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Sequencing Embedded Multimodal Representations in a Writing to Learn Approach to the Teaching of Electricity

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Abstract: In the study of science topics especially in physics students are expected to move between different modes of representation when dealing with a particular concept as any science concept can be represented in several different modes. The difficulty for students is that they are often unable to move between these multi-modal representations and thus struggle with having a rich conceptual understanding of the topic. In this study students are asked to explain their understandings of the topic through writing and embedding different modes of representation, text only, text plus math, and text plus graph. A pre-post test design was used to compare performances of groups who used different modes in their writing during a three-staged unit of electricity. While students' scores were not statistically different at the end of the first stage, at the end of the stage 2, students who were asked to embed mathematical representation in their letters to explain concepts of Faraday's Law of Induction had test scores that were significantly better than either of the other two conditions. At the end of the stage 3 there were several statistical mean differences noted supporting the pattern of the advantage of using embedded text plus mathematical representation in writings.

Keywords: physics; language of science and classrooms; science literacy; secondary; multimodal

This study seeks to engage with two connected but different areas of research that have been emerging in science education in the recent past that are informing discussions about science literacy. The first is research on multi-modal (or multi-media) representation and the second is on the use of writing to learn strategies within science classrooms. The reasons that these are important are grounded in the work of Norris and Phillips (2003, p. 296) who have addressed the role of language in science by stating that there are two essential senses of literacy that frame science. The first is the derived sense of literacy in which ''reading and writing do not stand only in a functional relationship with respect to science, as simply tools for the storage and transmission of science. Rather, the relationship is a constitutive one, wherein reading and writing are constitutive parts of science'' (p. 226). For Norris and Phillips this is critical because these constituents are the ''essential elements of the whole'' (p. 226), that is, remove these language elements and there is no science. Science is not something that can be done without language. To this derived sense of science literacy, we would expand Norris and Phillips' definition to include the different modes of representation. While this is implicit within reading and writing, there is a need to understand that different modes of science are integral to the concept of reading and writing, that is, science is more than just text. As Lemke (1998, p. 90) suggests ''to do science, to talk science, to read and write science it is necessary to juggle and combine in canonical ways verbal discourse, mathematical expression, graphical-visual representation, and motor operations in the 'natural' world''.

Examining the consequence of sequencing embedded multiple modal representations within a writing to learn approach to improving understanding of the physics topic of electricity.

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The second essential sense of literacy is the fundamental sense of science literacy. For Norris and Phillips the fundamental sense involves the ''reasoning required to comprehend, interpret, analyze, and criticize any text'' (p. 237). Importantly, they argue that science has to move past oracy and the oral traditions because ''without text, the social practices that make science possible could not be engaged with'' (p. 233). The important recording, presentation and re-presentation of ideas, and debates and arguments that constitute the nature of the discipline are not possible without text. These two essential senses of literacy are critical to the development of scientific literacy. Simply viewing acquiring of science content knowledge (the derived sense) as success denies the importance of being able to apply the reasoning structures of science (the fundamental sense) required for reading and writing about science.

However, we would argue that complete conceptual understanding of a science concept (derived) and the ability to apply these ideas (fundamental) requires dealing with the multi-modal representations of that concept. Thus multi-modal representation becomes important because the language is multi-modal, that is, concepts of science are described by and across different modal representations. Yore and Treagust (2006, p. 208) state however, that while multi-modal representation is critical to understanding science, there has been little research to explore the ''enhanced cognition that occurs during the transformation from one representation to another representation or one mode to another.'' Working in the area of mathematics Duval (2002, p. 4) reinforces the importance of cognition being involved in the transition or ''conversion'' between modal forms by suggesting, ''it is the activity of conversion which appears to be the fundamental representational transformation, the one which leads to the mechanisms underlying understanding.'' Like Yore and Treagust, ''Duval believes that as researchers'' we must spend time on why it is absolutely necessary to take the cognitive point of view into account in the analysis of learning and of the process of comprehension.''

These issues of representation, that is, the languages of science, and how we use language as a learning tool to promote understanding of science, are addressed below.

Multi-Modal Representation

In framing the discussions on multi-modal representation Lemke (1998) has stated ''Science is not done, is not communicated, through verbal language alone. It cannot be.'' He adds that scientists ''combine, interconnect, and integrate verbal text with mathematical expressions, quantitative graphs, information tables, abstract diagrams, maps, drawings, photographs, and a host of unique specialized visual genres seen nowhere else'' (p. 89). Kozma (2003, p. 205) concurs and emphasizes this concept in suggesting that ''scientists co-ordinate features within and across multiple representations to reason about their research and negotiate shared understanding based on underlying entities and processes''. Concurring with this viewpoint Kress, Jewitt, Ogborn, and Tsatsarelis (2001, p. 1) suggest that for any discipline the discourse of the discipline is made up of a number of modes, where spoken and written languages are examples of two such modes. In the areas of science Kress et al. pose the question ''what are the affordances of each mode used in the science classroom: what are the potential and limitations for representing of each mode?'' diSessa (2004, p. 296) takes this argument further by suggesting that the development of new representations should be considered as ''fundamentally important classes of advances'' in science. For him, the introduction of new forms of representations have allowed scientist to advance their understanding of knowledge and created new means of constructing and interpreting science. For Alvermann (2004, p. 227) translating this to schools means that learning should be focused around the concept that ''all meaning-making is multi-modal'' and that learners need to develop multiple literacies as a function of learning.

In adding to the discussion on representations Schnotz and Lowe (2003, p. 117) have suggested that multi-modal representations can be considered on three different levels. These being the ''technical level [which] refers to the technical device that are the carriers of the signs: the semiotic level [which] refers to the representation format of those signs: and the sensory level [which] refers to the sensory modality of sign reception.'' They suggest that a failure to recognize these different levels has resulted in the misconception that representation is only about information technology. For them the research emphasis needs to be on the effects of different forms of representations on student comprehension and learning. There is a need for a ''better understanding of the processing demands associated with different kinds of representations and their function in comprehension and learning'' (p. 118). Thus there is a need to engage with research on both the semiotic and sensory levels. Building on this need for further research, Airey and Linder (2006, p. 18) suggest for learners to know a subject like physics, they need to understand that a concept is represented by a critical constellation of modes, and that it is of the ''utmost importance that research be carried out into which constellations of modes open up the possibility for experiencing each of the particular ways of knowing physics.'' They further suggest that learning science is more than just exposure to the modes of science, rather it should be about allowing students opportunities in ''using the disciplinary discourse to make meaning for themselves,'' that is, using the constellation of modes for a topic to construct understanding of the topic.

In dealing with the semiotic level Lemke (in press) begins to provide explanations for its importance by suggesting that natural language, mathematics, and visual representations form a single unified system for meaning-making. Lemke argues that from a linguistic perspective both visual and mathematical languages are able to deal with particular meanings that natural language is unable to. For example, natural language tends to deal with categorical descriptions of phenomena as it is unable to describe more continuous descriptions of the phenomena. Both visual and mathematical representations provide a better language to deal with descriptions that are required for quantities that change by degrees. Thus Ainsworth (2006, p. 185) suggests that researchers in recognizing these various forms of representations should not consider them in isolation but rather view them as a form of ''representational chemistry'' and examine how they interact with one another. Such a view is supported by Harrison and DeJong (2005) who demonstrated that students' understandings and use of multiple analogies for chemical equilibrium shows a disconnection between the different types of analogies used to represent equilibrium and consequently may impact on their learning.

