Identifying Variables and Constructing Relations: Effects of Multiple Images and Texts Stimuli

Billie Eilam and Yael Poyas, University of Haifa, Mount Carmel, Haifa 31905, Israel.
Email: beilam@construct.haifa.ac.il; yaelp@construct.haifa.ac.il

Abstract: Does learning with multimedia promote students' ability to identify variables and infer relations among various elements within given textual and visual information, thus deepening system thinking? This study examined 150 undergraduate students' ability to identify systems' components (i.e., variables), overt and covert relations, as well as construct new relations among these variables, based either on a multiple-representation (MR) display that resembled rich textbook materials (*n*=82) or a single-representation (SR) text-only display (*n*=68). Findings showed that the experimental MR group elicited relations better than the controls (SR), regarding relations' accuracy, descriptive level, and novelty, and regarding number of information sources and diversity of variables used. Discussion focused on different visual representation types and on implications of this ecologically valid study for enhancing students' system thinking.

Revealing and comprehending relations among variables are essential cognitive operations for achieving system understanding in all domains. For the interpretation of behaviors involved in systemic phenomena, individuals have to identify relevant system components (variables), to describe the nature of overt relations among them and draw conclusions about covert systemic relations. Frequently, individuals are required to construct novel relations, not evidenced at first glance, which may promote explanations of the system behavior. The importance of the ability to elicit relations as an initial step towards developing system thinking, called for the present study. Therefore, we examined university students' ability to identify systems' components (i.e., variables), overt and covert interrelations, as well as to construct new ones. We compared this students' competence while learning given information in an ecologically valid setting (i.e., preparing homework) from multimedia displays versus learning from single-representation displays of textual information only.

The Importance of Eliciting Relations among Variables

A system is a collection of continuously interacting components, forming a functioning entity (Forrester, 1968). System thinking comprises a multifaceted high-order skill that incorporates the recognition of patterns of system behavior or the prediction of behaviors in particular conditions (Booth Sweeney & Sterman, 2000; Frank, 2000; Ossimitz, 2007). Underlying system thinking is the prerequisite basic ability of identifying the system's components (variables) and their diverse interrelations. The need to develop system thinking arises in all domains (Beach, 1998; Eilam, 2008; Eilam & Poyas, 2006; Hmelo, Holton, & Kolodner, 2000; Kali, Orion, & Elon, 2003; Senge, 1990). Mostly, relations' elicitation is carried out while learning from visual, textual, or multimedia representations of phenomena rather than identifying systemic relations in reality.

Visual Representations of Relations among Variables

Some visual representation types were found to surpass others in effectiveness for conveying relations (Kosslyn, 2006; Shah, Hegarty, & Mayer, 1999). Classic examples are pie, line, or bar graphs as well as tables of numbers to convey quantitative relations, and diagrams, charts, or schematic drawings to convey different types of qualitative relations among entities, like spatial, structural, functional, etc. Although maps convey quantitative relations, they do so concerning spatial entities only (Kosslyn, 2006). In all cases, learning outcomes do not depend on the features of such representations alone but also on their interaction with the cognitive processes involved in the information processing (Salomon, 1979), as well as with the type of task at hand (Carswell, 1992; Kosslyn, 2006; Meyer, 2000).

Differently from graphs, charts represent the quality of various entities in the form of maps, diagrams, flow charts, family trees and so forth, rather than representing these entities related amounts. Charts describe who (or which) relates to whom (or to which) or in certain cases also, who (or what) influences whom (or what). Charts' employment of diverse means (e.g., lines for connecting the different symbols, symbols' organization in a two dimensional space) enables representation of a great variety of relations, like spatial, functional, or relations of inclusion (Kosslyn, 2006). However, the very diversity of these means requires learner awareness of their properties.

