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RESEARCH

# A Comparative Study of Three Modes of Presenting Analogies in Chemistry

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*This paper presents results of an experimental study to compare the effects of three modes of analogy presentation—verbal, pictorial and computer simulation. Two hundred and sixty-six ninth-standard students were randomly assigned to the three treatment conditions. Five pre-test and two post-test measure were obtained. The five pre-test measures were—prior achievement in language, prior achievement in chemistry, analogical reasoning ability, visualisation ability and an imagery test measuring how students pictorially represent gas molecules. The two post-tests were a parallel form of the imagery measure and an achievement test. Analysis of variance results indicated that the simulation group performed significantly better on post-imagery than the pictorial group. Measures of achievement did not show any significant differences. However, there were aptitude-treatment interactions between student's analogical reasoning ability and pre-imagery with treatments.*

Analogies are argued to be excellent pedagogic tools in teaching and learning difficult scientific concepts (Duit, 1991[1] and Stepich and Newby, 1988[2]). The conceptualisation of human learning and memory as an information processing system offers an explanation to consider how analogies facilitate the acquisition of new knowledge. Central to this conception is prior knowledge which is organised and stored in learners memory and serves as a frame work (Mayer, 1980[3]) for the acquisition of new knowledge (Ausubel, 1960[4]). In this way prior knowledge is thought to mediate acquisition of new knowledge. Analogies form part of the prior knowledge which will also mediate acquisition of new knowledge.

Instructional techniques using analogies help students to use their existing knowledge to understand new knowledge (Zeitoun, 1984[5]; Clement, 1988[6]; Glynn, 1989[7]; and Thagard, 1992[8]). Analogies provide comparisons which can be used to explain a difficult-to-understand concept by pointing out its similarities to something easier to understand or already understood (Zeitoun, 1984[9]). An analogy is the "base" (Gentner, 1989[10]) or "source" (Rumelhart and Norman, 1981[11]) that is knows to the student to help think about complex and vague subjects

(Weller, 1970[12] and Stavy, 1991[13]). For example, the familiar concept of the solar system can be used to facilitate learning of an unfamiliar concept such as the hydrogen atom: the nucleus of the atom is analogous to the sun in the solar system, the electrons are similar to the planets, and the trajectories of planets are similar to the orbits of electrons.

The use of analogies in instruction is thought to assist the learner to achieve two important goals—acquiring knowledge of the content being presented and developing a strategy for thinking about a related situation. The first goal is to help students use familiar analogies to comprehend new content being presented. The second goal is to introduce to students analogical reasoning as a viable strategy to apply their knowledge reasoning as a viable strategy to phenomena.

**Review of Analogy Literature**

The extant research on the use of analogies is wide-ranging, involving both psychological and instructional studies. Most of the studies in psychology have examined the effect of one or more analogs in solving a problem and conditions for effective transfer (Gick and Holyoak, 1983[14]; Kaiser, Jonides and Alexander, 1986[15] and Gholson, Eymard, Morgan and Kamhi, 1987[16]). In education, most studies have explored the use of analogies as a pedagogic tool to enhance student's learning of curriculum (Gabel and Sherwood, 1980[17] and Gentner and Gentner, 1983[18]). Unfortunately, the results of studies in psychology and education are ambiguous, and it is not clear under what condition analogies are effective.

A possible reason for the ambiguity and conflicting results is that researchers have not taken into account how analogies are presented. However there is general research, suggesting that mode of presentation can in fact affect student learning (Arnold and Dwyer, 1975[19]; Rigney and Luts, 1976[20]; and Hayes and Henk, 1986[21]). Since analogies can be presented in a variety of ways, including verbally, pictorially, and with the use of physical models or three-dimensional animated graphics, it is possible that one mode of presentation is more effective than the other.

There are some thirty-three studies that have been conducted in the past twenty five years on the effectiveness of analogies. These studies include psychological studies which focus on the cognitive processes and the conditions of schema induction and analogical problem-solving. Out of the eighteen instructional studies examining the effectiveness of analogies as pedagogic tools to enhance learning in academic subjects such as chemistry, physics and biology, Table 1 summarises the twelve instructional studies that are comparable.

TABLE 1

**Summary of Instructional Studies by mode of Presentation**

| Number of studies | Mode of presentation | + | 0 | - |
|---|---|---|---|---|
| 5 | Verbal | — | 4 | 1 |
| 6 | Pictorial | 4 | 2 | — |
| 1 | Simulation | 1 | — | — |
| All Studies | — | 5 | 6 | 1 |

Note : + Indicates a significantly positive result, 0 indicates a non-significant result, and - indicates a significantly negative result.