There have been various models proposed such as the Cognitive Load of Multimedia Learning (Mayer, 1997), Cognitive Load Theory (Sweller, Merrienboer, & Pass, 1998) and Dual Coding Theory (Paivio, 1986) to explain how students simultaneously deal with the multiple representations of a concept. Ainsworth (2006) argues however, that the research on the processing and value of students engaging with multiple representations is not clear. While there have been positive results, there are an equal number of studies that fail to show benefits. She suggests that an alternative approach is to look at the key functions of multi-modal representations, with these being defined as complementary, constraining and constructing functions. As an example, the constructing function associated with engaging multi-modal representations revolves around the concept that students are required to extend from known to unknown aspects associated with the representations, to build relational understanding between the different representations and form abstractions across the presentations. Seufert (2003, p. 227) in building on Ainsworth's (2006) ideas of relational understandings suggests that learners need to ''create referential connections between corresponding elements and corresponding structures in different representations.'' She argues that ''only if learners are able to construct relations both within and between different representations can they acquire a deeper understanding'' (p. 228) of a concept. For diSessa (2004) in using such functions students are building their meta-representational competence (MRC). He argues that MRC is more than just the ''mere production and use of representations'' (p. 294) but rather ''stands as a free resource for further learning.'' By engaging their MRC students are able to build knowledge rather than simply recall/regurgitate the sanctioned representations supplied by textbooks.

An issue for diSessa (2004) is that MRC is something that is learnt through practice where students are required to be involved in building or using representations. He suggests that a major problem with much of the current research is that the focus is on instructional design and the production of multiple representations, and the difficulties students have in learning from these representations. For example, some of the work on analogies (Chiu & Lin, 2005) has demonstrated that these can be used to promote conceptual change and that there are benefits in building understanding of multiple representations of concepts. Work done by Winberg and Berg (2007) and Winn, Stahr, Sarason, Fruland, Oppenhiemer, and Lee (2006) has show that computer representations of laboratory work can be a useful representation form to promote students abilities in conducting laboratory activities. However, as shown by Sullivan (in press) much more attention needs to be paid to how representations, in his case, photographs, are used to demonstrate particular concepts so that children can have a greater sense of how different representations can assist their understandings.

Work done by Sherin (2001) has begun to examine the ways in which students understand physics equations and thus can build understanding of physics. He suggests students need to understand the representational messages denoted by the mathematical equations, and how using these equations will promote richer understanding of physics. While this work begins to extend the work of Kress et al. (2001) in general little attention has been given to how students build their own representations or how they use their representations to explain their understanding. An example of a study where students were able to construct their own representations rather than the traditional physics representation was by Marshall and Carrejo (2008) who showed that by encouraging students to use intuitive forms of representation they were able to engage with the more traditional representations of motion. This type of study supports Lemke's (1998, p. 90) suggestion that there is a need to support students in reasoning about ''natural and technological phenomena through integrated combinations of linguistic, mathematical, and visual tools.'' Importantly for him, there is a need to recognize the importance of ''language as the primary medium for reasoning and conceptualization in science'' and to restore narrative ''to a place of honor and prominence in science education.''

Writing to Learn Strategies

Klein (2006) in discussing the difficulties associated with students understanding the different modal representations of a concept and the relationship between the modes and to the concept, argues that we cannot view them as being well defined and consistent across contexts. Instead he argues that when viewed from a second generation cognitive science perspective, concepts and words are considered too fuzzy and contextually bound, and that narrative is central to the development of language and thought. This is important for science teaching because the emphasis has been on ''treating concepts classically, as a taxonomy of ideas, each with a necessary and sufficient set of defining features and abounded set of referents: these concepts correspond to words'' (p. 157). To move past this taxonomical approach, Klien suggests that students need to be provided opportunities to combine the scientific explanation and argumentation structures of first order cognitive science and narrative speech structures of second order cognitive science. This can be achieved by having students ''write informal, speech-like texts and narrative-argument blends; retaining pragmatic and dialogical aspects in argumentation and explicitly teaching science text genre'' (p. 171). In adding to this discussion Prain (2006) suggests that more diversified forms of writing should be used in science classrooms to promote richer conceptual understanding of concepts. He argues that teachers rather than being constrained by prescriptive generic rules for writing, need to be flexible and aware of incorporating multi-modal representation practices within text generation tasks for students.

By using the writing practices suggested by Klein and Prain, writing can be viewed as an epistemological tool, that is, writing can be viewed as a process which leads to construction of understanding. There have been a number of models put forward to examine the process of how writing supports learning. These models by Bereiter and Scardamalia (1987) and Galbraith (1999) argue for the involvement of two knowledge bases, science content knowledge and rhetorical knowledge. It is the interaction of these two knowledge bases in completing a writing task that promotes construction of new knowledge. Building on these models Hand and Prain (1996) in promoting the epistemic nature of writing to learn tasks have proposed a framework that consists of five components—method of text production, audience, purpose, type of text and topic. Klien (2006) has added a sixth component of source. Completing a writing task using these components requires the students to engage their content and rhetorical knowledge bases, with the target being writing to different audiences, for different purposes to build conceptual understanding.

Bangert-Drowns, Hurley, and Wilkinson (2004) in a meta-analysis on writing to learn strategies indicate that there are positive benefits to be gained through using these strategies. While this study focused on multiple disciplines, these researchers did not deal with the importance of pedagogical approaches that are required to have success with these strategies. Hand, Hohenshell, and Prain (2004) in a study on the importance of planning as a component of writing in science showed that there are pedagogical strategies that are critical for success when using writing to learn strategies. Building on this study, the present study attempted to focus on the use of writing to learn strategies on building conceptual understanding of physics concepts by embedding multimodal representations as a critical component of the task. As such the pedagogical requirements in setting up the task were structured based on the earlier work of Hand et al. (2004).

Context and Background of the Study

The intent of the study was to link previously mentioned two research areas; multimodal and writing to learn. Importantly, rather than focus on some instructional design for students to use, we wanted to build from previous research on writing to learn strategies to engage students in writing and embedding different modal representations. Such an approach we believe would respond to the call from Goldman (2003, p. 244) to examine ''comparisons of learning outcomes that result from juxtaposition of multiple representation'' in order ''to advance our understandings of learning in complex domains.'' From our perspective we believe there was a need to change Mayer's (2003, p. 128) basic question from ''do students learn more deeply from multimedia messages than from verbal-only ones?'' to do students learn more from having to construct multimodal text descriptions of a concept rather than text only descriptions. An example of a topic where this shift in framing of the question from one of interpreting a representation to one of construction is noted by the studies done on graphing. For example, the study by Abeg-Bengtsson and Ottosson (2006) focused on the conditions for reading graphs while the study by Potgeiter, Harding, and Engelbrecht (2008) was trying to determine the students application of mathematics when constructing graphs. Thus we based our approach on diSessa as described above, and were keen to encourage students to explain a scientific concept with an emphasis on embedding some different modal representations into their written products. Rather than allowing students freedom to choose whatever modal representation they wished we were guided by two particular criteria.

The first is based on the work of Ainsworth (2006) who suggested that the sequence of representations may be a critical factor, that is, is there a particular order in which students should engage with representations? The second is based on the work of Stern, Aprea, and Ebner (2003, p. 192) who suggest that in physics ''graphs and diagrams can bridge the gap between everyday knowledge based on verbal description, and mathematical formulas describing the central laws''. As a consequence we were guided by the following question:

> Is there a sequential impact of multimodal combination between text, mathematical and graphical representation within a writing to learn task that significantly advantages students on answering questions related to the topic of electricity?