Charts have properties of both texts and pictures. Although they have some text inserted in them, charts such as diagrams or family trees differ from texts in that the logical or syntactical relationships that exist among the concepts are described spatially, rather than in a sentential representation, therefore requiring lower amounts of mental effort to process them (Larkin & Simon, 1987; Winn & Holliday, 1982). Winn (1991) claimed that the type of spatial configuration for objects or concepts in a representation affects various processes that are involved in human perception. He discriminated between maps – that represent the spatial organization of objects included in a certain space – and diagrams – that express conceptual relationships spatially. Maps and diagram are effective for showing physical layout – how things are put together and work; can serve as a schema for organizing information; can represent abstract ideas in a concrete manner; and require the use of spatial skills. With less demands made on working memory, they leave cognitive resources that may enables learners to carry out higher level processing (Winn, 1991).

Use of different representation-types is abundant in educational settings. We next discuss learning with multi-representational displays and the elicitation of relations from information presented in them.

Learning from Multimedia

Multiple representation (MR) displays contain more than one type of representation of information and data, allowing learners to simultaneously inspect visual and textual materials. MRs' inclusion of visual displays may promote learners' ability to elicit relations more than do text presentation alone while requiring fewer cognitive resources (Larkin & Simon, 1987) as well as promote their systemic thinking (Kali et al., 2003). However, many studies have reported students' difficulties in translating and integrating multimedia information bits into a comprehensive whole, especially with regard to information presented concurrently in several representation modes (e.g., textually and visually) (Ainsworth, 1999; Goldman, 2003; van der Meij & de Jong, 2004; Yerushalmy, 1991). In spite of visual representations requirement for decreased mental efforts for processing each representation distinctly, their integration with other representations (visual or text) increases the mental efforts required due to learners' needs to actively construct understanding while learning, by building references and mapping across them, as well as translating between them (Mayer, 2003; Schnotz & Bannert, 2003). Investment of increased mental efforts may result in a high cognitive load and a decrease in available mental resources, which may impede learners' performance (Chandler & Sweller, 1992; Mayer, 2003; Mayer, Heiser, & Lonn, 2001; Tiene, 2000).

The Present Study

Based on reported principles of learning with multi-media the present study examined the effect of learning from an MR display versus a text-only display on university students' ability to elicit relations. Instead of the usually controlled, short-term, laboratory-like task conditions, the current MR and single representation (SR) displays were used for learning in an ecologically valid setting of preparing homework task during university courses in education. Our learning materials resembled the richness and complexity of current school textbook designs found in many subject-matter domains. *The aim* of the study was to examine if learning with a rich, complex MR display (experimental group) would improve students' ability to elicit relations better than learning from an SR display of text only (control group). We predicted that, overall, compared to SR students, students in the MR group would score higher on: (1) task performance as a whole; (2) the number of information sources (cards) used; (3) three aspects of relations – (i) accuracy, (ii) description level, and (iii) novelty; and (4) the number of variables used in eliciting relations.

Method

Participants

Participants were 150 undergraduate students (118 females and 32 males) aged 18 to 30 years who were enrolled in two education courses in the Faculty of Education. Eighty two students were assigned to the MR group; age of M = 23.31 years, SD = 2.58; 79% female. Sixty eight students were assigned to the SR group; age of M = 24.73 years, SD = 5.34, 88% female. The size difference between the groups (82 vs. 68) emerged after 14 students of diverse abilities from the SR group discontinued their participation, claiming boredom and lack of motivation to deal with the task. The two groups did not differ significantly in their mean grade point average: MR: 83.7 (SD = 4.54); SR: 84.8 (SD = 4.52), t (148) = 1.41, p = .16.

Materials

The materials consisted of 18 SR information cards comprising text only (each containing between 47 and 299 words, with most cards being around 120 words); 18 MR information cards comprising visual and textual data; and a homework task given to both groups. Cards and task information pertained to cellular phones.