**Summary of Findings on the Instructional Use of Analogy**

In general, verbal analogies used in instruction (Royal and Cable, 1976[22]; Gabel and Sherwood, 1980[23]; Simons, 1984[24]; Black and Solomon, 1987[25]; and Gilbert, 1989[26]) do not appear to facilitate learning, whereas analogies presented in a visual mode (Dowell, 1969[27]; Polland, 1978[28]; Brown, 1987[29]; Brown, 1992[30]; Dupin and Joshua, 1989[31]; Stavy, 1991[32]; and Rigney and Luts, 1976[33]) do seem to facilitate learning. How might these results be explained? Although several authors (Stepich and Newby, 1988[34]; Duit, 1991[35]; and Thagard, 1992[36]) claim that analogies make new information more concrete and easier to imagine, it is not clear in which way "analogical visuals" facilitate learning. It is possible that the verbal encoding might have worked in Conjunction with visual encodings to retrieve relevant information and thus effect learning (Paivio, 1986[37]). Similarly, Newby and Stepich (1987[38]) have also suggested that the combination format will be more effective because each form of analogy presentation will reinforce the other. However, Anderson (1980[39]) rejects the idea that information stored in memory is tied into particular sensory modality (only the meanings are encoded) but agrees with Kosslyn (1980[40]) that visual representation has a strong spatial structure.

**Purpose of the study**

The studies reviewed here are only suggestive, however, variation in curriculum materials, types of analogies, duration of treatment, and experimental subjects makes it difficult to draw firm conclusions about differential effectiveness of analogies. Therefore, the purpose of this study was to investigate the effect of three modes of presenting analogies on student learning. Two questions were addressed: (1) Does mode of analogy presentation affect student learning? and

(2) Does mode of analogy presentation affect all students equally? The second question was more exploratory in nature, and was addressed to examine possible interactions between instructional methods and type of students, important question in any instructional study (Cronbach and Snow, 1977[41]).

**Methodology**

The collision theory of gases was taught to ninth-grade students over a four-day instructional sequence. Students were randomly assigned to three modes of analogy presentation: (1) regular text material with analogies (Verbal Group), (2) text materials with analogies and diagrams (Pictorial Group), and (3) text material with analogies and animated graphics (Simulation Group). The basic text materials, demonstrations, and time spent on each analogy were similar in each of the three groups; the only difference was the mode of presentation.

***Sample***

Initially, 308 students from nine, ninth-grade classes taught by three chemistry teachers in three high schools in the Chavakkad Educational District, Kerala participated in the study. Students in these three schools came from middle and lower class homes. Two of the three schools are girl's high schools and are located in urban areas; the third co-educational high school is relatively new and is located in a rural area. A total of 42 students were either absent on one or more instructional days or did not take the post-test and were therefore dropped from the study. Consequently, the final sample consisted of 14 boys and 252 girls. Sample sizes, by school, are given in Table 2.

TABLE 2

**Treatment Group Sample Sizes by school**

| School | Simulation group | Pictorial group | Verbal group | Total |
|---|---|---|---|---|
| A | 17 | 26 | 18 | 61 |
| B | 35 | 38 | 35 | 108 |
| C | 29 | 35 | 33 | 97 |
| Total | 81 | 99 | 86 | 266 |

***Instrumentation***

Five pre-test and two post-test scores were obtained in this study. The pre-tests included two prior achievement measures, one in language and the other in chemistry. The pre-tests were—Language Test, Chemistry Test, Figure Analogy

Test, Visualisation Test and a Pre-imagery Test.

*Language Test*—This prior achievement was the end-of-year eighth-grade language (malayalam) examination score obtained from school records. The reliability of the test was not available.

*Chemistry Test*—A second prior achievement score, chemistry achievement, was the end-of-year eighth-grade chemistry examination score obtained from school records. The reliability of the test was not available.

*Figure Analogy Test*—Figure Analogy Test, Level D, from the Cognitive Abilities Test (Thorndike and Hagen, 1986[42]) was administered. The Kuder-Richardson reliability estimate of the test for the total sample is .89.

*Visualisation Test*—Visualisation Test, Level D, of the Cognitive Abilities Test (Thorndike and Hagen, 1986[43]) was administered. The Kuder-Richardson reliability estimate of the test for the total sample is .73.