Study Context

The study took place in a semi-private, boarding high school of approximately 700 total students in Istanbul, Turkey. While the participant school can be categorized as elite in terms of student selection, admission requirements, and academic demands, the demographics of the students were heterogeneous, that is, the school population consisted of students from different parts of the country with different ethnic and economic backgrounds. They were selected according to their success level on the standardized entrance exam, their middle school GPAs' with given more emphasis on science, mathematics and literacy graduation scores, and their responses' to extensive interview questions (e.g., carrier goals, interests, expectations from the high school and teachers, social life). All 172 participants were tenth-grade male students with an average age of 17. There were 7 tenth-grade classes participated in this study. Those classes were taught by one teacher who had 5 years of teaching experiences in the public and private schools. Further there was another physics teacher with similar teaching experience who took part in the study as an independent scorer. Moreover, in this boarding school, students' are randomly assigned to sections or classes, so not only participating students' academic achievements were some what equivalent (due to entrance criterion), but also the academic achievement levels' of the classes were comparable.

Research Design

A quasi-experimental, pre-post test design with students in seven pre-existing Year 10 physics classes was used for this study. All classes were taught by the same teacher, covered identical conceptual materials, applied the same instructional methods and each lesson was allocated a 40-minute span of time. The study took place at the middle of a year-long physics course in which all students were working towards the completion of course work in physics based on the national curriculum. The study had a three-stage design involving three separate units—magnetic effect of electric current, Faraday's law of induction, and alternating current—that were a normal part of curriculum of this year-long physics course and were covered during the spring term. The study explored the effects of three synthesis tasks across three physics units under the overarching theme of electricity.

The study was designed around three distinct stages. In the first stage, the purpose was to provide a common diversified writing experience for every student where all students were asked to summarize the unit studied with a letter written for the teacher. That is, the aim of the first stage was establishing similarity across intact groups and preliminary introduction of writing task to level the learning field. In the second stage, the purpose was to investigate the impact of particular synthesis tasks where students in each of three groups were asked to write letters to a 9th grade student but the embedded representational modes were varied for each group. Three classes were asked to use only text (text only group), two other classes were asked to embed mathematical representation (text plus math group), and the other two classes were asked to use graphical representation (text plus graph group) in their letters where they were asked to elaborate the concepts of the unit studied. In this stage classes were randomly assigned into three groups. For the convenience of the third stage group assignment, three classed were used in the text only group and four classes were used in the math and graph groups. During the third stage, while three classes remained as a text only group, one class from the math group was asked to use embedded graphical representation instead of mathematical representation, and one class from the graphical group was asked to use embedded mathematical representation in their writing assignment rather than the graphical representation. Thus, in the third stage of the study there were a number of different combinations of experience that were examined. There were three groups that were text only (i.e., all their experiences had been in one mode, that of text), one group that was text plus mathematical representation only (stage 2 and 3), one group that was text plus graphical representation only (stage 2 and 3), one group that was text plus mathematical (stage 2) then becoming text plus graphical (stage 3), and one group that was text plus graphical (stage 2) then becoming text plus mathematical (stage 3). The implementation program for the study is given in Tables 1 and 2 below. In all three stages students were asked to prepare required assignments independently and to hand these. However to ensure this independence, students were not only asked to prepare their assignments out of the class but also to rewrite them on the day they were collected. The instructor briefly analyzed assignments for consistencies between handed in and written in the class. On the other hand, students were encouraged to have dialog and discussions about the assignments.

First Stage

During the first stage of the study, the unit was comprised of seven 40-minute lessons that dealt with the magnetic effect of an electric current. One course-hour was devoted to pre-test, four course-hours to studying the unit, one hour to setting up the writing task, and 1 hour to the post-test. All classes carried out the identical diversified writing activity—that of writing a letter to the teacher about the topic studied. Aside from the purpose stated above this stage was used to compare the performance on the pre- and post-test between classes to be able to investigate possible differences among the classrooms prior to study and after leveling them with common writing treatment so that later stage differences in the writing experiences themselves could be disregarded as a contributing factor to achievement. Further, post-test scores of the first stage were planned to be used as a covariate in the analyses of other stages.

Table 1
Table of treatment conditions

Classes	N	Stage 1 Magnetic Effect of Current	Stage 2 Faraday's Law of Induction	Stage 3 Alternating Current
A	27	Text only	Text only	Text only
B	25	Text only	Text only	Text only
C	27	Text only	Text only	Text only
D	25	Text only	Text plus math	Text plus math
E	26	Text only	Text plus math	Text plus graph
F	25	Text only	Text plus graph	Text plus graph
G	26	Text only	Text plus graph	Text plus math

Table 2
Implementation schedule

Stages	Classes	Topic of Activity	Explanations
(1) Magnetic effect of current	ABCDEFG	Application of pre-test	Pre-test of magnetic effect of electric current
	ABCDEFG	Study of the unit	Lecturing, laboratory activities and problem sessions
	ABCDEFG	Preparing for the writing task and evaluating	Introducing the writing task (only text) ant its' demands and the evaluation rubric
	ABCDEFG	Application of post-test	Post-test of magnetic effect of electric current
(2) Faraday's Law of Induction	ABCDEFG	Application of pre-test	Pre-test of faraday's law of induction
	ABCDEFG	Study of the unit	Lecturing, laboratory activities and problem sessions
	AB	Preparing for the writing task and evaluating	Introducing the writing task (text and graph) and the evaluation rubric
	CD	Preparing for the writing task and evaluating	Introducing the writing task (text and math) and the evaluation rubric
	EFG	Preparing for the writing task and evaluating	Introducing the writing task (text only) and the evaluation rubric
	ABCDEFG	Application of post-test	Post-test of faraday's law of induction
(3) Alternative current	ABCDEFG	Application of pre-test	Pre-test of alternating current
	ABCDEFG	Study of the unit	Lecturing, laboratory activities and problem sessions
	AC	Preparing for the writing task and evaluating	Introducing the writing task (text and graph) and the evaluation rubric
	BD	Preparing for the writing task and evaluating	Introducing the writing task (text and math) and the evaluation rubric
	EFG	Preparing for the writing task and evaluating	Introducing the writing task (text only) and the evaluation rubric
	ABCDEFG	Application of post-test	Post-test of alternating current

Instruction was given to all students through discussion, laboratory activities, and problem solving sessions. At the completion of a unit, all groups wrote a hand written letter of three pages explaining the topic to the instructor as their audience. They were given 1 week to complete the task. Using the model produced by Hand and Prain (1996), the audience, purpose, type of writing, topic, method of text production, and evaluation rubric were all discussed by the entire class at the outset of activity. The writing task given during this stage had a constraint of being composed of only text, that is, students were not allowed to include graphical or mathematical modes of representation.

Writing assignments for all sections were evaluated by an external reader, another physics teacher in the same institution, to ensure independence of assessment and to increase the reliably of scoring. Writing tasks have been evaluated with the rubric provided in Appendix 1 prepared based on 6-Traits of writing (Spandel, 2004a,b) over 100 points. While the evaluation rubric was discussed and provided to all students during the introduction of the writing assignment, a summary of the evaluation report was returned to all students before the post-test. All sections were administered a post-test at the end of the unit after evaluation of the feedback (see Table 2).

Unit 1 Test (Magnetic Effect of Electric Current)

The same pre/post-test instruments used in this stage were prepared by using items from the Turkish National University Entrance Test and items from widely used university entrance test preparation question banks. Ten multiple choice topic-relevant questions were drawn from these test banks and analyzed by the researchers, the teacher and an independent teacher for internal consistency. Moreover, to ensure the face validity of modalities represented on the test an equal number of questions with textual, mathematical, and graphical representations was included. Further, an independent university professor from the physics department was involved in evaluating the test's face validity and conceptual consistency. The professor was also asked to analyze and provide feedback about modalities as well. Additionally, such procedures were followed for the remaining stages (see Appendices 2 and 3 for exemplary multiple choice questions and discrimination and difficulty indexes of the unit 1 test). The multiple choice questions were graded over 100 points and were evaluated by optical reader (post-test analyses indicated that the Cronbach's alpha for Unit 1 test was 0.56). It is worth mentioning that the student's test results were analyzed before the second stage took place and thus we decided to increase the number of questions to have a better reliability measure.