SR and MR Information Card Sets: Each card in each set offered only one representation mode—either textual or pictorial. Each MR card contained highly similar information (in content and details) to that contained in its twin SR card of text only; namely, each set of cards contained similar information represented by different symbolic language. Similarity was ensured by two experts, each describing the information contained in either each of the 18 MR or SR cards. Descriptions given for twin cards of each pair were compared in order to determine their degree of overlapping. Cards representations were refined until achieving a minimum of 75% of overlapping information. The MR cards contained minimal printed texts (e.g., headings, labels, legends), and included 4 text cards and 14 pictorial cards like bar chart, line graph, pie chart, drawing, map, numerical tables and a technical schema. The topic selected was the cellular phones representing various systemic aspects and levels (i.e., transmission of radio waves, coverage areas, cell phones' general properties and functions, users' characteristics, hazards in use, and the history of this technology). Each aspect could be represented by one or few cards. Components and their interrelations could be found or inferred from information presented either on single cards (thus in one mode only) or on several cards (thus in several representation types for the MR group). Card numbering enabled students to report the particular cards they had employed for responding to each task question, permitting the identification of the specific information sources (cards) and the number of cards used.

Displaying information on distinct cards enabled students to organize them in space in ways that increased learners' gains from the spatial contiguity effect (Mayer, 2003). However, simultaneous processing of information that is presented in several cards may overload the limited capacity of working memory and impede performance due to a high cognitive load (Chandler & Sweller, 1992).

Homework Task: The task contained three open-ended questions. Question 1 asked students to elicit four relations among the various components that they had identified in the cards information. This question aimed to reveal students' ability to identify components (variables) of the systems as described overtly in the cards, to verbalize the relations they perceive between these overt components, to formulate covert relations, and/or to integrate information across various cards to infer novel relations. Question 2 required students to construct a novel relation between the given variables presented on a single textual card (i.e., thermal effect, time, and users' health) and another variable they had to identify on a different card (age). Question 3 directed students to two specific cards (i.e., a pie graph and a geographical map for the MR group and two text cards for the SR group) and asked them to infer new relations from the information presented in them. In addition, students were asked to locate an additional information card that verified these inferred relations (i.e., a numerical table card for the MR group and a text card for the SR group). This task required the integration of information presented in three cards, namely, three different representation types for the MR group and three texts for the SR group.

Procedure

This study is a part of a larger study (Eilam & Poyas, 2008). Students were told they would receive a set of information cards that contained all the information they would need for completing the task. To prevent interference by the course contents, students in each group (SR and MR) received a hard copy of 18 SR or MR cards in the beginning of the course. Cards remained at students' disposal while completing the task. They were told that they could arrange the cards as they deemed convenient and efficient. The task comprised routine homework for credit to promote students' motivation and to optimize their cards' exploration. Performance time was not limited, and each student signed a written consent to work alone.

Data Coding and Analysis

Each elicited relation in students' responses to the three questions was coded, using each of the relevant following criteria, and scored accordingly. Differences between groups and between the various criteria below were calculated using the Mann-Whitney test.

General Performance: For both student groups, the total performance score for eliciting relations was calculated as the sum of the following three scores, with possible scores ranging from 0 to 35 as described next:

(1) Number of Information Cards Used (relevant only to Question 1): As described above, each card was numbered. Based on students' indication of the card number used for each elicited relation, the following criteria and scoring were applied: (i) missing response, no indication of card number, or erroneous card number - 0 points. (ii) use of a single card per relation - 1 point. (iii) use of more than a single card per relation – 2 points. Inasmuch as Question 1 asked students to elicit four core relations, possible scores ranged from 0 to 8.

(2) Relation Description Level (relevant only to Questions 1 and 3): this criterion, referring to participants' level of description for the elicited relations. An inaccurate or a missing response scored 0 points. Regarding accurate responses, three levels of description were coded: (i) identification of the variables only (1 point), e.g., "age and cell phone bills." (ii) qualitative, narrative-type verbal description of the relation (2 points), e.g., "the antennae transmit to three cells." (iii) quantitative description of the relations (3 points), e.g., "the less distance from the antennae – the higher the radiation intensity." Possible scores ranged from 0 to 15.