*Pre-imagery Test*—This measure consisted of a five-item imagery drawing developed by the investigator and modelled on items developed by several others (Novick and Nussbaum, 1978[44]; Wheeler and Kass, 1978[45]; Novick and Nussbaum, 1981[46]; Nussbaum and Novick, 1982[47]; Renner, Abraham, Grzybowski and Marek, 1990[48]; and Benson, 1991[49]). Each of the five items asked students to draw pictorial representation of their conception of gases and their properties. The Kuder-Richardson reliability estimate of the test for the total sample is .83.

The two post-tests were a post-imagery test and a chemistry achievement and transfer test.

*Post-imagery Test*—The format of the post-imagery test was identical to the pre-imagery test, but all five items were different. The Kuder-Richardson reliability estimate of the test for the total sample is .79.

*Chemistry Achievement and Transfer Test*—The 15-item multiple-choice chemistry test and the 10-item multiple choice transfer test was based on a standardised chemistry achievement test previously constructed by the investigator (Rajan, 1982[50]). Unfortunately, the achievement and transfer test turned out to be quite difficult for the students, and generated low Kuder-Richardson reliability estimates for both measures. This is not surprising given the fact that the score variability was restricted because of high item difficulty (Cronbach, 1951[51] and Nunnally, 1978[52]). The Kuder-Richardson reliability calculation is based on the assumption that each item on the test is correlated with all other items and all items are equivalent to each other, measuring a single trait. Because of high item difficulties, the correlations between items were attenuated, causing low reliability estimates. To resolve the issue of low reliability, a total of six items with negative point-biserial correlations were removed. The Kuder-Richardson reliability estimate of the 19-item test for the total sample is .47.

***Instructional Treatments***

To control for teacher effects, one teacher at each of the three schools taught each group for one hour a day for four days. Prior to the initiation of the programme, the investigator met with co-operating teachers to discuss the use of the drawings and simulations. Uniform written instructions were given to the teachers. During the one-week instructional period, teachers were told to abstain from providing any outside help to students other than the specified instruction.

The unit of instruction was collision theory of gas which included concepts such as gas particles are uniformly distributed in a closed system, heating and cooling of gas result in change in motion of gas particles, change in pressure and volume result in variation in collision among atoms and molecules and the Le Chatelier principle. Five analogies were used in explaining the concepts of instructional unit. The five analogies were: (1) gas molecules as bouncing balls, (2) gas molecules escaping from a bottle as honey bees coming out of an opening, (3) the motion of gas molecules as wandering of mice, (4) backward and forward reaction rates as water systems having different pipe diameters, and (5) chemical reactions as coloured tennis balls colliding and changing colours.

Every effort was made to make instruction similar for the three groups by following the same protocol for lessons. Instructional activities included lecture, demonstration, board work, and use of analogy. Analogies were used in all three treatment groups during four days of instruction. On average, 7-9 minutes were spent each day using one or more analogies as a pedagogic tool.

The only difference in each of the three groups was mode of analogy presentation. In the verbal group, the teacher explained the instructional unit verbally using the analogies. In the pictorial group, the teacher explained the instructional unit verbally using the same analogies but with the help of drawings. In the simulation group, the teacher explained the instructional unit verbally using the same analogies but with video simulations. For example, on Day 1 of instruction, while explaining the concept that gas molecules are in constant motion, the teacher verbally explained the analogy of bouncing balls to the verbal group, used a 3' x 2' drawing of the bouncing balls with the pictorial group, and used dynamic simulations of bouncing balls on a television screen with the simulation group.

***Procedure***

During the course of the study the investigator was present in the classroom. On the first day of the study, the investigator met with each of the nine classes and briefly described the programme telling the students that they would be taking a few tests and learning a new chemistry unit for next four days. They were told that they would not have any home-work. Also, a gift was promised for those who did not miss a single day of instruction and testing.

On Day 1, the Figure Analogy Test, the Visualisation Test and the Pre-imagery Test were administered under power conditions. Students were given an interval of five minutes after completion of each test. After students had completed the pre-tests, the teacher instructed each group for an hour on the collision theory of gases, starting with the Simulation Group. On Days 2-4, there was only instruction for an hour for each group. On Day 5, there was no instruction, and two post-tests—Post-imagery Test and Chemistry Achievement and Transfer Test—were administered to students.