Second Stage

The second stage of the study involved all seven sections who participated in the first stage. These sections were randomly divided into three groups consisting of text only (three classes), text plus math expressions (two classes), and text plus graphical representations (two classes). Instruction dealing with Faraday's Law of induction was given to all students in the same manner, that is, all groups received similar instruction on the topic. Consistent laboratory work, individual homework, and discussions were undertaken to ensure similar time on task for all groups. At the completion of the unit of study, each group again wrote a letter containing explanations to 9th grade students about the production of electromotive force induced by the change of magnetic flux. Students were informed that this homework task was to be hand written, no more than two A4 pages, and was to be completed in 1 week. The difference between the writing tasks among the groups was the restrictions in the modes required within the writing task. Two sections were assigned to write a letter containing text plus graphical representations (graph), two sections were assigned to write a letter containing text plus mathematical expressions (math). Three sections were viewed as control sections and were assigned to write a letter using text only.

Upon completion of the writing tasks, for all three stages, the letters were given to 9th grade students in the same institution. The students were asked to evaluate if there appeared to be major concepts explained in the letter and if they understood these concepts specifically and overall. The students were asked to rate the student letters using the scale of "I did not understand," "I understood a little," "I almost understood," "I understood exactly." Further, the student letters were evaluated by an external reader and feedback was provided to each student as in the case of stage one. Thus, each student received a feedback form from the external reader and 9th grade students. All groups were administered a post-test after evaluating the feedback.

Unit 2 Test (Faraday's Law of Induction)

The pre/post-test instrument used to measure the understanding of electromotive force induced by the change of magnetic flux was designed using a mixture of nationally recognized question banks. While the same test preparation procedure was followed as in the first stage, this time the test consisted of 35 multiple choice items in order to increase reliability. The test was evaluated over 100 points and contained qualitative and quantitative questions at the level of knowledge, comprehension, application, analysis, synthesis and evaluation (see Appendices 2 and 4 for example multiple choice questions, and difficulty indexes of the unit 2 test). All questions were evaluated by optical reader. Post-test analyses at the end of the second stage indicated that the Cronbach's alpha for Unit 2 test was 0.68.

Third Stage

The third stage of the study again involved three groups. Instruction dealing with alternating current was given to all students in the same manner, as for the first and second stage. At the completion of the unit of study, each group again was asked to write a letter containing explanations to 9th grade students, this time about the alternating current with 1 week given to complete the task. The difference between the writing tasks among the groups was restrictions in the modal representations embedded in the text. To examine the impact of different modal representations, variations to stage two tasks were implemented. The two sections that completed the text plus mathematical representation task in stage two were randomly divided into two treatments. One section maintained the text plus mathematical representation while the second was now required to change to text plus graphical representation. The two sections that completed the text plus graphical representation task in stage two were randomly divided into two treatments. One section maintained the text plus graphical representation task while the other was required to complete the task using text plus mathematical representation. The three sections acting as the control sections maintained the text only format. As in the second stage, writing tasks were evaluated by an external reader and a 9th grade student with evaluation forms and feedback sent to the author students. All groups were administered a post-test after evaluating the writing task and feedback (see Table 2).

Unit 3 Test (Alternating Current)

The pre- and post-test instruments used to measure the achievement on the topic of alternating current was designed using the same test banks as in the case of the second stage. Furthermore, whereas the same test preparation procedure was followed as in the first and second stage, the third test consisted of 47 multiple choice items in order to have a better reliability measure. The test was evaluated over 100 points and contained qualitative and quantitative questions at the level of knowledge, comprehension, application, analysis, synthesis and evaluation (see Appendices 2 and 5 for exemplary multiple choice questions, and discrimination and difficulty indexes of the unit 3 test). All questions were evaluated by optical reader. Finally post-test analyses indicated that the Cronbach's alpha for Unit 3 test was 0.84.

Statistical Analysis

To test for equivalency of groups for comparison, analyses of scores on the pre-tests given prior to the synthesis tasks were conducted using ANOVA. The pre-test items were the total scores on multiple-choice questions. The effect of the groups with embedded multi-model representations were analyzed using ANCOVA with pre-test measures included as covariates in the model. Statistical significance was determined at an alpha level of 0.05 for all statistical tests. In the ANOVA analyses, the means reported were unadjusted and in the ANCOVA analyses means reported are adjusted means, with adjusted means and standard errors (SE) being used to calculate t values. Non-significant results were not reported. Finally, in this study we reported effect sizes to recognize the magnitude of intervention on students' learning (Sheskin, 2004; Wilkinson & Affairs, 1999).

Assumptions

There are three general statistical assumptions involved in this study with analysis of variance, as stated by (Mertler & Vannatta, 2002, pp. 341–42):

- Normality: Assumption that each variable and linear combinations of variables are normally distributed
- Linearity: Assumption that there is a straight line relationship between two variables
- Homogeneity: Assumption that the variables in scores for one continuous variable is roughly the same at all values of another continuous variable.

Results

A simple graphical method and normal probability plots of model residuals along with Kolmogorov–Smirnov test were used to examine the normality assumption for all stages. Analyses indicated that the normality assumption was met for tests used on the three stages. The linearity assumption is addressed by plotting standardized residual values against the predicted values. Examination of the Normal Q-Q Plots obtained through SPSS explore procedure yield that the patterns of lines resembled linearity for all stages. Finally, the homogeneity assumption is examined by using Levene's test for equal variances within each ANCOVA analysis presented below.

Table 3
Pre-tests scores for the unit 1 test

Groups	n	Multiple Choice T	
		M	SD
Text	49	16.531	13.625
Math	49	19.130	16.031
Graph	67	15.882	14.886

First Stage

Pre-Test Analysis. Since the purpose of the first stage was to provide a common diversified writing experience for students, there was no control or specific treatment group in this stage as stated above. However, treatment groups were randomly identified in order to compare performances. To compare groups prior to the study, ANOVA analyses were constructed on the pre-test total. Results indicated that group' performances on those items were not statistically different (see Table 3 for mean and standard deviation).

Post-Test Analysis. Since there were no significant differences detected among sections one way ANOVA and Tukey HSD multiple comparisons tests were conducted on the post-test total. Results indicated significant performance differences among groups (F (2, 166) = 4.173, P = 0.017). Pairwise comparisons indicated that the group who was going to be text only treatment (M = 72.055, SE = 12.579) outperformed students in the group who was going to be graph treatment (M = 65.294, SE = 16.168), t (122) = 2.504, $P < 0.05$. There was no other statistically significant performance difference detected (see Table 4 for mean and standard deviation). Due to the fact that there were significant performance differences among groups at the end of the first stage, the first round post-test total scores were used as a covariate within the second and third stage analyses.

Second Stage

Post-Test Analysis. One-way ANCOVA results indicated that the first stage post-test total score as a covariate did not significantly influence the dependent variable (F (1, 137) = 2.229, P = 0.138, $\eta^2 = 0.016$). Also, the main effect for group was not significant F (2, 137) = 1.257, P = 0.288, $\eta^2 = 0.018$. Finally pairwise comparisons indicated that there were no significant mean differences among three groups (see Table 5 for means and standard errors). Finally, Levene's test of equality of error variance shows significant results (F (2, 138) = 3.080, P = 0.050), which confirms one of the assumptions, the error variance of the dependent variable is equal across groups, was not violated.

