, as well as links among these concepts throughout the study. Indeed, use of icons decreased as the study progressed. What is more, use of icons did not seem to differentiate between students according to their performance on the conceptual understanding component of the achievement test. There are several explanations to account for these findings. First, it might be the case that the training was not effective in introducing students to icons and their use in mind maps. More concerted effort might be needed to provide students with more opportunities to choose and use icons when representing their knowledge structures. Second, having not made extensive use of icons in general, participants might have found using words easier to express their ideas and understandings. Third, it might well be the case that icons are actually not central to the effectiveness of mind maps. Ascertaining the viability of one or the other of these possible explanations requires further research studies.

To say that icons were not necessarily central to the maps produced by participants does not apply to visual imagery in general. The results indicate that color was a significant component of mind maps in this study. A majority of participants (more than 60%) used colors to represent *all* major and minor concepts in their maps throughout the study. Probably more significant was the fact that use of colors was a major difference between mind maps produced by participants with good, medium, and poor conceptual understandings. For instance, use of color to represent *all* major and minor concepts was respectively evident in 80 and 60% of the GCU mindmaps as compared to 55 and 44% of the mindmaps constructed by students in the PCU group.

The centrality of the web-like structure of mind maps was evident in the present study. Throughout the study, all participants built mind maps with web-like structures and none of them produced anything like the hierarchical or regimented structures required of students by some visual tools, such as concept and flow maps. Of course, this is not to say that students do not benefit from having to think about science content in hierarchical or regimented ways. After all, research indicates that students benefit from using structured visual tools such as concept maps (Horton et al., 1993). However, it seems that when given a choice, students would tend to represent their knowledge structures in more fluid and idiosyncratic ways. This latter aspect of mind maps might contribute to their being effective in enhancing learning irrespective of students' prior achievement level. Of course, ascertaining whether mind maps are superior to concept maps and other structured visual tools requires further research using direct comparison with the same groups of participants. Additionally, like other visual tools, mind maps seem to promote meaningful learning as was evident by gains achieved across all target categories and levels of achievement. Indeed, in addition to using color to represent major and minor concepts, the ability to build multiple and accurate links between subject matter concepts represented the major difference between participants in the GCU, MCU, and PCU groups. Participants in the GCU group built substantially more accurate links (100% vs. 50 and 67% for the MCU and PCU groups respectively) between the central theme and major concepts, as well as substantially more valid links between major and minor concepts. Finally, it should be noted that results of the present study are necessarily tentative in nature and further research is needed to ascertain the present findings across more contexts and content areas.

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