The Importance of the Path Not Taken:
The Value of Sharing Process as Well as Product

FINAL REPORT

Theresa M. Vitolo, Ph.D.

Department of Computer and Information Science
Gannon University
109 University Square, PMB 3163
Erie, PA 16541
USA

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Abstract

SMART Board™ interactive whiteboards and associated technological aspects were used to assess the technology's contribution in producing a higher-quality analysis diagram as opposed to paper-based analysis. The analyses were in the domain of database modeling of entity-relationship diagrams (ERDs). ERDs are commonly used and taught to systems-related professionals. ERDs capture in a graphic format the structure and meaning of business elements to a database domain. The evaluation of the experimental groups to the control groups with respect to the quality of the analyses showed that the groups using the SMART Board interactive whiteboard produced analyses:

(1) with greater semantic congruency between the diagrammer's and their other members' diagrams

(2) with greater comparable number of elements to the analysis, and

(3) with less structural congruency between the diagrammer's and their other members' diagrams.

On time aspects, however, the diagrammers of the experimental and control groups were not significantly different. However, the members of the SMART Board interactive whiteboard groups when producing the test analyses took 75% longer than the paper-based groups. The quality results seemed to indicate that the layers provided by the SMART Board interactive whiteboard allowed members of the experimental groups to reach greater semantic similarity. The work had hypothesized that the SMART Board interactive whiteboard would help the members to produce graphs quicker. In fact, the experimental groups took almost twice as long to produce their analyses, but their analyses were of a higher semantic quality than the paper-based ones. The work supports the hypothesis that a higher-semantic quality of analysis can be fostered in others when layers of the analysis are available during training. Consequently on-line education and distance education initiatives should consider including the access to layers and incremental versions in teaching analysis-based topics.

Overview Statement of Research Context

Systems professionals are responsible for describing different aspects of systems with different diagramming approaches. In fact, the diagramming approach is not only used to describe a system, but also to analyze its problems. Hence, the better one diagrams a system, the better the solution.

Often in classrooms, students are requested to diagram a system. For example, its data structure or its network architecture may be the aspect to be diagrammed. If students work in small groups to do the analysis, inevitably one student is doing the actual diagramming, making the graphic in a notebook, correcting the graphic as discussion about the system occurs among the group members. What is lost in this mode of conceptualization are the versions of the final diagram.

As versions are lost, so are the explicit records of the reasoning steps for changing the diagram. Given the limits of short-term memory and human information processing, these intermediate steps must be removed so that information-handling and cognitive resources can be made available to the solution process and the ongoing critique of the evolving diagram.

Often the student who learns to diagram best is the student who actually did the diagramming, made the changes, and implicitly captured the record of the version changes. The others in the small group – due to their less active engagement with the *process* – acquire less understanding of the conceptualization. Even if the members of the group rotate the diagramming task, each member will only directly and significantly benefit from the time when he/she handled the diagramming task, the duration when involved actively with the analytical reasoning steps of the task.

Alternatively, if the individual handling the diagramming could capture the state of the version at the point when a fundamental change was to be added to the diagram, then the sequence of the analysis thought process could be captured. The captured versioning sequence could be replayed to the other members of the group so that each could actively experience the reasoning process and the effects of the reasoned changes upon the final product.

Ultimately what can be shared among learners, then, is not only the product, but also the process of the diagramming. By capturing the process, the reasoning and decision analysis can be communicated. Communicating the analytical thinking allows others to absorb this richer information structure for themselves, thereby gaining a better understanding. Added to the benefit of communicating the analytical process is the benefit of possessing and manipulating the versions as an information structure in itself – the increments of refinement to the solution to be manipulated and studied.

The outcome of understanding the role of the availability of layers of analysis when communicating an analysis can be important to on-line and distance-learning initiatives. Due to the nature of non-face-to-face (Internet-to-Internet, that is, "i2i') communication in education, often just the end product – the "solution" of an analysis is provided. During the face-to-face communication, student to professor, the professor provides the path to the solution and essentially trains the student in the analysis process. If this component of the learning system does not occur, the overall quality of analysis may suffer. If capturing and conveying versions of analysis shows improvement for students in the experimental frame, then capturing and conveying versions of analysis may be a necessary component of i2i-communication for learning environments.

Research Question

The target question of the research effort was: Does an undergraduate's ability to produce a diagram of a system improve when the versions of the stages of diagram refinement are communicated and studied? Improvement would be assessed in terms of speed to complete a diagram and in terms of the quality of the analysis when evaluated by academics within the profession.