Third Stage

Post-Test Analysis. As in the second stage, because of non-equivalency of the groups at the end of the first stage, the first stage post-test total was used as a covariate with the third round pre-test total score.

Table 4
Pos-tests scores for the unit 1 test

Groups	n	Multiple Choice T	
		M	SD
Text	51	65.294	16.168
Math	45	65.556	16.453
Graph	73	72.059	12.579

Table 5
Post-test scores for the unit 2 test

Group	Adj. M	SE
Text only	35.377	1.502
Text plus math	38.988	1.701
Text plus graph	36.915	1.218

One-way ANCOVA results indicated that the covariate first stage post-test total score (F (1, 114) = 1.174, $P = 0.281$, $\eta^2 = 0.010$) did not significantly influence the dependent variable of third round post-test total scores. Conversely, the main effect for group was significant F (4, 114) = 4.304, $P = 0.003$, $\eta^2 = 0.131$. Pairwise comparisons indicated that there were performance differences among groups where text plus math—text plus graph group out performed the text plus graph—text plus math, text plus graph-text plus graph and text only—text only groups; the text plus math—text plus math group outperformed the text plus graph—text plus math group; and the text only—text only group outperformed the text plus graph—text plus math group (see Tables 6 and 7). Mean Square Error for this model was 338.312, and Levene's test of equality of error variance showed significant results (F (4, 115) = 2.641, $P = 0.037$), which confirms the assumptions, error variance of the dependent variable is equal across groups, was violated. This violation of the assumption indicates that there is a significant interaction between covariate (first round post test total) and third round group.

Cohen d Effect Sizes on Stage 3

In this analysis, we have used the Cohen *d* index, which is widely used in social science because it enables us to measure "the difference between two means expressed in standard deviation units" (Sheskin, 2004, p. 835). The criteria for identifying the magnitude of an effect size is as follows: (a) A small effect size is between 0.2 and 0.5 standard deviation units; (b) A medium effect size is between 0.5 and 0.8 standard deviation units; and (c) A large effect size is 0.8 or more SD units (Rosenthal & Rosnow, 1984; Sheskin, 2004). Effect sizes smaller than 0.2 standard deviation units are named trivial (Kulik, 2002). The effect size results of each stage measure are given in Table 8.

The effect size calculations for the second stage of the research design indicate that using text with embedded mathematic representations resulted in a small effect ($d = 0.26$) when compared to using text embedded with graphical representations. The effect size between using text embedded with mathematical representations and using text only was trival ($d = 0.15$). Effect size calculations for the third stage indicated that effect size of using text with embedded mathematical representations in the second stage and using text with embedded graphical representation in the third stage as opposed to using other combinations created effects ranging from large to small. That is, preparing text with embedded mathematical representation in the second stage and text with graphical representation in the third stage resulted in a large effect (*Cohen's* $d = 1$) when compared to preparing text with embedded graphical representation in the second stage and text with mathematical representation in the third stage, resulted in medium effects (*Cohen's* $d = 0.5$) when compared to preparing text with embedded graphical representation two times in a row and only textual representation two times in a row, and resulted in a small effect (*Cohen's* $d = 0.5$) when compared to preparing text with embedded mathematical representation two times in a row.

Table 6
Post-tests scores for the unit 3 test

Group	Adj. M	SE
Text plus graph (stage 2) to text plus graph (stage 3)	65.435	4.229
Text plus graph (stage 2) to text plus math (stage 3)	53.556	4.225
Text plus math (stage 2) to text plus graph (stage 3)	79.122	4.664
Text plus math (stage 2) to text plus math (stage 3)	69.653	5.150
Text only (stage 2) to text only (stage 3)	65.678	2.620

Table 7
Pairwise comparisons for group mean scores on unit 3 post-test

Group (I)	Group (J)	Mean Difference (I–J)	*t*-value
Text plus math (stage2) to text plus graph (stage 3)	Text plus graph (stage 2) to text plus graph (stage 3)	13.687	2.174[a]
	Text plus graph (stage 2) to text plus math (stage 3)	25.566	4.063[b]
	Text only (stage 2) to text only (stage 3)	13.435	2.511[a]
Text plus math (stage2) to text plus math (stage 3)	Text plus graph (stage 2) to text plus math (stage 3)	16.097	2.417[a]
Text only (stage 2) to text only (stage 3)	Text plus graph (stage 2) to text plus math (stage 3)	12.131	2.440[a]

[a]The mean difference is significant at the 0.05 level.
[b]The mean difference is significant at the 0.01 level.

Moreover, preparing text with embedded mathematical representations two times versus preparing text with embedded graphical representations two times, preparing text two times without other modalities, and preparing text with embedded graphical representations in the second stage and test with embedded mathematical representations in the third stage created respectively small (*Cohen's* $d = 0.2$), small (*Cohen's* $d = 0.2$) and medium (*Cohen's* $d = 0.6$) effects. Finally, preparing text with embedded graphical representation or without any embedded modes two times in a row versus preparing text with graphical representation in the second stage and mathematical representation in the third stage yielded medium effects (*Cohen's* $d = 0.5$).

Discussion

Before discussing the results, we would like to reiterate the context for the study. This study was completed in an institution in Turkey that is considered to be one of the elite institutions with very exacting admissions standards. Students are generally considered to be in the top 10% of all high school-aged students in Turkey. We have restated this because these students are generally very successful in mathematics and science subjects and are perceived to have more than adequate skills in undertaking the different modal tasks required of them in their school work. Further, the topic of electricity is an appropriate area to examine with respect to multi-modal representation because there is a constant and necessary movement between textual, mathematical, graphical and pictorial representations used to explain the concepts related to the topic. Thus, by necessity, the students are required to engage in dealing with multimodal representation to succeed in the course.

Table 8
Cohen d effect sizes on the second and third stages

Compared Groups	Cohen's *d*	Scale
Text + math (S2) vs. text + graph (S2)	0.26	Small
Text + math (S2) to text + graph (S3) vs. text + graph (S2) to text + graph (S3)	0.5	Medium
Text + math (S2) to text + graph (S3) vs. text + graph (S2) to text + math (S3)	1	Large
Text + math (S2) to text + graph (S3) vs. text + math (S2) to text + math (S3)	0.4	Small
Text + math (S2) to text + graph (S3) vs. text only (S2)-text only(S3)	0.5	Medium
Text + math (S2) to text + math (S3) vs. text + graph (S2) to text + graph (S3)	0.2	Small
Text + math (S2) to text + math (S3) vs. text + graph (S2) to text + math (S3)	0.6	Medium
Text + math (S2) to text + math (S3) vs. text only (S2)-text only(S3)	0.2	Small
Text only (S2)-text only(S3) vs. text + graph (S2) to text + math (S3)	0.5	Medium
Text + graph (S2) to text + graph (S3) vs. text + graph (S2) to text + math (S3)	0.5	Medium

Note: Trivial effects were not shown.

