Comparing Student Understanding of Quantum Physics When Embedding Multimodal Representations into Two Different Writing Formats: Presentation Format Versus Summary Report Format

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ABSTRACT: Physics as a subject for school students requires an understanding and ability to move between different modes of representation for the concepts under review. However, the inability of students to have a multimodal understanding of the concepts is seen as restricting their understandings of the concepts. The aim of this study was to explore the effectiveness of using writing-to-learn strategies that required students to embed multimodal representations of the concepts. In particular, the study compared a presentation format with a summary report format for students learning quantum theory. A pre–post test design was used to compare performances of these two groups across two units. For unit 1, students' scores from groups that completed either a presentation format (PowerPoint presentation) or a summary report format (chapter summary) were compared. No limits were placed on the amount of text or the number of representations used. For unit 2, products of

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both groups were constructed for an audience of year 10 students. The presentation format group (PowerPoint) was limited to 15 slides, with a maximum of 10 words displayed per slide; a script was written to accompany the presentation. Slides could include graphical and mathematical formulae; however, the text could not. The summary report format group that wrote out its explanations was limited to four pages and was required to incorporate multimodal representations. Results indicated that for both units students using the presentation format group scored significantly better on tests than the summary report format group. The effect size difference between the groups increased for the second unit, indicating that more practice was leading to better student understanding of the physics concepts.
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INTRODUCTION

The use of writing as a learning tool in science classrooms has begun to receive much attention over the last decade. Major reviews of the literature (Holliday, Yore, & Alvermann, 1994; Klein, 1999; Yore, Bisanz, & Hand, 2003) indicate that there are many questions yet to be addressed in how to use these strategies and what learning arises from their use. The importance of writing and language forms, in general, within science is clearly articulated by Norris and Phillips (2003) who indicated that without language there is no science. To build our understanding of the use of writing-to-learn strategies, Rivard (1994) has proposed the need for more quantitative studies to enrich our understandings, while Prain and Hand (1996) have advocated the need for more diversified uses of writing, including purposes and audiences to which students write. Importantly, the use of writing-to-learn strategies within science classrooms is seen as involving students in having to move between different forms of the same language (Prain & Hand, 2005), that is, between canonical forms of the language and the everyday language of the student. Yore and Treagust (2006) have extended this argument to frame the concept of Science Language Learners (ScLL), paralleling the concept of English Language Learning (ELL). By this they mean that students are constantly trying to understand science language through their own language, requiring a translation of understanding between these different language forms.

While advocating an enhanced and richer set of language experiences to help promote learning of science concepts, the research work has been centered predominately around reading, writing, and talking. However, Prain (2006) has advocated the need to broaden the efforts of research to examine the emerging technologies available for science classrooms and how these impact not only the presentation of concepts but also the opportunities for re-representation of ideas. Technologies incorporating multimedia offer unique opportunities for students to move through different representation modes and thus engage concepts in a variety of ways (Mayer, 2003). Thus, in the science classroom, this requires that students not only translate language about the topic between science and everyday language in the text-dominant classroom but also have experiences at re-representing the concepts discussed across the various modes used within the topic.

However, Schnotz and Lowe (2003) caution researchers that there is an existing misconception that "the technical medium itself is presumed to have an impact on learning" (p. 117). They state that research on "media effects has clearly established that it is misguided and overly simplistic to compare different technical media with regard to their effects on learning without taking account of semiotic and sensory aspects." Mayer (2003) also argues the same position when he states that

> In rejecting a technology-centered approach, I conclude that media environments do not cause learning, cognitive processing by the learner causes learning. If an instructional

> method promotes the same kinds of cognitive processing across different media, then it will result in the same benefits across the media. (p. 137)

In focusing the attention on the language requirements as part of the cognitive processing needed to move between modes, Bernsen (1993) suggests that "multimodal representations are combined from something, namely unimodal representations" (p. 3). He argues that there is generally not a universal decoding system for the various modalities used, requiring the learner to have additional knowledge to move between modes. Pineda and Garza (2000) reinforce this viewpoint when they suggest that the importance of moving from a unimodal representation system to a multimodal one is centered on translating language between the modes. They argue that these translation activities are qualitatively different "from a symbolic manipulation process operating on expressions of a single language" and thus require much more cognitive work on behalf of the learner.

While this argument is clear about the need for students to be cognitively active when dealing with different modes of representation, there is recognition that there are different types of modal clusters. Schnotz and Lowe (2003) have suggested that there are three different levels of multimodal resources. These are technical devices to produce the representations; the semiotic or representational format, that is, texts, pictures, and sounds; and the sensory mode, that is, the visual and auditory modalities. Bernsen (1993) and Pineda and Garza (2000) have used the terms representational modes and psychological modes to differentiate between the semiotic and sensory modes defined by Schnotz and Lowe. The representational mode is viewed as a cognitive mode that is dealing with the production of external representations of a learner's internal representation of an idea. The psychological mode deals with the senses and with touch and sound; that is, this mode deals with different physical modalities to support the learning.

The representational position adopts the view that moving between the different modalities requires that processing of the language of each mode occur in such a way that the information that is extracted from one modality can be used in the other (Pineda & Garza, 2000). For Mayer (2003), learning from multimodal opportunities occurs because learners have to move between words and pictures, requiring them to construct meaning from different components of working memory. He argues that there is evidence to suggest that single modes such as text only do not always work, and that for deep learning to occur, learners need opportunities to move between modes. Pineda and Garza (2000) suggest that coming to an understanding of how the different modalities deal with the same concept involves a process of incremental inference constraints. They suggest that learners construct rich understandings of the language between modes through reasoning and inference, and that this is done through incremental steps.