(3) Relation Novelty (Relevant only to Question 1): An inaccurate or a missing response scored 0 points. Three levels of novelty were coded for accurate relations: (i) no novelty, i.e., verbalizing a relation that was overtly presented verbally or visually (1 point), e.g., directly presented text like "many governmental regulations control transmission frequencies" or a relation presented inherently in a particular graph or table. (ii) low-level novelty, i.e., inferring a relation that was covertly presented verbally or visually on a single card (2 points), e.g., inferring spatial relations from the map card. Low-level novelty may reflect only a limited and local understanding of the given information, regarding one particular relation in the relevant system, and thus does not ensure a systemic understanding of the phenomenon. (iii) high-level novelty, i.e., inferring a new relation that was not presented in

any one card; rather, students had to synthesize a new relation from information presented verbally or visually on more than a single card (3 points). Possible scores ranged from 0 to 12.

Relation Accuracy: Each relation in all three questions was scored as either accurate (1 point) or inaccurate (0 points) with regard to the information presented in the cards, therefore reflecting students' understanding of this information and ability to elicit relations relevant to it. Possible scores ranged from 0 to 6.

Number of Variables Used in Eliciting Relations (relevant only to Question 1): The number of different variables that students elicited in forming their relations was analyzed. Based on the greater salience, explicitness and distinctiveness of system components when presented via visual rather than textual modes, we hypothesized that the MR group would identify a larger number of variables in comparison to the SR group.

Results and Discussion

General Effects of MRs on Elicitation of Relations

The findings (see Table 1) supported our first hypothesis; namely, the MR group scored generally significantly higher than the SR group (range: 0 to 35), U = 1644.00, p < .001, significantly higher than SR students on eliciting four core relations as desired (Question 1), U = 1673.50, p < .001, but no significant difference emerged between the groups for eliciting a novel relation using three cards (Question 3), U = 2426.50, p = .13. This latter question required students to integrate three different representation types, a pie graph, a geographical map, and a numerical table, shown to cause a high cognitive load. Such integration possibly hindered students' performance, offsetting the advantages of learning with multimedia. The MR students scored significantly higher than the SR students on each of the four possible core relations that could be elicited in Question 1, U = 1891.00, p < .001; U = 1770.00, p < .001; U = 1828.00, p < .001; and U = 2008.00, p < .01, respectively.

Table 1: Mean scores (and SD) for elicitation of relations among variables by multiple representation (MR) and single representation (SR) groups.

Criteria	Group	Question 1					Question 3	Total
		RAV1	RAV2	RAV3	RAV4	Total Q1		
Total performance score	MR	3.99 (2.06)	3.87 (2.29)	3.84 (2.12)	3.41 (2.31)	15.11 (6.95)	1.93 (1.37)	17.04 (7.35)
	SR	2.78 (2.34)	2.29 (2.36)	2.38 (2.29)	2.21 (2.42)	9.66 (7.56)	1.54 (1.43)	11.21 (7.83)
No. of information cards used	MR	.99 (.55)	.91 (.57)	.94 (.57)	.84 (.69)	3.65 (1.73)	—	3.65 (1.73)
	SR	.71 (.60)	.71 (.60)	.54 (.50)	.57 (.68)	2.34 (1.72)	—	2.34 (1.72)
Level of relation description	MR	1.96 (1.08)	1.94 (1.19)	1.93 (1.28)	1.77 (1.28)	7.60 (3.83)	1.93 (1.37)	9.52 (4.27)
	SR	1.29 (1.13)	1.12 (1.23)	1.25 (1.29)	1.09 (1.27)	4.75 (4.06)	1.54 (1.43)	6.29 (4.42)
Level of relation novelty	MR	1.04 (.71)	1.02 (.79)	.98 (.68)	.84 (.69)	3.87 (2.07)	—	3.87 (2.07)
	SR	.92 (.76)	.85 (.77)	.81 (.67)	.57 (.68)	2.57 (2.05)	—	2.57 (2.05)

The relatively high standard deviations that were obtained for all of the results may be attributed to the large heterogeneity of the university's student body.