The first stage of the research design was intended to provide all students with the opportunity to use a more diversified type of writing task than they were familiar with in their physics class. We did not want lack of experience with this type of writing to impact on stage 2 and 3 of the design. The results for stage 2 and 3 do indicate that the type of condition that they were involved with impacted on students' test scores. In stage 2, the effect size calculations indicate that students who constructed text with embedded mathematical representations performed better than students who constructed text only representations (trivial effect) or text with embedded graphical representations (small effect). In stage 3, the two sections of text plus mathematical representation in stage 2 were split into one section who repeated the treatment, that is, text plus math (stage 2) and text plus math (stage 3), while the other section was asked to embed graphical representation in their letter, that is, text plus math (stage 2) and text plus graph (stage 3). The two sections who embedded graphical representation into their letters in stage 2 were split into one section who repeated the treatment, that is, text plus graph (stage 2) and text plus graph (stage 3) while the other section was asked to embed mathematical representation into their letter, that is, text plus graph (stage 2) and text plus math (stage 3). The three remaining sections maintained the same treatment, that of text only, that is, text only (stage 2) and text only (stage 3). There were three significant results.

The first is that the sequence of embedding the mode within the text does appear to influence student performance on test questions. While there was no significant difference in stage 2 between any of the writing conditions, the effect size calculations do indicate that there were some trends beginning to appear. The students who embedded mathematical representations in their text had the highest mean scores on the stage 2 test. In stage 3 these students as a group outperformed the other students. However, the students who had the sequence of embedding mathematical representations in text followed by graphical representations in text had the highest score and largest effect size differences compared to the other conditions. The students who repeated the embedding mathematical representation in both stages also performed better than students who had the text only or embedded graphical representation treatment in stage 2. These results suggest that there is some value in requiring students to engage with explaining mathematical representations as a precursor for moving to the graphical representation of the concept.

The second is that students in the text plus graph (stage 2) and text plus math (stage 3) treatment condition were significantly disadvantaged statistically than the text plus math (stage 2) and text plus graph (stage 3) treatment condition, the text plus math (stage 2) and text plus math (stage 3) treatment condition and the text only treatment condition. That is, the students who initially had to explain concepts by embedding graphical representation in their text (stage 2) and then were asked to change and embed mathematical representation in their text (stage 3) were disadvantaged compared with all other treatment conditions except the text plus graph (stage 2) and text plus graph (stage 3) group treatment condition. This result does raise the question about the value of asking students to explain a concept by embedding graphical representations before dealing with mathematical representations of the same concept.

The third is that using the single mode of text only is more advantageous statistically than multi-modal representation when the condition is text plus graph (stage 2) and text plus math (stage 3) (effect size 0.6). That is, the students in this study who used the single mode of text were able to score significantly better on text questions involving movement between modes than students who were asked to explain the concepts using multi-modal representation when the specific condition of text plus graph followed by text plus math was used.

In recognizing the limitations of this single study, the researchers would suggest that there are a number of important implications that arise. The first is that the task required of the students was not the typical physics problem solving task, that is, the students were not asked to practice a lot of problems prior to the test. The writing task was oriented toward the students explaining the concepts of the topic to younger students. They were required to engage their understanding of the topic and use this along with available resources to write an explanation that was understandable to the younger audience. Importantly, in stages 2 and 3 the audience was not the teacher—they could not simply use terminology that had been given to them by the teacher, they had to translate the physics language into more everyday language for the younger audience (Gunel & Hand, 2005). Using Klein's (2006) arguments in relation to second-generation cognitive science, the students were required to explain the classical taxonomy of the physics concepts as presented in the topic, in a narrative manner for their younger audience. However, the nature of the embedded multimodal representation within the text does appear to be a critical factor in promoting understanding of the topic, that is, the value of the writing to learn approach in this case was dependent on the type of embedded mode and the sequence of use of the modes. Having to embed mathematical representation as a means to explain the concept appears to be advantageous to students as noted by results in stage 2 and the follow up combinations in stage 3, than beginning with graphical explanation or a text only explanation. Such a result would appear to contradict the comments by Beilfuss, Hagevik, and Dickerson (2006) who suggest that graphical interpretation is the bridge between verbal and mathematical.

In examining the results that advantage the text plus math mode for stage 2 and 3, the researchers would suggest that building on the argument of writing as an epistemological tool (Prain, 2006) does provide some possible explanation. Writing is an epistemological tool in that it requires students to take existing knowledge and build richer connections between different elements of this knowledge through the process of writing. Hence students come to know the subject matter in a richer and stronger manner than prior to the writing process. By having to embed multiple modes within the text produced and explain the connection between these modes to a younger audience, the students are building a richer connection between the modes. The results from stage 2 would suggest that having to explain the concepts in text and explaining how the concepts can be expressed mathematically does begin to advantage the students. Further, the value of explanation is enriched in stage 3 when the students were required to embed either mathematical or graphical modes within text. The highest mean score for stage 3 was the group that was text plus math (stage 2) and text plus graph (stage 3).

This may suggest that understanding how the concepts can be represented in text and mathematically in stage 2 promotes an understanding of the value of graphical representation in stage 3. Building an understanding of the relationship between the mathematic representation and text explanation appears to benefit the understanding of the relationship of graphical representation to text. As such the results would lend support to Duval's (2002) ideas discussed earlier that understanding of the mathematics involved in the study of physics does help students in being able to undertake the conversions between modes of representation that are necessary for fully understanding any concept.

The reverse of this process does not appear to advantage the students. That is, the students who were asked to explain the concept using text and graphical representation in stage 2 and then move to text and mathematical representation in stage 3 were the most disadvantaged students. That is, the sequence of use in embedding modes within text appears to be critical for student understanding. Importantly, these results support the work of Seufert (2003) and Ainsworth (2006) as discussed earlier, in that there would appear to be a relational aspect to construction of understanding of the different modal representations of a concept. For example, since a graph is a representation of a mathematical function, the researchers would suggest that building understanding of the mathematical representation of the concept does result in a better connection to the graphical representation of the concept. That is, by building an understanding of the mathematical representations of a concept through the writing experience, the students are better able to connect to the related aspects of the concept as they are represented in a graphical form. However, in recognizing the work of Airey and Linder (2006) into constellations of modes involved in understanding a topic, the researchers would point out that the research undertaken in this study was only done with one topic of physics, that is, electricity. We are cautious in suggesting that the order of representational understanding, that is, mathematical before graphical would be constant across different physics topics.

The researchers would reiterate that the tasks completed by the students were writing tasks that required explanation of the physics concepts and not the traditional problem solving tasks that are given at the end of a unit. However, the test items were traditional multimodal physics problems that did not require written explanation but rather mathematical and graphical manipulation. Rather than practicing problem solving and learning the appropriate algorithm, these students were required to build understanding of the concepts and then apply this understanding to the problem solving.

Implications

A major implication arising from the study is the pedagogical consequences that need to shape student engagement with multimodal representation for success in understanding physics concepts. The results suggest that teachers should focus on encouraging students to engage with understanding the link between mathematical and textual representation prior to moving toward graphical representation. Rather than focus only on problem solving as is typically the case in physics class, students should be encouraged to engage with the concept of representation, that is, they need to build an understanding of the concepts under study and how these concepts can be represented. If we are to help students become scientifically literate we need to encourage them to be able to understand the full range of modes used to represent a concept and how to use these modes as tools to solve problems. This study was framed around exploring students' production of text in ways different to general physics classrooms that tend to be more textbook dominated in terms of chapter summaries and end of chapter questions and answers. As such the results would suggest that while graphical representations are very common in textbooks and that teachers constantly use them as part of the teaching approach, students may be better off having to engage with mathematical representation as a precursor to dealing with graphical representation, through having to write about them in the more non traditional ways used in this study.

The other major implication is the need for further studies across different physics areas and other science disciplines such as chemistry, biology and earth sciences. Students are constantly having to move between multiple modes of representation, yet we do not know enough to answer such questions as: are there particular modes which predominate in terms of promoting conceptual understanding of given concepts? What are the appropriate pedagogies to promote multi-modal understanding?