Such an explanation parallels that put forward by Galbraith (1999) in his explanation of the writing process. Galbraith argues that the production of text is one in which knowledge is constituted within a process of cycling through a network of content knowledge (dispositional dialectic) and linguistic knowledge. Each successive cycle is constrained by the number of connections that are made to the ideas being represented in the text until there are no more connections possible within a learner's cognitive network. This explanation deals with text-based language only; however, given that multimodal representation is about representing knowledge in different language forms, the same argument can be made for the constraint satisfaction requirement. That is, translation between different modes of language will occur through a cyclic process until all connections have been exhausted. The level of connections will be dependent upon each learner's conceptual framework.

Technology in the Classroom

The use of educational technology has increased in popularity since the birth of the electronic superhighway. The tools associated with teaching and learning, such as computers, multimedia presentation, and software applications, have earned a pride of place in teacher education textbooks (Chiappetta & Koballa, 2002; Roblyer, Edwards, & Havriluk, 1997; Trowbridge & Bybee, 1996). Researchers argue that knowing how to use graphical representation software is an important component of technological literacy for teachers (Moursund & Bielefeldt, 1999; I. G. Rosenthal, 1999). It has become part of a science teacher's responsibility not only to use various technologies to support student learning but also to make such resources accessible to students for sense-making within a constructivist framework (National Research Council, 1996). The push to incorporate educational technology in lessons is not confined to the United States. Initiatives to develop national education in Turkey have influenced an effort to improve teacher competency in using computers, including Microsoft PowerPoint software (Asan, 2001).

Despite these concerted efforts, there is some controversy surrounding the most appropriate ways to use PowerPoint in particular. The research to date on the effectiveness of this software program in terms of student learning is limited. Most of the research found that investigating PowerPoint has been conducted in undergraduate classrooms with mixed results. The purpose of the present study was to explore one claim present in multimedia learning research; that is, when different instructional methods across various media engage the same cognitive processes, no difference in learning will be apparent (Mayer, 2003).

PowerPoint as a Presentation Format

In summarizing the research, the literature reviewed addresses the advantages and disadvantages of the PowerPoint software program as an educational tool, provides a theoretical base for instructional design that focuses on students as active constructers of presentations, and sets the base for the investigation of the effectiveness of instructional methods that encourage use of multiple representations.

While PowerPoint has been available as a tool for the teaching–learning repertoire for some time, much of the literature indicates that the program is primarily at the command of teachers, teachers-in-training (Clark & Wiebe, 2001; Irving, 2003), and professors (Bartsch & Cobern, 2003; Carlson, 2002; Cassady, 1998; Holland, 1996; Lowry, 1999; Mantei, 2000; Perry & Perry, 1998; Ricer, Filak, & Short, 2005; Susskind, 2005; Szabo & Hastings, 2000), with the primary function to deliver information to students, that is, as a presentation format for information.

In the research that has investigated the effectiveness of PowerPoint in comparison to other formats, there appears to be a mismatch between subjective and objective results. In general, the findings indicate that students prefer presentations with PowerPoint to those displayed with overhead transparencies (Bartsch & Cobern, 2003; Cassady, 1998; Perry & Perry, 1998), although some authors report equal student ratings of the instructional media (Ricer et al., 2005). In an undergraduate psychology course, Susskind (2005) compared traditional lectures (lecture notes written on a whiteboard and graphics displayed overhead) to those presented with PowerPoint. Students perceived that the multimedia lectures were more organized, interesting, and enjoyable, and reported more positive attitudes and greater self-efficacy. It was easier to take notes and to understand material, and students reported being more confident in preparation for the exam even though they reported equal study time for tests. The majority of these studies were situated in an instructional design that focused on delivery of information.

In terms of students' performances on tests, several studies have failed to show that multimedia presentations offer an advantage over other media types (Bartsch & Cobern, 2003; Ricer et al., 2005; Stoloff, 1995; Szabo & Hastings, 2000). In the study Bartsch and Cobern conducted, students did perceive they learned more from PowerPoint lectures compared to lectures with transparencies, and students' quiz scores were higher after basic PowerPoint presentations compared to an expanded version with relevant pictures but extraneous sound effects. Extraneous sounds (Moreno & Mayer, 2000) or impertinent pictures (Mayer, 2001) may have detrimental effects on the ability to comprehend the material in the presentation, which may lead to a decrease in performance on quizzes following lecture with irrelevant additions (Bartsch & Cobern, 2003). Some researchers have found that cohorts of students experiencing PowerPoint lectures performed better than past cohorts taught with traditional lecture methods (Lowry, 1999; Mantei, 2000). Since the confoundedness has been reviewed elsewhere (Susskind, 2005), it will not be reiterated here other than to note that when students' primary role is as the audience, there is little objective evidence to indicate that learning is dependent on the format of the lecture. Rather, it appears that the combination of representations contributes most to student learning (Mayer, 2003).

RESEARCH DESIGN AND METHOD

The Study

Building on our work in examining the value of using writing-to-learn strategies in science classrooms, we are interested in exploring the outcomes associated in linking these approaches with multimodal representations. Rather than adopting the position of creating multimodal representations for students to translate into their conceptual schema, we are interested in promoting opportunities to embed multimodal requirements into the writing undertaken by students. Thus, we are focused on changing the question posed by Mayer (2003) from "do students learn more deeply from multimedia messages than from verbal-only ones?" to "does constructing text passages that embed multimodal representations assist in promoting deep leaning opportunities for students?" The intent of this particular study was to examine the impact of different representational opportunities on student performance on test items related to the physics concepts on quantum physics. In particular, the focus of the study was on examining the value of multimodal representation based on the medium used, and multiple representation based on repeated opportunities for students to represent the concepts. As such we were interested in comparing a traditional type of writing activity such as the end of chapter summary with a presentation-type format such as PowerPoint. The specific questions addressed were as follows:

1. Is there a difference in performance on test items when students complete a summary report writing task compared to a presentation format, with both formats requiring them to use multiple modes?
2. Does student performance on test items vary with practice between those who complete a presentation format compared to students who completed the more traditional summary report writing format?