**Data Analysis**

All tests were hand scored by the investigator. Except for the prior achievement scores, individual item level data on all pre-and post-tests were recorded on a scannable sheet to create data files for analysis. The data were then stored as an ASCII file and analysed using the SPSS-X programme (Norusis and SPSS Inc., 1990[53]).

Data analyses focused on the major questions of the study: (1) Does mode of analogy presentation affect student's post-imagery and achievement? and (2) Does mode of analogy presentation affect all students equally? To examine the first question, both one-way and two-way analysis of variance (ANOVA) were employed. A one-way fixed effect ANOVA was conducted to test the equality of treatment groups prior to instruction. Two separate two-way mixed effects ANOVAs were employed to test main effects for teacher, treatment, and treatment by teacher interaction. A *post hoc* Scheffe test was used to test pair-wise comparisons on post-imagery and achievement measures. To answer the second question, the two dependent measures, post-imagery and achievement were regressed on to each aptitude measure, a coded vector representing treatment, and a term representing the aptitude-treatment interaction.

**Results**

A one-way fixed-effect analysis of variance (ANOVA) was conducted on each of the five pre-test measures. Using the 5% level of significance, none of the five pre-test measures reached significance, indicating that the three groups can be considered as having been drawn from the same population (language, $F = 1.55$, $p = .21$; chemistry, $F = 2.13$, $p = .12$; analogy, $F = .03$, $p = .97$; visualisation, $F - .54$, $p = .58$; pre-imagery, $F = .70$, $p = .50$). Thus, with random assignment and these additional pre-test ANOVAs, there is good evidence that the three treatment groups were equal prior to instruction.

The means and standard deviations of the post-imagery and achievement scores for the three treatment conditions are presented in Table 3. The magnitude of the post-imagery means are in the expected order, i.e. Simulation Group greater than Pictorial Group and Pictorial Group greater than Verbal Group.

TABLE 3

**Means, Standard Deviations (SDs) and Sample Sizes (N) for Post-imagery and Achievement by Teacher and Treatment**

| | | | Post-imagery | | Achievement | |
|---|---|---|---|---|---|---|
| Teacher | Treatment | N | Mean | SD | Mean | SD |
| | Simulation | 17 | 3.24 | 2.95 | 6.82 | 2.30 |
| 1 | Pictorial | 26 | 2.23 | 1.73 | 6.31 | 2.77 |
| | Verbal | 18 | 2.22 | 2.24 | 5.83 | 1.89 |
| | Simulation | 35 | 4.71 | 3.34 | 7.77 | 2.38 |
| 2 | Pictorial | 38 | 4.16 | 2.67 | 7.79 | 2.61 |
| | Verbal | 35 | 3.57 | 3.27 | 8.23 | 3.10 |
| | Simulation | 29 | 4.72 | 3.06 | 8.66 | 2.30 |
| 3 | Pictorial | 35 | 4.51 | 2.73 | 8.03 | 2.42 |
| | Verbal | 33 | 3.45 | 2.76 | 8.21 | 2.71 |
| All | Simulation | 81 | 4.41 | 3.18 | 7.89 | 2.40 |
| Three | Pictorial | 99 | 3.78 | 2.63 | 7.48 | 2.66 |
| Teachers | Verbal | 86 | 3.24 | 2.90 | 7.72 | 2.88 |

A two-way mixed-effects ANOVA was conducted to determine main effects for teacher, treatment, and to test for a teacher by treatment interaction. Treatment was considered a fixed effect, but teachers were viewed as random effects. The results for post-imagery show significant main effects for both teacher and treatment, but no teacher suggests a differential effectiveness of teachers. However, since each teacher taught students in each of the three treatments, teacher differences were distributed across treatments and are not of concern. The absence of a teacher by treatment interaction is important, however, because it suggests that the treatment effects is stable across teachers. Unlike the post-imagery results, the two-way, mixed effects ANOVA on achievement did not show a significant main effect for treatment nor for the teacher by treatment interaction.

The ANOVA result for the post-imagery is presented in Table 4. The main effect for treatment is significant ($F = 14.02$ with $df = 2$ and $4$, $p = .02$). The Scheffe multiple-comparison test revealed that the simulation group mean (4.41) is significantly different ($p = .04$) from the verbal group mean (3.24) but not from the pictorial group mean (3.78).