The authors acknowledge the help of Sevket Gunduz in implementation of the study. We express our thanks to him for his contribution to the study.

Appendix 1: Rubric for Writing Evaluation

Score of 5	Score of 20	Score of 40
Big ideas/conceptual knowledge		
Conceptual science knowledge and big ideas are not evident. Concepts are confusing, incorrect, and flawed	Conceptual science knowledge is evident in much of the project. Most ideas and concepts used are clearly linked to the big idea and correct	Conceptual science knowledge and big ideas are evident throughout the project. All concepts are clear and correct
The writer still needs to clarify the big ideas and concepts	It is easy to see where the writer is headed, even if some telling details are needed to complete the picture	The paper creates a vivid impression, makes a point, or conveys the concepts and big idea of the topic
The writer has assembled a loose collection of concepts that do not as yet, have any real focus	The reader can grasp the big ideas but yearns for elaboration	Thoughts and concepts are clearly expressed and directly relevant to a big idea, or story line
Everything seems as important as everything else	General observations and common knowledge are as plentiful as insights or close-up details	Concepts are based on investigation of a topic and goes beyond common knowledge
It is hard to identify the main theme or concept: what is this writer's main point or purpose	There may be too much detailed information: it would help if the writer would trim the deadwood (fluff)	Carefully selected examples, rich details, mathematical, graphical representations and/or anecdotes bring the topic to life and lend the writing authenticity
	As a whole, the piece hangs together and makes a clear general statement or tells a science concept	The reader is not left with important unanswered questions. That is, reader can easily understand the topic, concepts and big idea

Score of 5	Score of 15	Score of 30
Organization		
The writer skips randomly from point to point, leaving the reader scrambling to follow	Sequencing seems reasonably appropriate	The organization showcases the central theme or story line
No real lead sets up what follows	Placement of details is workable, although sometimes predictable	Details seem to fit right where they are places, even when the writer hits the reader with a surprise
No real conclusion wraps things up	The introduction and conclusion are recognizable and functional	An inviting lead draws the reader in; a satisfying conclusion helps bring the reader's thinking to closure
Missing or unclear transactions force the reader to make big leaps	Transitions are present but may sound formulaic-for example, "My first point...," "My second point..."	Pacing feels natural and effective; the writer knows just when to linger over details and when to get moving
It is difficult to see any real pattern or structure in this writing	Structure may be so dominant that it overshadows both ideas and voice; it is impossible to stop thinking about it!	Organization flows so smoothly that the reader does not need to think about it

Score of 1	Score of 3	Score of 5
Voice		
The writer does not seem to reach out to the audience or to anticipate their interests and needs	The writer has not quite found his or her voice but is experimenting-and the result is pleasant and sincere, if not highly individual	The tone and flavor of the piece fit the topic, purpose, and audience well
Although it may communicate on a functional level, the writing takes no risks and does not involve or move the reader	Moments here and there snag the reader's attention, but the writer holds passion and spontaneity in check	Clearly. The writing belongs to this writer and no other
The writer does not yet seem sufficiently at home with the topic to personalize it for the reader	The writer often seems reluctant to reveal him or herself and is "there" briefly-then gone	The writer "speaks" to the reader in a way that makes him or her feel like an insider
	Although clearly aware of an audience, the writer only occasionally speaks right to that audience	Narrative test is open and honest
	The writer often seems right on the verge of sharing something truly interesting—but then pulls back as if thinking better of it	Expository or persuasive text is provocative, lively, and designed to prompt thinking

Score of 2	Score of 5	Score of 10
Word choice		
Vague words and phrases ["She was nice...," "It was wonderful...," "The new budget had impact"] convey only the most general sorts of messages	Most words are correct and adequate, even if not striking	The writer's message is remarkably clear and easy to interpret
Redundancy is noticeable-even distracting	Energetic verbs or memorable phrases occasionally strike a spark, leaving the reader hungry for more	Phrasing is original-even memorable-yet the language is never overdone
Clichés and tired phrases pop up with disappointing frequency	Familiar words and phrases give the text an "old comfortable couch" kind of feel	Lively verbs lend the writing power. Precise nouns and modifiers make it easy to picture what the writer is saying
Words are used incorrectly ["The bus *impelled* into the hotel"]	In one or two places, language may be overdone—but at least it is not flat	Striking words or phrases linger in the writer's memory, often promoting connections, memories, reflective thoughts, or insights
The writer overloads the text with ponderous, overdone, or jargonistic language that is tough to penetrate	Attempts at colorful language are full of promise, even when they lack restraint or control	

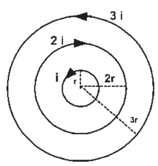
Score of 2	Score of 5	Score of 10
Sentence fluency		
Irregular or unusual word patterns make sentences hard to decipher or make it hard to tell where one sentenced ends and the next begins	Sentences are grammatical and fairly easy to get though, given a little rehearsal	Sentences are well-crafter, with a strong and varied structure that invites expressive oral reading
Ideas hooked together by numerous connectives [and, but so then, because] create one gangly endless "sentence"	Graceful, natural phrasing intermingles with more mechanical structure	Purposeful sentence beginnings show how each sentence relates to and builds on the one before it
Short, choppy sentences bump the reader through the text	Some variation in length and structure enhances fluency	The writing has cadence, as if the writer hears the beat in his or her head
Repetitive sentence patterns grow monotonous	Some purposeful sentences beginnings help the reader make sentence-to-sentence connections	Sentences vary in both structure and length, making the reading pleasant and natural, never monotonous
Transitional phrases are so repetitive that they become distracting		Fragments, if used, add to the style
The reader must often pause and reread to get the meaning		

Score of 1	Score of 3	Score of 5
Conventions		
Errors are sufficiently frequent and/or serious as to be distracting; it is hard for the reader to focus on ideas, organization, or voice	There are enough errors to distract an attentive reader somewhat; however, errors do not seriously impair readability or obscure meaning	Errors are so few and so minor that a reader can easily overlook them unless searching for them specifically. Highly skilled writers may "play" with conventions for special effect
Errors in spelling, punctuation, or grammar cause the reader to pause, decode, or reread to make sense of the text	It is easy enough for an experience reader to get through the text without stumbling, but the writing clearly needs polishing. It is definitely not "ready for press"	The text appears clean, edited, and polished
Extensive editing would be requited to prepare this text for publication	Moderate editing would be required to get this text ready for publication	Older writers (grade 6 and up) create text of sufficient length and complexity to demonstrate control of a range of conventions appropriate for their age and experience
	The paper reads like an "on its way" rough draft	The text is easy to mentally process; there is nothing to distract or confuse a reader
		Only light touch-ups would be required to polish the text for publication

Appendix 2: Exemplar Questions From the Tests Used

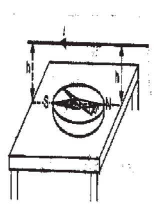
Stage 1- Magnetic effect of electric

8-



Three circle wires with r, 2r and 3r radiuses and I, 2I and 3I currents were centered on the same plane system. The directions of the current flows were shown in the picture. If the magnetic field created at O point by the smallest circle wire is B what would be the total magnetic filed on O point created by all three wires?

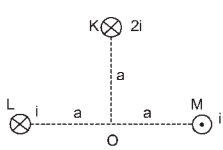
9-



When the wire with *i* flowing current placed h distance above the compass on the table, The needle of the compass moves 30 degree on vertical plane. If the vertical component of the Earth's magnetic field is 2 x 10^{-5} what is the magnitude of magnetic filed created by the wire at the point that compass was placed on?