Research Design

A quasi-experimental, pre–post test design with students in six preexisting physics classes was used for this study. The study explored the effects of two synthesis tasks across two physics units under the overarching theme of quantum theory. The study was designed around two distinct stages. In the first stage, to address question 1, we used computer technology for both groups—Microsoft Word® for the summary report writing task and PowerPoint for the presentation format. The second stage was to address question 2—in this stage where the emphasis was on the medium, we continued with PowerPoint as a computer technology medium compared with a traditional handwritten summary report.

Study Context

The study took place in a semiprivate, boarding high school of approximately 700 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. All 132 participants were 11th-grade male students, with an average age of 18 years. Near the middle of a yearlong modern physics course based on the national curriculum, students explored quantum theory within which two unit topics were the focus for this investigation, the photoelectric effect and Bohr's atom model. Six classes of students taught by the same instructor were randomly assigned to one of two comparison groups. Instructional methods, procedures, materials, conceptual topics, and sequence were the same for all classes; the only distinction between the comparison groups was in the synthesis task completed at the end of the units (outlined in Table 1). Procedures, which were similar for all students, are explained first, followed by the distinguishing features of the synthesis tasks, which characterize the differences between the comparison groups.

Each unit began with administration of a pretest. Lectures, discussion, and problem-solving sessions typified the instructional phase. Students completed their synthesis tasks, either constructing PowerPoint presentations or writing a paper. After the synthesis tasks were evaluated, the unit posttest was administered. Classes met each school day for a 40-minute session.

TABLE 1
Outline of the Implementation Schedule and Research Design

Class Day	Group	Activity
1	All	Photoelectric effect pretest
2–7	All	Lectures and problem-solving sessions
8–12	PowerPoint	Construction of PowerPoint slides and class presentation with no limitations
8–12	Writing	Computer-generated summary report
13	All	Photoelectric effect posttest
14	All	Bohr's atom model pretest
15–20	All	Lectures and problem-solving sessions
21–25	PowerPoint	Construction of PowerPoint slides and presentation script with limitations
21–25	Writing	Handwritten research paper with page limit (could include mathematical expressions and graphical representations)
26	All	Bohr's atom model posttest

Synthesis Tasks of Comparison Groups

The two comparison groups, each composed of three classes of students, were defined by the type of synthesis task completed in both units. Students either completed a presentation (PowerPoint group) or wrote explanations of the topic in the format of a summary report (Writing-only group). For both groups, the audience, purpose, topic, type of task, and method of text production were all discussed by the entire class at the outset of the activity. However, the specific features of the synthesis tasks varied slightly for each unit.

For the first unit on the topic of the photoelectric effect, students in the PowerPoint group prepared presentations for the teacher. There were no constraints for this task; that is, students were not limited in the number of slides they used, the number of words per slide, or the representations they used in the slides (i.e., mathematical formulae and graphical representations could be included in the slides). Students in the Writing group prepared a written report in Microsoft Word®, explaining the topic they studied to the teacher as their audience. Again, there was no limit placed on the number of words or modes used.

Synthesis tasks for both groups were evaluated by an external reader, who was another physics teacher in the same institution, using a 100-point rubric prepared by the teacher and researchers. The evaluation rubric was prepared by using the 6-Traits writing assessment model (Spandel, 2004a, 2004b) (see Appendix A). The rubric was discussed with both groups before starting the writing task. Each student had a copy of the rubric during and after the discussion session. When writing assignments were evaluated by an external science teacher, there was an evaluation feedback form prepared and returned to each student about their writing task (see Appendix B).

In the second unit, the synthesis tasks for both groups included written products, explaining Bohr's atom model to an audience of grade 10 students. Students in the presentation format group prepared PowerPoint presentations that were limited to 15 slides and 10 words per slide. To accompany the slides, students completed a script in Microsoft Word®, which was limited to 750 words. Graphical representations and mathematical expressions could be included on the slides but not in the script. Students in the summary report format group (Writing group) completed a research paper explaining Bohr's atom model to an audience of 10th-grade students. This task was handwritten, limited to a maximum of four, A4 pages, and could include graphs and mathematical formulae.

The audience for the task in the second unit was authentic in that the products from both groups were distributed to 10th-grade students for review. In their evaluation, the grade 10 students identified the main concepts in the writing, and commented on the degree of understanding conveyed for each main concept as well as the overall task by marking a continuum on a scale of "I did not understand," "I understood a little," "I understood almost," or "I understood exactly." This feedback from the 10th-grade students was in addition to the feedback provided by the external reader as in the tasks for the photoelectric effect unit. The same evaluation rubric and external evaluation forms used with first stage were used again in the second stage (see Appendices A and B).

Because of constraints at the school, the teacher involved was unable to use computers for the summary report writing group for unit 2. The researchers acknowledge that there is a difference in production of text between the hand-writing process and the computer-generated writing and that this can be seen as a confounding variable or limiting factor. However, in building on comments of Mayer (2003) above, the limiting factor is not the technology but rather the cognitive demands placed on students. We believe that while these two text-based tasks were different in method of text production, the cognitive demands of the task were the same.

Test Item Variables

In each stage, the pretests were also used as the posttest. Test questions were prepared from items on the Turkish National University Admittance Test. For each unit, 10 multiple-choice questions relevant to the topic were drawn from this test bank to achieve reliability of instrument. Each multiple-choice item was scored with an optical reader and weighted at 10 points. Exemplary questions from each test are provided in Appendix C. Difficulty and discrimination indexes for each question used in both stages are provided in Appendix D. Finally, exemplary questions were chosen according to a difficulty index to represent low, medium, and high difficulty levels.