Effects of MRs on Various Aspects of Relation Elicitation

Number of cards used

Our second hypothesis was confirmed as well. As can be seen in Table 1, the MR group used significantly more cards for eliciting each of the four relations in Question 1, U = 2119.50, p < .01; U = 1903.00, p < .001; U = 1857.50, p < .001; and U = 2137.50, p < .01, respectively, and for all of them together, U = 1762.00, p < .001. The use of a higher number of cards may reflect MR students' identification of more components in the visual cards, due to these variables' higher salience and distinctiveness in pictures compared to their salience in texts. This saliency released learners from the need to perform a systematic reading of card information that would reveal additional, less salient components and relations in this same card.

Level of Relation Description

Relations' level of description may reflect students' competencies regarding the identification of components (variables) in the system and the verbalization of their quantitative interrelations (see Table 1). For Question 1 (eliciting four core relations), the MR group students scored significantly higher on relation description level than did their SR counterparts, both generally, *U* = 1734.50, *p* < .001, and for each of the four relations separately, *U* = 1873.00, *p* < .001; *U* = 1789.50, *p* < .001; *U* = 1984.50, *p* = .001; *U* = 1997.50, *p* < .01, respectively. Again, no significant difference between the groups was found for Question 3, which required the integration of three representation-types. As mentioned above, the characteristics inherent to certain representation types, like tables and graphs, directly and explicitly represent quantitative relations. This may have enabled MR students' to formulate higher level quantitative relations, which not necessarily stem from a better systemic understanding. However, based on theories of learning with multimedia, these results may also suggest MR students' increased general understanding of the information, which enabled them to formulate relations at a higher quantitative level.

Level of Relation Novelty

MR group students scored significantly higher on relations novelty level than did their SR counterparts (see Table 1), both generally, *U* = 1978.00, *p* < .01, and for each of the four relations separately, *U* = 2199.00, *p* < .01; *U* = 1940.50, *p* < .001; *U* = 1961.00, *p* = .001; *U* = 2176.50, *p* < .01, respectively. These findings may be interpreted by considering the characteristics of a system. Ability to infer new relations may demonstrate a global understanding of occurrences in the represented system, whereas the verbalization of relations that are explicitly or even implicitly presented in the cards may suggest a limited understanding of local occurence rather than the global complexity of the system.

Accuracy

The mean accuracy score for all three questions combined was significantly higher for the MR group (*M* = 4.28, *SD* = 1.45) than for the SR group (*M* = 2.93, *SD* = 1.81), *U* = 1582.50, *p* < .001(see Table 2). This pattern emerged for the set of four relations required in Question 1 (MR group: *M* = 3.16, *SD* = 1.31; SR group: *M* = 2.16, *SD* = 1.62), *U* = 1841.50, *p* < .001. Chi-tests performed for each relation in Question 1 showed the same pattern of MR significantly outperforming SR. This same pattern also emerged for Question 2, which required students to form novel relation between given variables presented on a single textual card and another variable they had to identify on one of the other cards. This pattern did not emerge for Question 3, which required students to integrate 3 representation-types, probably causing cognitive overload, hindering performance.

Table 2: Frequencies (and percentages) of accurate responses for each question, and for relations in question 1.