A) 4 x 10^{-5} N/Am
B) $2\sqrt{3}$ x 10^{-5} N/Am
C) 2 x 10^{-5} N/Am
D) $\sqrt{3}$ x 10^{-5} N/Am
E) $2/\sqrt{3}$ x 10^{-5} N/Am

10-



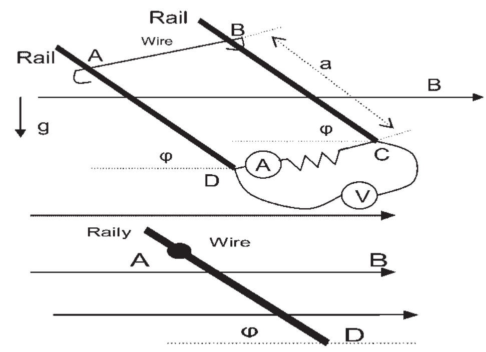
If the magnitude of the magnetic field created at O point by K wire is B then which one of the following represents total magnitude and the direction of the total magnetic filed at O point?

A) → B
B) ← B
C) ↙ $B\sqrt{2}$
D) ↘ 2B
E) ↑ $B\sqrt{3}$

Stage 2- Faraday's Law of Induction

Problem Statement: Following pictures represents a situation where piece of metal wire is fixed on the frictionless parallel rail system where it can freely move. The rail system and the wire were placed into uniform B magnetic field with φ angle. The distance between rails is L and the lengths of the rails are long enough.

A represents ampere meter and V represents volt meter



19- For the given problem statement above which of the followings represents the reading from the voltmeter?

A) qvBSinφ
B) BLvSinφ
C) BLv
D) BLvCosφ
E) Zero

22- Which one of the following properties of the wire would change if the direction of the magnetic filed (B) turned to the opposite side (180 degree)?

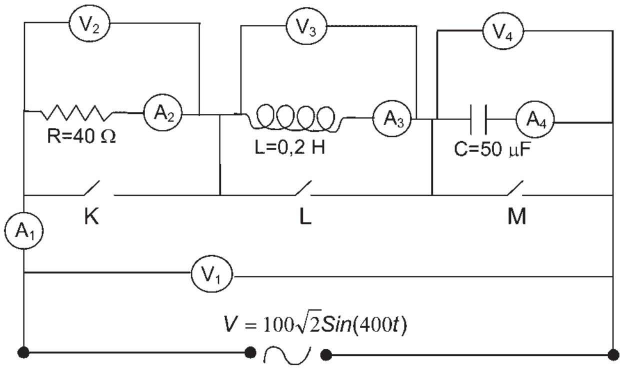
A) Speed
B) Acceleration
C) Direction of the current
D) Magnitude of the current read by ampere meter
E) Potential read by voltmeter

29- If the wire is released when the angle φ is equal to 90 degree, how would the current change in comparison to current position given above?

A) Increase
B) Decrease
C) No change
D) No current will accrue to be read

Problem Statement: The resistant (with resistance R), inductor (with inductance L), and capacitor (with conductance C) were connected to alternating current source as shown in the picture.

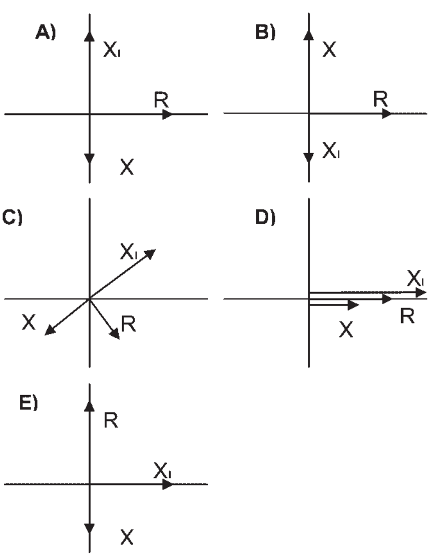
A represents ampere meter and V represents voltmeter.



Sin0=Cos90=0
Sin30=Cos60=1/2
Sin37=Cos53=3/5
Sin45=Cos45= $\sqrt{2}/2$
Sin53=Cos37=4/5
Sin60=Cos30= $\sqrt{3}/2$
Sin90=Cos0=1
2π rad=360°

1- What is the angular frequency of the circuit (in *rad/s*)?
A) 100 B)100√2 C)200 D) 400 E) 800

8- Which of the following graph correctly represents the reactance of the resistant, inductor, and capacitor?



21- Which one of the following represents the current-time function read from the A_1 ampere meter?

A) $i = 2\sqrt{2}Sin(400t - \frac{\pi}{5})$

B) $i = 2\sqrt{2}Sin(400t)$

C) $i = \frac{5}{2}Sin(400t - \frac{\pi}{5})$

D) $i = 2\sqrt{2}Sin(400t + \frac{\pi}{5})$

E) $i = 2.Sin(400t - \frac{\pi}{5})$

2- If the M switch is closed how the values read from V_1 and V_3 voltmeters changes?

A) V_1 does not change
B) V_3 decrease
C) V_3 increase
D) V_3 does not change
E) V_1 increase

Appendix 3: Item Analyses for Unit 1 Test

Question #	Difficulty Index	Discrimination Index
1	0.87	0.36
2	0.93	0.29
3	0.80	0.53
4	0.63	0.45
5	0.02	0.04
6	0.91	0.50
7	0.74	0.39
8	0.89	0.40
9	0.31	0.32
10	0.73	0.45

Appendix 4: Item Analyses for Unit 2 Test

Question #	Difficulty Index	Discrimination Index
1	0.35	0.28
2	0.79	0.31
3	0.58	0.29
4	0.56	0.53
5	0.76	0.29
6	0.49	0.32
7	0.24	0.41
8	0.58	0.34
9	0.42	0.06
10	0.36	0.43
11	0.74	0.32
12	0.13	0.44
13	0.28	0.19
14	0.03	0.13
15	0.08	0.38
16	0.26	0.16
17	0.04	0.25
18	0.18	0.38
19	0.71	0.20
20	0.37	0.20
21	0.14	0.06
22	0.93	0.33
23	0.08	0.13
24	0.11	0.21
25	0.07	0.18
26	0.50	0.35
27	0.02	0.24
28	0.04	0.02
29	0.03	0.15
30	0.50	0.31
31	0.48	0.28
32	0.10	0.15
33	0.18	0.25
34	0.37	0.31
35	0.16	0.14

Appendix 5: Item Analyses for Unit 3 Test

Question #	Difficulty Index	Discrimination Index
1	0.80	0.19
2	0.89	0.33
3	0.93	0.31
4	0.78	0.44
5	0.91	0.52
6	0.82	0.43
7	0.93	0.46
8	0.47	0.32
9	0.77	0.50
10	0.80	0.50
11	0.72	0.55
12	0.72	0.52
13	0.70	0.49
14	0.52	0.39
15	0.70	0.32
16	0.43	0.30
17	0.91	0.40
18	0.67	0.34
19	0.50	0.38
20	0.66	0.41
21	0.33	0.20
22	0.22	0.44
23	0.17	0.32
24	0.22	0.41
25	0.16	0.28
26	0.64	0.40
27	0.39	0.35
28	0.51	0.30
29	0.44	0.41
30	0.50	0.35
31	0.42	0.43
32	0.41	0.49
33	0.23	0.44
34	0.30	0.31
35	0.16	0.18
36	0.45	0.39
37	0.29	0.42
38	0.25	0.28
39	0.31	0.38
40	0.34	0.30
41	0.42	0.37
42	0.23	0.27
43	0.18	0.27
44	0.12	0.22
45	0.06	0.24
46	0.27	0.24
47	0.21	0.31

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