Conceptual questions were developed by the teacher in consultation with a researcher and colleagues on staff at the school to agree upon the type of problem and question design appropriate to the topics under study. One conceptual question (20 points) was included on the photoelectric effect test and two conceptual questions (15 points each) were used as a measure of understanding for the Bohr's atom model unit.

The conceptual questions were scored by an independent marker, ensuring that in essence, a blind review process was implemented. Appendix E provides typical responses to each conceptual question for both stages. The conceptual questions used were as follows.

Photoelectric Effect Conceptual Question. It is known that electrons are extracted from a special metal's surface when lit with a certain wavelength. In order to explore the change in the number of electrons depending on the wavelength and the intensity of the light, you are planning to conduct an experiment. Write about the (A) Steps of the experiment; (B) Hypothesis about the results of the experiment; and (C) Reasons for verification of the hypothesis.

Bohr's Atom Model Conceptual Questions.

1. Using Bohr's atom model, find the energy, wavelength, frequency, and change of angular momentum of an electron that fell from the second energy level to the first energy level in terms of h and π ($R = 13.6$ eV, $ZH = 1$, $hc = 12400$ eV A, $h = 6.62 \times 10^{-34}$ J s).
2. Using an analogy, explain the energy levels of the hydrogen atom to somebody who doesn't know anything about physics.

Test questions and relevant samples of student work were initially translated by the teacher, and a collaborative effort was made on the part of the teacher and the researchers to ensure accuracy of representation through review and revision of manuscript drafts. For both units, the dependent variables consisted of posttest items, total scores on multiple-choice questions, one conceptual question on the photoelectric effect, and two conceptual questions on the Bohr's atom model.

Statistical Analysis

To test for equivalency of groups for comparison, analyses of scores on the pretests given prior to the synthesis tasks were conducted using analysis of variance (ANOVA). The pretest items were the total scores on multiple-choice questions and each conceptual question. The effect of the groups' synthesis tasks were analyzed using analysis of covariance (ANCOVA), with pretest 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, means reported are unadjusted, whereas in the ANCOVA analyses, means reported are adjusted. Furthermore, in this study we reported effect sizes to recognize the magnitude of intervention on students' learning. There are three advantages of reporting effect sizes. First, reporting effect size makes meta-analyses possible for a given report. Second, effect size reporting allows a researcher to determine more appropriate study expectations in future studies. Third, reporting and interpreting effect sizes facilitate assessment and comparison of a study's results across existing-related studies (Sheskin, 2004; Wilkinson & Task Force on Statistical Inference, APA Board of Scientific Affairs, 1999).

Assumptions

In this study, there are three general statistical assumptions involved with ANOVA, as stated by Mertler and Vannatta (2002, pp. 341–342):

- *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.

A simple graphical method and normal probability plots of model residuals along with Kolmogorov–Smirnov test were used to examine the normality assumption. Analyses indicated that while normality assumption was met for multiple-choice questions total on the first and second stages, this assumption was violated for conceptual question scores on both stages. Transformations were not applied since the groups' distributions had opposite skewness signs. That is, while any possible transformation helps to reduce skewness of one group's distribution, it increases the skewness of the other group's distribution. Furthermore, distribution of those variables (conceptual questions in both stages) indicated that the treatment group had negative skewness and the control group had positive skewness (Stevens, 1992; Tabachnick & Fidell, 2000). 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. Finally, the homogeneity assumption is examined by using Levene's test for equal variances within each ANCOVA analysis presented below.

RESULTS

The results are presented in two stages to reflect the two questions that were used to guide the research.

Stage 1 Results

Photoelectric Effect Pretest. Results from pretest analyses indicated that group performances on the independent variable of pretest multiple choice total were not statistically different (F (1, 128) = 3.791, $p = 0.054$). No other significant differences among classes were found. Similar ANOVA analysis on pretest conceptual question scores indicated that group performances were not statistically different (F (1, 128) = 0.257, $p = 0.613$) (see Table 2 for M and SD distribution of groups).

TABLE 2
Group Distribution and Pretest Scores on Multiple-Choice Questions, and Conceptual Question on the Test of the Photoelectric Effect

		Multiple-Choice Total		Conceptual Question	
Group	*n*	*M*	SD	*M*	SD
PowerPoint	64	18.095	13.779	2.127	1.680
Writing	68	22.941	14.641	2.000	2.142

Photoelectric Effect Posttest

Multiple-Choice Question Total Score. A one-way ANCOVA model with posttest multiple-choice questions total as a dependent variable, group as an independent variable, and students' pretest multiple-choice questions scores as a covariate was conducted. Results from such analysis indicated that the pretest total score as a covariate did not significantly influence the dependent variable of posttest multiple-choice questions total (F (1, 128) = 3.444, $p = 0.066$, $\eta^2 = 0.026$). Furthermore, the main effect for group was not significant (F (1, 128) = 0.994, $p = 0.321$, $\eta^2 = 0.008$) (see Table 3 for adjusted means and standard error distribution of groups). Mean square error was 448.608, and adjusted R-squared was 0.015 for this model. Finally, Levene's test of equality of error variance showed nonsignificant results (F (1, 129) = 0.727, $p = 0.395$), which confirms one of the assumptions, the error variance of the dependent variable is equal across groups, was not violated.

Conceptual Question. When a similar ANCOVA model was conducted on conceptual question scores, pretest conceptual question scores as a covariate did significantly influence the dependent variable of posttest conceptual question (F (1, 127) = 7.727, $p = 0.006$, $\eta^2 = 0.057$). Furthermore, results did indicate a significant main effect for group (F (1, 127) = 10.481, $p = 0.002$, $\eta^2 = 0.076$). Students in the presentation format group outperformed students in the summary report format group (t (128) = 3.210, $p < 0.05$) (see Table 3). Mean square error was 19.563, and adjusted R-squared was 0.117 for this model. Finally, Levene's test of equality of error variance showed nonsignificant results (F (1, 128) = 2.369, $p = 0.124$), which confirms one of the assumptions, the error variance of the dependent variable is equal across groups, was not violated.