		Question 1				Question 2	Question 3
Group	*n*	RAV1	RAV2	RAV3	RAV4		
Multiple representation	82	69 (84.1%)	65 (80.2%)	66 (80.5%)	59 (72.0%)	35 (42.7%)	57 (69.5%)
Single representation	68	43 (63.2%)	35 (51.5%)	36 (52.9%)	33 (48.5%)	12 (17.6%)	40 (58.8%)
$\chi^2_{(1)}$		8.59**	13.87***	12.96***	8.60**	10.83***	1.86

** *p* < .01. *** *p* < .001.

Number of Variables Identified

We examined variable diversity for the four core relations elicited in Question 1. We computed the number of diverse variables (e.g., distance from antennae, radiation) that the students as a group identified for each pair of variables comprising a relation (see Table 3). In other words, the 82 students in the MR group showed relatively low component diversity in both steps of constructing the first relation: As a group, they elicited only 12 different components as their first variables and 23 different components as their second variables in the first relation. Note that the variables could overlap between the four relations. SR group also identified similar number of first and second variables in the first relation. However, Table 3 demonstrates the increasing difficulty of the SR students to identify new, different variables as they progressed from the first to the fourth relation, as compared with the MR students' performance (see especially the fourth relation). This difficulty supports our assumption regarding the advantages inherent in presenting information via visual modes, due to the components' higher salience and distinctiveness in pictures than in texts and due to the relations' more direct presentation in some of the pictorial cards.

Table 3: Variable diversity: The number of different variables used by multiple representation and single representation groups for each relation.

Group	RAV1		RAV2		RAV3		RAV4	
	Variable 1	Variable 2	Variable 1	Variable 2	Variable 1	Variable 2	Variable 1	Variable 2
Multiple representation	12	23	15	29	18	24	17	24
Single representation	12	22	12	18	13	15	9	14

An additional phenomenon seen in this table for both student groups was that the diversity of the second variable always surpassed that of the first. We believe this phenomenon reflects students' tactics in eliciting relations: first locating the most salient variable; only then looking for a second variable that could interrelate with the salient first one. Since the second variables were less salient, students possibly located a large variety of them, leading to the second variables higher diversity. It is also possible that the search for a second variable was more comprehensive and deep because of their lessened saliency.

Use of Representation Types by MR Students

Finally, we examined our assumption that the level of relation description as well as the level of relation novelty would be related to specific characteristics of particular visual representation types. For each representation type, we calculated the mean frequency of respondents who indicated that they had used it when eliciting relations (by indicating the card number they used). Table 4 presents the data for the more frequently used representation types, regarding the level of description and of novelty achieved.

Table 4: Frequencies (and percentages) of MR students' usage of different representation types when eliciting relations of differing descriptive and novelty levels.

Representation type	Mean no. of users (n=82)	Distribution of each representation type's users by level					
		Level of description			Level of novelty		
		1	2	3	1	2	3
Missing/Error	17 (21%)						
Text (4 cards)	25 (30%)	5 (20%)	16 (64%)	4 (16%)	23 (92%)	1 (4%)	1 (4%)
Table (4 cards)	20 (24%)	3 (15%)	1 (5%)	16 (80%)	18 (90%)	1 (5%)	1 (5%)
Line graph (1 card)	8 (10%)	1 (13%)	0	7 (87%)	8 (100%)	0	0
Map (1 card)	4 (5%)	0	1 (25%0	3 (75%)	0	3 (75%)	1 (25%)

Note. Data pertain to all four relations from Question 1 together (8 identified variables per student).

Generally, the number of respondents who used text was highest (30%), followed by users of tables (24%), the line graph (10%), and the map (5%). Interestingly, although better performance has often been reported for learning with multimedia, our students still preferred to elicit relations from texts.

Most learners who elicited accurate relations from textual cards (64%) described them only qualitatively, in a narrative manner (level 2 of description), whereas most learners who elicited accurate relations from graphs (87%) or numerical tables (80%) reached a higher, quantitative level of description (level 3) (see Table 4). Therefore, a higher score on the level of description does not necessarily appear to suggest a deeper systemic understanding but rather the use of certain representation types.