TABLE 4

**Summary of Two-way ANOVA for the Post-imagery Test**

| Source | df | SS | MS | F | P |
|---|---|---|---|---|---|
| Teacher | 2 | 132.15 | 66.07 | 8.23 | S |
| Treatment | 2 | 56.93 | 28.47 | 14.02 | S |
| Teacher x Treatment | 4 | 8.12 | 2.03 | .25 | NS |
| Residual | 257 | 2062.27 | 8.02 | | |
| Total | 265 | 2259.04 | 8.52 | | |

Note : S indicates a significant p and NS indicates a non-significant p at the .05 level.

A significant treatment effect in favour of the Simulation Group on the post-imagery measure does not necessarily mean that analogical simulation is better for all students. Similarly, a non-significant treatment effect on achievement does not mean that the treatments affected all students equally. To assess whether treatments affect all students equally, it is necessary to examine within-treatment relations between pre-tests and post-tests and to consider possible interactions between treatments and pre-tests of students.

The correlations (excluding correlations with the two pre-tests for which reliability data were lacking), corrected for attenuation using the standard formula (Nunnally, 1978, pp. 219-220[54]) are given in Table 5. The correlations among measures are significantly different across groups. Of particular interest are the low correlations between pre-imagery and the two post-tests in the Simulation Group and the low correlation between analogical reasoning ability and post-imagery in the Verbal Group. These differences suggest that treatments are changing the relationships among pre-test and post-test variables.

TABLE 5

**Corrected Intercorrelations of Measures by Treatment Groups**

| | | Simulation group | | | | Pictorial group | | | | Verbal group | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Measure | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 1. | Analogy | - | | | | - | | | | - | | | |
| 2. | Visualization | 61 | - | 61 | - | 63 | - | | | | | | |
| 3. | Pre-imagery | 16 | 23 | - | 07 | 04 | - | 32 | 21 | - | | | |
| 4. | Post-imagery | 48 | 33 | 29 | - | 51 | 37 | 78 | - | 07 | 04 | 61 | - |
| 5. | Achievement | 61 | 58 | - | 06 | 43 | 25 | 52 | 25 | 77 | 60 | 55 | 44 59 |

Note : Decimals have been omitted from the intercorrelations. Correlations greater than, 22 for Simulation Group, .20 for Pictorial Group, and .21 for Verbal Group are significant at the .05 level.

The differential effectiveness of treatments was examined using regression analysis. The two dependent variables, post-imagery and achievement were each regressed on to each the three pre-test measures (analogy, visualisation, and pre-imagery), a treatment term, and an interaction term in six separate analyses. As suggested by Pedhazur (1982[55]), the level of significance was set more liberally (.10) to lessen type II errors. The summary of analyses for post-imagery and achievement is presented in Tables 6 and 7.

TABLE 6

**Summary of Aptitude-Treatment Interaction Analyses for Post-imagery**

| Aptitude | Step | Variable | Multiple R | $R^2$ | $R^2$ Change | F Change | P |
|---|---|---|---|---|---|---|---|
| | 1 | Analogy (A) | .2655 | .0687 | .0687 | 19.4853 | .00 |
| Analogy | 2 | Treatment (T) | .3042 | .0925 | .0238 | 3.4347 | .03 |
| | 3 | AxT | .3351 | .1123 | .0197 | 2.8914 | .06 |
| | 1 | Visualization (V) | .1455 | .0212 | .0212 | 5.7129 | .02 |
| Visualization | 2 | Treatment (T) | .2182 | .0476 | .0264 | 3.6329 | .03 |
| | 3 | VxT | .2492 | .0621 | .0145 | 2.0117 | .14 |
| | 1 | Pre-imagery (P) | .3603 | .1298 | .1298 | 39.3759 | .00 |
| Pre-imagery | 2 | Treatment (T) | .3847 | .1480 | .0182 | 2.7954 | .06 |
| | 3 | PxT | .4129 | .1705 | .0225 | 3.5236 | .03 |

Note : Aptitude (A), treatment (T), and the interaction (AxT) were each entered separately in three steps.