The research question focuses on several aspects:

- The active engagement with the material by communicating the solution,
- The direct manipulation of a <u>tangible</u> <u>representation</u> of an abstract thought process by the individual who created the solution -- *the version-capture*, and

- The direct manipulation of the representation, the version-capture, by individuals who did not directly create the solution.

Background

The project is connected to various theories of information science, cognitive science and learning. The salient points are listed below:

- Short-term memory (STM) has a working limit of 5 $\pm$ 2 units of information. Often mental processing tasks require STM to remove items of information that are "old" or "non-essential" to the task. Hence, remnants of a thought process are removed. If the analysis path being constructed fails to meet criteria and the analyst must return to a former path, then mentally, parts of the abandoned path must be reconstructed both mentally as well as physically.

- Direct manipulation of an environment allows a learner to directly experience the constraints of the environment, thus directly incorporating the constraints through the senses. If abstract processes can be translated into direct-manipulation processes, then the learner of an abstract process gains the benefit of being explicitly involved with the concepts.

- While direct manipulation has the benefit of involving the senses for a more total experience, direct manipulation also forces the learner to be an active learner by default.

- *The Taxonomy of Educational Objectives* ([1956] 1984) edited by B. Bloom identifies a structure for instructional efforts. As instructors move students into the higher-order educational objectives, then methods enabling the teaching of these objectives are desirable. When students operate with systems' diagrams, they are operating at Bloom's Level 4: Analysis and Level 5: Synthesis – with only Level 6: Evaluation remaining.

Methodology

The research perspective spearheaded was: (1) Does the *manipulation of the version-capture* improve analysts' ability to do analysis? Three-member groups were constructed, with one individual being the diagrammer. A total of seven groups were constructed, four in an experimental setting and three in a control setting. One of the control groups had its members reduced to only one. The other member exhibited better diagramming capabilities than the named diagrammer, in all respects of analysis. Hence a total of 20 individuals participated in the study.

The experiment proceeded in three stages:

1. Training: Only SMART Board interactive whiteboard diagrammers underwent training so that they could be comfortable with the use of the SMART Board interactive whiteboard. The training period of each diagrammer was limited to a maximum of 60 minutes, if needed.
2. Instruction: Diagrammers in both groups met with other members of the group. In a period of time not to exceed 60 minutes for each analysis, diagrammers would communicate – instruct – their analysis of a specific scenario to the other members.
3. Test: All members of either group were given a scenario to analyze, producing a final diagram on paper for evaluation.

Essentially, the diagrammers of the control groups versus the experimental group differed in what they were able to show the other members during the instruction stage. For three mini-case studies, the diagrammers analyzed the situation and the versions of the analysis process were drawn. Experimental-group diagrammers captured their analysis through a SMART Board interactive whiteboard. Control-group diagrammers produced a paper copy. After each analysis, the diagrammer communicated the solution process to the other two members of the group until they indicated that they understood how the diagrammer reached the final system description. Control-group diagrammers were only allowed to use their final analysis in the instruction stage. Experimental-group diagrammers were allowed to reference any segment of their captured analysis. (See Appendix: Project Materials, Items 3 through Item 6 for the instructions given to each different type of member.)

The testing stage was comprised of a fourth mini-case given to all group members to individually analyze. The analysis of the fourth mini-case was timed and evaluated by three separate evaluators. An evaluation rubric used by the evaluators assessed both syntactic and semantic aspects of the diagrams of members as compared to the diagrammer's analysis, within their own group. (See Appendix: Project Materials, Item 9. for the rubric.)

The case studies were composed specifically for the research project. (See Appendix: Project Materials, Item 7.a-7.c and Item 8.a.) The scenarios of the case studies described a situation requiring a database to support its functioning. A high-level analysis used by systems professionals to capture the fundamental business elements, their features, and their connections to one another is an entity-relationship diagram (ERD). ERDs serve as a high-level blueprint for database application development.

The subjects were undergraduates and graduate students – most within systems-related majors, all within a technical discipline. Diagrammers were required to have been exposed to the concepts of the diagramming technique by taking a course where the material is presented. This initial exposure rarely makes a student well versed in creating the diagrams, but rather versed in the diagramming rules. The other members of the groups did not have any restriction on their education, although a majority of the students had taken a course teaching the technique. Knowledge of the members' abilities was gathered with the individuals' consent. (See Appendix: Project Materials, Item 1 and Item 2.)