Concerning the levels of novelty, Table 4 shows that the accurate relations elicited by 92% of those students who used texts merely verbalized a relation that was overtly presented in the cards (level 1). The same pattern of results was found for tables (90%) and graphs (100%), due to the inherent properties of these representations, which explicitly present relations. On the other hand, the few students who used the map to elicit relations achieved the second level of novelty (a relation presented implicitly in the information). One student even inferred a new relation (third level), reporting the use of a map jointly with the pie graphs. Hence, like the outcomes for description level, the findings for novelty level indicated that the relations that students elicited from the information cards were connected to the information's representation type.

Conclusions

In the present study, we inquired about the various aspects related to eliciting relations. Our claim is that an inability to identify systemic components and their interrelations will preclude individuals' deep understanding of a system's events and phenomena. We further assert that a local understanding of only specific relations may hinder these individuals' understanding of the systemic functioning and general patterns of behavior, as would be expressed in their inability to elicit new relations for this system.

Generally, our study corroborated prior findings reporting that learning from multimedia resulted in better performance than learning from text alone. Our study's contribution originates from: (a) the unique type of task administered to students – eliciting relations, (b) the information cards' resemblance to actual textbook chapters in terms of their richness and variety of representation types, and (c) the performance of the task in an ecologically valid university education setting. These design properties permitted further insights into some aspects of learning with multimedia. Like other studies, we have shown that MR students performed better regarding various aspects of eliciting relations (number of cards used, descriptive level, novelty, accuracy, as well as the diversity of the variables used for forming relations), in comparison to SR students. The better performance found in the MR group for all these aspects may evolve from the principles of learning with multimedia (Mayer, 2005), and more specifically in our study the effect of factors like the salience of variables presented in a pictorial format as well as the inherent characteristics of certain representation types. Both these factors increase learners' awareness about components in the system as well as their interrelations. These also brought about the use of more cards for identifying variables and a broader diversity of variables in the elicited relations.

Levels of description and novelty may serve as indicators for a deeper and holistic system understanding rather than a superficial and local one. The ability to infer novel relations suggests a more comprehensive perception of a phenomenon functioning within the system; it demonstrates learners' conceptualization of implicit behavior patterns within the system and thus its complexity. This ability to infer new relations required students' integration of bits of information from more than a single card. Therefore, high-level relations' novelty may suggest students' construction of mental models that reflect the systemic nature of the information (Ben-Zvi Assaraf & Orion, 2005; Goldman, 2003; Ossimitz, 2007).

Our findings concerning the integration of three different representation-types (Question 3), showing no difference between the MR and SR groups, was explained in the literature by the difficulties inherent to the integration of various representation types (Ainsworth, 1999; van der Meij & de Jong, 2004; Yerushalmy, 1991). In our case, to respond to the question, students had to integrate among a pie chart, a map, and a table of numbers, which, according to Kosslyn (2006), all represent quantitative relationships. In this respect, they were expected to be integrated by students without specific difficulty. However, pies and tables convey quantitative relationships concerning amounts, whereas maps convey quantitative relationships concerning spaces. In this sense, integration was probably hindered and posed an obstacle for students' performance, which offset the advantages inherent to visual representations.

An examination of the kind of representations MR students used for eliciting relations suggested that they preferred to explore texts and familiar representations that are frequently used in school learning materials, hardly considering other representation types such as technical schema.

Inasmuch as we did not measure students' motivation in the present study, we cannot exclude the possibility that this may have also affected results as well, because learning from multimedia may be more motivating and interesting than learning from text alone, as suggested by other studies (Ainsworth, 1999; Peeck, 1993) and by the fact that all 14 students who dropped out of the current study were assigned to the text-only control group. It is important to scrutinize this issue in future research.