Stage 2 Results

Bohr's Atom Model Pretest. One-way ANOVA results indicated some performance differences on second-stage pretest measures. The performance differences between the

TABLE 3
Group Distribution and Posttest Scores on Multiple-Choice Questions, and Conceptual Question on the Test of the Photoelectric Effect

		Multiple Choice Total		Conceptual Question	
Group	*n*	Adj. *M*	SE	Adj. *M*	SE
PowerPoint	63	60.120	2.689	10.236	0.558
Writing	67	56.639	2.587	7.718	0.541

TABLE 4
Group Distribution and Pretest Scores on Multiple-Choice Questions, and Conceptual Question on the Test of the Bohr's Atom Model

		Multiple Choice Total		Conceptual Question #1		Conceptual Question #2	
Group	*n*	*M*	SD	*M*	SD	*M*	SD
PowerPoint	63	17.143	13.492	0.318	1.446	2.191	2.687
Writing	68	24.118	13.185	1.221	2.232	2.456	3.117

presentation format group and the summary report format group were significantly different on multiple choice total (F (1, 129) = 8.949, $p = 0.003$) and conceptual question #1 (F (1, 129) = 7.426, $p = 0.007$) where the summary report format group outperformed the presentation format group on both measures. Yet, there was no significant mean difference between the two groups (F (1, 129) = 0.270, $p = 0.604$) on conceptual question #2 (see Table 4 for *M* and SD distribution of groups).

Bohr's Atom Model Posttest

Multiple-Choice Questions Total. After completing the second synthesis, to account for the variety of experiences both groups had up to that point, three covariates were included in the analyses, pretest multiple choice total and pretest conceptual questions #1 and #2. Results from the ANCOVA analysis indicated that the pretest multiple choice total scores (F (1, 126) = 6.764, $p = 0.010$, $\eta^2 = 0.051$) and pretest conceptual question #2 (F (1, 126) = 6.674, $p = 0.011$, $\eta^2 = 0.050$) as covariates did significantly influence the dependent variable of posttest multiple-choice questions total. Furthermore, the main effect for group was significant (F (1, 126) = 19.400, $p < 0.001$, $\eta^2 = 0.133$), as the presentation format group outperformed students in the summary report format group (t (129) = 4.534, $p < 0.05$). Mean square error was 351.167, and adjusted R-squared was 0.161 for this model. Finally, Levene's test of equality of error variance showed nonsignificant results (F (1, 129) = 0.039, $p = 0.824$), which confirms one of the assumptions, the error variance of the dependent variable is equal across groups, was not violated (see Table 5 for Adj. *M* and SE distribution of groups).

Posttest Conceptual Question #1. Results from a similar ANCOVA model indicated only pretest conceptual question #1 scores had a significant influence as a covariate (F (1, 126) = 7.319, $p < 0.001$, $\eta^2 = 0.055$). Again, the main effect for group was noted (F (1, 126) = 15.870, $p < 0.001$, $\eta^2 = 0.112$); students in the presentation format group outperformed students in the summary report format group (t (129) = 4.098, $p < 0.05$).

TABLE 5
Group Distribution and Pretest Scores on Multiple-Choice Questions, and Conceptual Question on the Test of the Bohr's Atom Model

		Multiple Choice Total		Conceptual Question #1		Conceptual Question #2	
Group	*n*	Adj. *M*	SE	Adj. *M*	SE	Adj. *M*	SE
PowerPoint	64	60.701	2.437	12.313	0.510	8.707	0.592
Writing	68	45.380	2.341	9.415	0.490	6.022	0.569

Mean square error was 15.361, and adjusted R-squared was 0.128 for this model. Finally, Levene's test of equality of error variance showed significant results (F (1, 129) = 8.391, $p = 0.004$), which indicates one of the assumptions, the error variance of the dependent variable is equal across groups, was violated (see Table 5).

Posttest Conceptual Question #2. The only significant covariate in the ANCOVA model was the pretest conceptual question #2 scores (F (1, 126) = 18.921, $p < 0.001$, $\eta^2 = 0.131$). Again, the main effect for group was noted (F (1, 126) = 10.087, $p = 0.002$, $\eta^2 = 0.074$) as students in the presentation format group outperformed students in the summary report format group (t (129) = 3.270, $p < 0.05$). Mean square error was 20.739, and adjusted R-squared was 0.161 for this model. Finally, Levene's test of equality of error variance showed nonsignificant results (F (1, 129) = 2.538, $p = 0.114$), which confirms one of the assumptions, the error variance of the dependent variable is equal across groups, was not violated (see Table 5).

Cohen *d* Effect Sizes on Both Stages

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 (SD) units; (b) A *medium effect size* is between 0.5 and 0.8 SD units; and (c) A *large effect size* is 0.8 or more SD units (R. Rosenthal & Rosnow, 1984; Sheskin, 2004). The effect sizes of treatment on each dependent measure are given in Table 6.

Effect size calculations indicated that at the first stage of the study the benefit of using multimodal task versus unimodal task was small (Cohen's $d = 0.2$) for the multiple-choice questions, and was medium (Cohen's $d = 0.6$) for the conceptual question. Furthermore, at the second stage of the study, the sizes of effects of using multimodal task embedded in PowerPoint presentation opposed to using multimodal task embedded in handwritten text were large (Cohen's $d = 0.8$) for the multiple-choice questions and medium (Cohen's $d = 0.7$ and 0.6) for both conceptual questions.