TABLE 7

**Summary of Aptitude-Treatment Interaction Analyses for Achievement**

| Aptitude | Step | Variable | Multiple R | $R^2$ | $R^2$ Change | F Change | P |
|---|---|---|---|---|---|---|---|
| | 1 | Analogy (A) | .2975 | .0885 | .0885 | 25.6388 | .00 |
| Analogy | 2 | Treatment (T) | .3038 | .0923 | .0038 | .5477 | .57 |
| | 3 | AxT | .3335 | .1112 | .0189 | 2.7629 | .07 |
| | 1 | Visualization (V) | .3045 | .0927 | .0927 | 26.9721 | .00 |
| Visualization | 2 | Treatment (T) | .3155 | .0996 | .0069 | .9988 | .37 |
| | 3 | VxT | .3211 | .1031 | .0035 | .5098 | .60 |
| | 1 | Pre-imagery (P) | .1520 | .0231 | .0231 | 6.2452 | .01 |
| Pre-imagery | 2 | Treatment (T) | .1618 | .0262 | .0031 | .4116 | .66 |
| | 3 | PxT | .2195 | .0482 | .0220 | 3.0041 | .05 |

Note : Aptitude (A), treatment (T), and the interaction (AxT) were each entered separately in three steps.

Four of the analyses suggested interaction effects between treatments and analogical reasoning ability and pre-imagery; visualisation did not interact with the treatments. Table 8 presents the unstandardised regression coefficients and their standard errors within each group. The regression coefficients show that the simulation treatment requires more analogical ability (.20) compared to pictorial (.12) and the verbal treatment (.03). Also, the verbal treatment requires more of pre-imagery (.47) compared to the pictorial (.42) and the simulation treatments (.15).

TABLE 8

**Within-Treatment Regression Coefficients from Regressing Post-imagery and Achievement on to Pre-imagery and Analogy**

| Treatment | Post-imagery | | | | Achievement | | | |
|---|---|---|---|---|---|---|---|---|
| | Pre-imagery | | Analogy | | Pre-imagery | | Analogy | |
| | b | SE | b | SE | b | SE | b | SE |
| Simulation | .15 | .11 | .20 | .05 | -.02 | .08 | .12 | .04 |
| Pictorial | .42 | .09 | .12 | .04 | .14 | .10 | .07 | .04 |
| Verbal | .47 | .09 | .03 | .05 | .29 | .10 | .21 | .05 |

Note: b = unstandardised regression coefficient, SE—Standard error of b.

**Discussion and Conclusions**

In contemplating the results of the study, three possible limitations should be kept in mind. First, the study involved only ninth-grade students; and the sample composition (only 14 boys) should be noted as a factor that may tend to restrict the generalisability of the results (Snow and Swanson, 1992[56] and Dowell, 1969[57]). A second possible limitation is that the achievement measure used in the study was quite difficult, the mean score was approximately eight out of a possible maximum score of nineteen. The restricted range of scores may have caused the achievement measure to be less sensitive to instructional effects. A third and final limitation of the study is that the length of treatment was short. Although several studies reviewed had even shorter treatment duration than this study, it is possible that the instructional differences among treatments may not have been sufficient to effect measurable differences.

What conclusions can be drawn from the results? What accounts for the superiority of the simulation treatment on the post-imagery measure but not on the achievement measure? Two explanations are offered here: The first explanation is based on the dual-coding theory of Paivio (1986[58]) and the nature of what was assessed by the two outcome measures. The second explanation is based on the analogy literature that students do not always use analogies even when they have learned them. Both explanations are developed below.

Paivio suggested that visual and verbal information is processed and stored in separate sub-systems. Memories in these sub-systems are modality-specific encodings where words activate verbal systems and pictures activate symbolic systems. Thus, both encoding and activation of memory depend on the stimulus presented (Paivio[59], 1986, p. 63). Since items on the post-imagery test required students to respond with drawings, it is possible that visual memories were selectively activated to generate more accurate drawings. This explanation accounts for the superiority of the simulation treatment on the post-imagery measure. The achievement items were calling upon student's verbal encodings which were identical across three treatments and accounts for the non-significant difference on the achievement measure.

An alternative explanation for the finding is based on the work of Reed, Ernst, and Banerji (1974[60]), Clement (1988[61]), and Gentner (1989[62]). This explanation is that students used the analogies in the simulation group to develop their imagery of the content but that this imagery was not used in solving the achievement items. In other words, having an analogy is no guarantee that a student will know how or when to apply it. This argument is based on the presumption that the post-imagery items provided cues to the learners to use the analogies while the achievement items did not. Gick and Holyoak (1980[63], 1983[64]), for example, found that providing a direct hint to use analogies will facilitate student's use of analogies in novel situations.

Both explanations are equally possible and both are supported in the literature. However, this kind of data from this study cannot be used to support one or the other explanation. Future research might explore the viability of these two explanations. It will be particularly important to design outcome measures that specifically require verbal or visual information and that are administered under two specific testing condition, hints versus no hints. This would provide data that may help tease apart the two explanations.

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