Theoretical and Practical Implications: With system thinking considered currently to constitute a core issue for instruction, relation elicitation should be a basic requirement. Our results may inform curriculum designers, teachers, and researchers concerning the ability to elicit relations while learning with multimedia. Our "noisy" field study suggests that its ecologically valid findings are particularly meaningful for decision making regarding learning this issue in actual educational systems.

Study Limitations and Future Directions: Despite its advantages, some limitations may emerge from the "noisiness" of this field research when it is applied in authentic educational contexts. Possible intervening factors might be, for example, students' prior knowledge concerning cell phones and representation types, as well as their motivation. Moreover, the present study did not examine students' academic background or disposition (i.e., scientific versus humanistic), which could have affected students' abilities regarding the elicitation of relations. We suggest that future research should carefully measure students' motivation, attend to possible differences in students' background knowledge, and deepen the examination of students' strategies for eliciting the relations presented in MR displays, which may inform textbook and technology curriculum designers.

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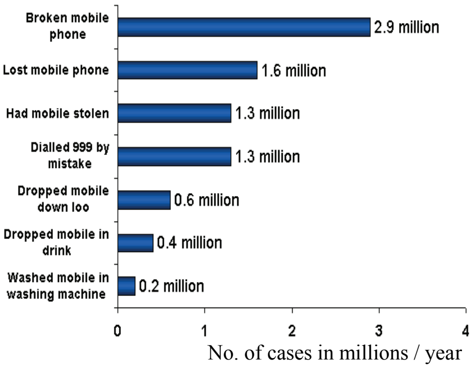
Appendix

Examples of three pairs of twin cards

Multiple Representation Display

Card 3: Visual representation



Textual Representation Display

Card 3: Descriptions as printed text

Broken mobile phones - 2.9 million

Lost mobile phones - 1.6 million

Had mobile stolen - 1.3 million

Dialed 999 by mistake - 1.3 million

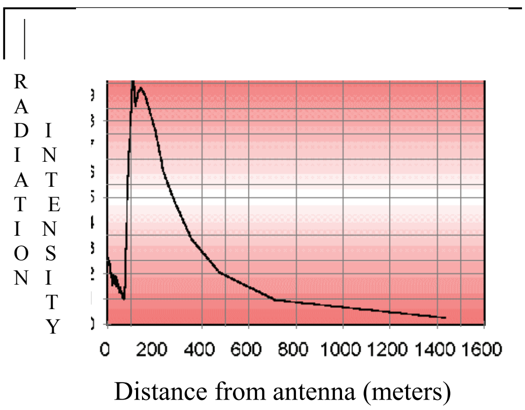
Dropped mobile down toilet - 0.6 million

Dropped mobile in drink - 0.4 million

Washed Mobile in washing machine - 0.2 million

No. of cases in millions / year

Card 11: Visual representation



Card 11: Descriptions as printed text

A line goes through the following points in a 2-axes graph: It starts at a distance of sixty meters from the antenna and a very low radiation intensity; the line rises sharply and reaches a maximum intensity at about one hundred meters' distance from the antenna; the line continues down gradually and reaches average radiation intensity at about four hundred meters from the antenna; The line reaches a low intensity at a distance of eight hundred meters, and is reaching a close to zero radiation at a distance of one thousand and four hundred meters from the antenna.

Card 7: Explanatory Text

7-1 The cellular phone roots back to the 1940s when commercial mobile telephones began. This mobile wireless hasn't progressed further in the last 60 years as did other technologies. For example, we don't have low cost video watch phones. Some of the reasons for this delay were technology and federal regulations.

7-2 The wireless revolution began only after low cost microprocessors and digital switching became available.

7-3 The regulations of the Federal Communications Commission, who controlled frequencies, constituted the most significant factors hindering telephone development, especially the cellular type, delaying that technology in America by years. It took even longer in Europe and Japan. The first commercial cellular telephone systems started in Bahrain, Tokyo, Osaka, and Mexico City.

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