Comparison of Synthesis Tasks

Several task features were explored in the synthesis tasks completed by both groups. The average number of various task features students used is presented in Table 7. In stage 1, it should be noted that the total number of words used by the presentation format group was

TABLE 6
Cohen *d* Effect Sizes on Both Stages

Stage	Measure	Cohen's *d*	Scale
Stage 1—multimodal vs. unimodal	Multiple choice total	0.2	Small (multimodal)
	Conceptual question	0.6	Medium (multimodal)
Stage 2—PowerPoint vs. handwritten	Multiple choice total	0.8	Large (PowerPoint)
	Conceptual question #1	0.7	Medium (PowerPoint)
	Conceptual question #2	0.6	Medium (PowerPoint)

TABLE 7
The Average Number of Each Task Feature Students Exhibited in the Synthesis Tasks for the Photoelectric Effect and Bohr's Atom Model Topics

Group	Task Feature (Average Number)	Photoelectric Effect	Bohr's Atom Model
Presentation format	No. of slides	11	10
	No. of words per presentation	40	15
	No. of words in script	X	510
	No. of pictures + no. of graphs	2 + 3	7
	No. of formulae	7	15
Summary report format	No. of pages	4	4
	No. of words	650	610
	No. of pictures + no. of graphs	1 + 4	4
	No. of formulae	6	15

Note. X indicates the feature was either not part of the task assignment or was excluded in the limitations of the task.

440 (11×40) compared to 650 with the summary report format group. However, in stage 2, the total number of words used was almost equal—660 for the presentation format group ($15 \times 10 + 510$ of script) and 650 for the summary report format group.

DISCUSSION

Before discussing the results of this study, the authors would like to reiterate that the study is an initial exploration into the use of multimodal representation linked to writing-to-learn strategies. We recognize that the population of students in this study is from an elite school with strict entrance requirements, and, thus, they do not represent the typical student body population.

The intent of the research was to build on previous work on using writing-to-learn strategies to assist students in constructing understanding of science concepts. The results of Stage 1 do suggest that there are benefits in requiring students to engage in constructing presentation formats rather than summary report formats. While this stage was framed on the argument of equal amount of cognitive work being done despite the type of medium, given that the effect size was 0.6 (medium) for the presentation format group, the research would suggest that the cognitive work undertaken by this group led to better understanding. For the presentation format group, the total number of words used was approximately 66% of the total amount used by the summary report format group. Even though there were almost the same number of pictures, graphs, and formulae used, the presentation format group was advantaged in answering the conceptual question. A possible explanation is based on the amount of translation that is being required by the learner in having to move between the different representations. While this requires translation work to be done (Prain & Hand, 2005) between the representation of the science discipline knowledge, a representation for the audience and a representation for self, the introduction of multiple modes requires much more translation work to be done. Multimodal representation requires translation not only across these three different forms but also between all the modes used, that is, between the mathematical, graphical, pictorial, and text modes used. As explained in the Introduction section, the importance of multimodal representation is the necessity to ensure that language used in one representational mode matches that used in a different mode. The difference between the presentation format and summary report groups is that the presentation format group used fewer words; that is, the amount of text used to explain the concept was less for the presentation format group. This means that the learner has to be more exact with the text to ensure that the link between all the modes of representation is clear. In terms of Galbraith's explanation, the students in the presentation format group may have to cycle through their conceptual framework more often and in a more exacting manner to have less text constructed. This cycling process would require the students to have to engage with their conceptual understandings in a more concise manner than the less restrictive nature of the summary report format.

While the students were not restricted in stage 1 in terms of the number of slides used or the amount of text required, this was not the case in stage 2. In stage 2, there were limitations placed upon the amount of space that was allowed for the production of the final product—15 slides for the PowerPoint group plus associated text and four pages for the handwritten group. The intent was to encourage students to have to do more translation work between the modes of representation, rather than letting the text mode be the predominate mode. Importantly, on the pretest for this topic, the summary report format group was significantly better in their initial understanding. However, the effect size results for posttest measures indicate that the PowerPoint group was advantaged in terms of multiple-choice questions (0.8, large effect), conceptual question #1 (0.7, medium effect), and conceptual question #2 (0.6, medium effect). Building on the argument related to translation that was used for stage 1, the authors would argue that the relationship between text and the other modes of representation impact the type of cognitive processing undertaken by the learner. For students who used the PowerPoint medium, the text was used to explain and support the different modal representations used on each slide. Each slide contained multiple modes (pictorial, mathematical, and graphical) and the text was used to provide some explanation of the connection between the modes and the science concepts. That is, the text was used to translate the representations on the slides into an explanation mode to inform the audience. For the summary report format group, the text was the predominant mode with a different mode inserted where necessary or appropriate. The orientation was on the production of the text with different modal representations being inserted for support or re-enforcement. Thus, the translation was on different modes to support text, rather than text in support of the different modes as with the PowerPoint. The PowerPoint medium would appear to place more demands on the translation work done by the text in relation to the other modal representations than the summary report format and hence enable the construction of a richer set of conceptual understandings to be generated as evidenced by performance on higher order conceptual questions.

These results would suggest requiring students to explain concepts using multiple modes, and limiting the amount of text available for explanation is beneficial to learning. Importantly, requiring the focus to be on presentation formats that emphasize nontext-dominated modes places more demands for the students to map text to the different modes. The authors are not suggesting that PowerPoint is the only medium for use with multimodal representation. Other media such as posters, newspapers articles, or report formats that require students to translate across modes should/could be equally as valuable. One advantage of PowerPoint is that by its very nature it is limited in the amount of possible text on any one slide. Of interest would be to repeat the study but have a group where there was not accompanying text for the PowerPoint presentation. Such a task would place even more demands on the languages (mathematical, graphical, pictorial, and text) of the slides to be clear and concise enough for the reader to make meaning. We believe that such a task would further increase the translation demands on the students.

Building on the writing-to-learn research, the authors believe that multimodal tasks need to be set where the students are required to translate these representations for audiences other than the teacher, as was the case in stage 2 of this study. In our study, the audience for each task was involved in reviewing all the presentations and, thus, the task was viewed as being real in that translation for the younger audience was a necessary component.

CONCLUSION

This study was conducted with a group of students at an elite school in Turkey and explored the use of different writing-to-learn formats for building conceptual understanding of the topic. Students were required to embed multimodal representations, that is, text, mathematical, graphical, and pictorial, within the body of the presentation format (PowerPoint) or summary report format that was completed at the end of each of the two topics studied. The results indicate that the students who used the presentation format were significantly advantaged over the students who used the summary report format. This initial study does provide encouragement for exploration into other writing-to-learn formats and multimodal representation to determine which formats are most successful. Is there a connection between format related to topics, do combinations of multimodal representations can across topics and disciplines, and does an emphasis on multimodal representation within text help long-term retention of concepts?

APPENDIX A: RUBRIC FOR WRITING EVALUATION

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

ORGANIZATION			
Score of 5	Score of 15	Score of 30	Score
✓ The writer skips randomly from point to point, leaving the reader scrambling to follow. ✓ No real lead sets up what follows. ✓ Missing or unclear transactions force the reader to make big leaps. ✓ No real conclusion wraps things up. ✓ It is difficult to see any real pattern or structure in this writing.	✓ Sequencing seems reasonably appropriate. ✓ Placement of details is workable, although sometimes predictable. ✓ The introduction and conclusion are recognizable and functional. ✓ Transitions are present but may sound formulaic—for example, "My first point . . . ," "My second point . . . " ✓ Structure may be so dominant that it overshadows both ideas and voice; it's impossible to stop thinking about it!	✓ The organization showcases the central theme or story line. ✓ Details seem to fit right where they are places, even when the writer hits the reader with a surprise. ✓ An inviting lead draws the reader in; a satisfying conclusion helps bring the reader's thinking to closure. ✓ Pacing feels natural and effective; the writer knows just when to linger over details and when to get moving. ✓ Organization flows so smoothly that the reader does not need to think about it.	
VOICE			
Score of 1	Score of 3	Score of 5	Score
✓ The writer does not seem to reach out to the audience or to anticipate their interests and needs. ✓ Although it may communicate on a functional level, the writing takes no risks and does not involve or move the reader. ✓ The writer does not yet seem sufficiently at home with the topic to personalize it for the reader.	✓ The writer has not quite found his or her voice but is experimenting—and the result is pleasant and sincere, if not highly individual. ✓ Moments here and there snag the reader's attention, but the writer holds passion and spontaneity in check. ✓ The writer often seems reluctant to reveal him or herself and is "there" briefly—then gone. ✓ Although clearly aware of an audience, the writer only occasionally speaks right to that audience. ✓ The writer often seems right on the verge of sharing something truly interesting—but then pulls back as if thinking better of it.	✓ The tone and flavor of the piece fit the topic, purpose, and audience well. ✓ Clearly. The writing belongs to this writer and no other. ✓ The writer "speaks" to the reader in a way that makes him or her feel like an insider. ✓ Narrative test is open and honest. ✓ Expository or persuasive text is provocative, lively, and designed to prompt thinking.	
WORD CHOICE			
Score of 2	Score of 5	Score of 10	Score
✓ Vague words and phrases ["She was nice . . . ," "It was wonderful . . . ," "The new budget had impact"] convey only the most general sorts of messages. ✓ Redundancy is noticeable—even distracting. ✓ Clichés and tired phrases pop up with disappointing frequency.	✓ Most words are correct and adequate, even if not striking. ✓ Energetic verbs or memorable phrases occasionally strike a spark, leaving the reader hungry for more. ✓ Familiar words and phrases give the text an "old comfortable couch" kind of feel.	✓ The writer's message is remarkably clear and easy to interpret. ✓ Phrasing is original–even memorable—yet the language is never overdone. ✓ Lively verbs lend the writing power. Precise nouns and modifiers make it easy to picture what the writer is saying.	

Continued

Continued

WORD CHOICE			
Score of 2	Score of 5	Score of 10	Score
✓ Words are used incorrectly ["The bus *impelled* into the hotel"]. ✓ The writer overloads the text with ponderous, overdone, or jargonistic language that is tough to penetrate.	✓ In one or two places, language may be overdone—but at least it isn't flat. ✓ Attempts at colorful language are full of promise, even when they lack restraint or control.	✓ Striking words or phrases linger in the writer's memory, often promoting connections, memories, reflective thoughts, or insights.	
SENTENCE FLUENCY			
Score of 2	Score of 5	Score of 10	Score
✓ Irregular or unusual word patterns make sentences hard to decipher or make it hard to tell where one sentenced ends and the next begins. ✓ Ideas hooked together by numerous connectives [and, but so then, because] create one gangly endless "sentence." ✓ Short, choppy sentences bump the reader through the text. ✓ Repetitive sentence patterns grow monotonous. ✓ Transitional phrases are so repetitive that they become distracting. ✓ The reader must often pause and reread to get the meaning.	✓ Sentences are grammatical and fairly easy to get though, given a little rehearsal. ✓ Graceful, natural phrasing intermingles with more mechanical structure. ✓ Some variation in length and structure enhances fluency. ✓ Some purposeful sentences beginnings help the reader make sentence-to-sentence connections.	✓ Sentences are well crafted, with a strong and varied structure that invites expressive oral reading. ✓ Purposeful sentence beginnings show how each sentence relates to and builds on the one before it. ✓ The writing has cadence, as if the writer hears the beat in his or her head. ✓ Sentences vary in both structure and length, making the reading pleasant and natural, never monotonous. ✓ Fragments, if used, add to the style.	
CONVENTIONS			
Score of 1	Score of 3	Score of 5	Score
✓ Errors are sufficiently frequent and/or serious as to be distracting; it is hard for the reader to focus on ideas, organization, or voice. ✓ Errors in spelling, punctuation, or grammar cause the reader to pause, decode, or reread to make sense of the text. ✓ Extensive editing would be requited to prepare this text for publication.	✓ There are enough errors to distract an attentive reader somewhat; however, errors do not seriously impair readability or obscure meaning. ✓ 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." ✓ Moderate editing would be required to get this text ready for publication. ✓ The paper reads like an "on its way" rough draft.	✓ 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. ✓ The text appears clean, edited, and polished. ✓ 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 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.	

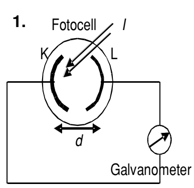
APPENDIX B: WRITING EVALUATION FEEDBACK FORM

Areas	Score	Comments if any
Big ideas/conceptual knowledge		
Organization		
Voice		
Word choice		
Sentence fluency		
Conventions		
Total score		

APPENDIX C: EXAMPLE QUESTIONS FROM TESTS USED EACH STAGE

Stage 1—Photoelectric Effect

1.



When the light with the intensity I was sent to the fotocell, it is observed that a weak current is passing over galvanometer. In order to increase this current which one of the following quantities must be increased?

d, distance between KL plakets
S, the surface area of K plaket
I, intensity of an incident light
λ, wavelength of an incident light

(A) d and S
(B) d and I
(C) I and λ
(D) S and I
(E) S and λ

7. Magnitude of the photoelectric current caused by incident X, Y, Z light beams bombarded on a katot in the photocell and corresponding stopping potential values were given in the table below.
According the table given, which one of the following choices is correct about the frequencies of the incident light beams?

	I, Photoelectric current	V_K, Stopping potential
X	I	V
Y	I	$2V$
Z	$2I$	V

(A) X and Y have the same, but Z has smaller.
(B) X and Y have the same, but Z has bigger.
(C) X and Z have the same, but Y has bigger.
(D) X and Z have the same, but Y has smaller.
(E) X, Y, and Z all have different frequencies.

9. In a photoelectric tube, in order to increase the kinetic energy of the photoelectrons; which of the following processes must be followed?
I. using the light having smaller wavelength.
II. using the metal having greater work energy as catot.
III. increasing the intensity of incident light.

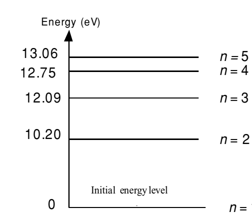
(A) Only I
(B) Only III
(C) I and II
(D) II and III
(E) I, II, and III

Stage 2—Both's Atom Model

1. Which of the following events does Bohr's Atom Model fail to explain?
I. Formation of the spectrum lines and energy levels of an one-electron atom.
II . Fine-structure of spectrum lines.
III. Structure of a many electron atoms.

(A) Only I
(B) Only II
(C) I and III
(D) II and III

7.



Hydrogen atom's energy levels were given above. This atom is exposed to electrons with 12.8 eV energy. In the spectrum, which of the following lines will accrue with Lyman and Ballmer series?

	Lyman series	Ballmer series
(A)	–	H_β
(B)	–	H_α, H_β
(C)	α, γ	H_β
(D)	α, β	H_α, H_β
(E)	α, β, γ	H_α, H_β

10. According to Bohr's Atom Model which of the followings increase(s) if the principal quantum number increases from n to $n + 1$?

I. Total angular momentum of the atom.
II. Electron's circling period
III. Electron's rest energy level

(A) Only I
(B) Only II
(C) I and II
(D) II and III
(E) I, II, and III

APPENDIX D: ITEM ANALYSES OF THE TESTS USED IN BOTH STAGES

		Item Analyses	
Stage	Question #	Difficulty Index	Discrimination Power Index
1—Photoelectricity	1	0.78	0.34
	2	0.61	0.35
	3	0.48	0.48
	4	0.48	0.54
	5	0.69	0.40
	6	0.70	0.41
	7	0.36	0.45
	8	0.88	0.40
	9	0.52	0.60
	10	0.50	0.55
2—Bohr's Atom Model	1	0.36	0.35
	2	0.76	0.55
	3	0.46	0.49
	4	0.34	0.40
	5	0.36	0.45
	6	0.70	0.39
	7	0.79	0.51
	8	0.56	0.52
	9	0.20	0.27
	10	0.51	0.46

APPENDIX E: EXAMPLES OF RESPONSES TO CONCEPTUAL QUESTIONS

Stage 1—Ege (Presentation group)

(A) In order to investigate how the number of electrons varies with respect to the wavelength and intensity of an incident ray liberated from atoms, first of all we construct an experiment of photocell. After that, we send a light at different color whether its wavelength affects, after that we increase the intensity of a light whether its intensity affects the number of an electrons.

(B) We conclude in this experiment that:

(1) To what extend we change the wavelength of a light, it doesn't effects the number of an electrons, but it effects the kinetic energy of an electrons.

(2) When we increase the intensity of light, the number of electrons separated from atoms increases, in other words the number of electrons is proportional to intensity of light.

(C) The wavelength of a light effects to the kinetic energy of electrons [the reason was omitted]. In other word, it causes the electrons to be slower or speedy. Intensity of a light affects the number of electrons. The higher we send the light intensity the higher in number we make electrons to be free.

Stage 1—Ali (Writing group)

(A) In the next experiment we send red light firstly, and then we send green and then violet color light, and we measure the current. So, we clarify the change depending on wavelength.
(B) We observe that the current increases when the intensity and wavelength of a light increase.
(C) Light intensity.

Stage 2/Question 1—Kaan (Presentation Group)

This situation is analogus to daily shoping. For electron, in order to excite the atom it has to buy an energy. If we have not enough money to buy cheapest thing in large store, we leave from there without shoping, but with money in our poket. If we can buy a few thing, we buy them and leave from there with change. Similarly, elecron can excite the hydrogen atom up to the its maximum energy level. For example, electron with 12.8 eV can bring atom into 2, 3, 4 levels.

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