Results

The primary outcomes of the project are statistical averages of the degree of improvement made in a student's ability to analyze systems as evidenced by the time to complete an analysis diagram and by the evaluated quality of the diagram. Quality of the diagram is assessed along the dimensions of structure and semantics. The following chart lists the aspects considered and the assessed average value of the aspect for both the paper version as well as the SMART Board interactive whiteboard versions. Highlighted rows mark the aspects where the SMART Board interactive whiteboard version exhibited better performance than the paper one. The language used on the evaluation rubric is also included. In this way, the interpretation of the aspect can be understood in the context in which it was evaluated.

Aspect	Paper	SMART Board Interactive Whiteboard
STRUCTURE … **The Member's diagram…….as the Trainer's diagram**	Max = 7	Max = 7
Uses the same structural notation	5.27	4.71
Has a similar amount of detail	4.60	4.29
Is as clear	4.53	4.38
Shows participation	6.00	4.85
Shows cardinality	5.71	4.32
Shows key concepts	3.85	4.48
Shows attributes	5.87	4.29
SEMANTICS … **On the Member's diagram…as on the Trainer's diagram**		
The level of vocabulary is the same	4.86	5.04
A similar depth of interpretation is achieved	4.53	4.63
Comparable relationships are identified	4.42	4.50
Comprehension is expressed	4.00	4.76
Keys correspond to the scenario	4.08	4.06
Significant business rules are expressed	5.40	5.13
Important points are captured	5.30	5.31
Attributes hold similar roles	4.07	3.63

TABLE 1: Averages for Evaluated Aspects.

Summarizing the averages over the categories of structural comparisons, semantic comparisons, and combined aspects, the data values are shown in Table 2:

Comparison	Paper	SMART Board Interactive Whiteboard
	Max = 7	Max = 7
Structural	5.12	4.47
Semantic	4.58	4.63
Combined	4.83	4.56

TABLE 2: Combined Averages for Aspects in Categories.

Table 3 shows the percentage improvement the SMART Board interactive whiteboard analysis had over the paper versions, for the aspects where greater quality of analysis was exhibited.

Aspect	Percentage Improvement of SMART Board Interactive Whiteboard Use Versus Paper

STRUCTURE … **The Member's diagram…….as the Trainer's diagram**	
Shows key concepts	16.38%
SEMANTICS … **On the Member's diagram…as on the Trainer's diagram**	
The level of vocabulary is the same	3.80%
A similar depth of interpretation is achieved	2.02%
Comparable relationships are identified	1.89%
Comprehension is expressed	19.12%
Important points are captured	0.24%

Table 3: Percentage Improvement in an Evaluated Aspect

Gross comparisons of structure similarity, shown in Table 4, were assessed by assessing the number of major elements – entities and relationships – diagrammers and other members had on their charts.

Gross Structure Comparison	Paper	SMART Board Interactive Whiteboard
For diagammers: • Average number of structural elements	6.17	6.43
For other members: • Average number of structural elements	5.30	5.94
Percentage similarity between diagrammers' element count compared to other members' element count	85.95%	92.36%
Percentage dissimilarity between diagrammers' element count compared to other members' element count	14.05%	7.64%

Table 4: Gross Structure Comparisons

Time comparisons were also made between the two groups, (Table 5). The time measures for the diagrammers were only averaged for the fourth, test, scenario.

Time Comparison	Paper (minutes)	SMART Board Interactive Whiteboard (minutes)	Duration Comparison SMART Board Interactive Whiteboard Versus Paper
For diagammers: • Average	26.00	38.75	49.04% longer
For other members: • Average	25.40	44.50	75.20% longer
Average difference between each diagrammer's time to other members' time	7.00 less	5.75 more	

Table 5: Time Comparisons

Discussion

The evaluation of the experimental groups to the control groups with respect to the quality of the analyses showed that the groups using the SMART Board interactive whiteboards produced analyses having the following traits.

(1) Greater semantic congruency between the diagrammer's and the other members' diagrams.

- On five out of eight categories, the SMART Board interactive whiteboard analyses were more similar to each other while the paper versions were less similar to each other in capturing the relevant meaning of the scenario. In Appendix: Project Graphs, Item 1 shows the plot of these categories.

(2) Greater comparable number of elements to the analysis.

- The SMART Board interactive whiteboard analyses used roughly the same number of elements to express the analysis. The experimental groups showed a convergence between the diagrammer's choice and the other members' choice in selecting the number of elements to capture the essence of the scenario.

(3) Less structural congruency between the diagrammer's and the other members' diagrams.

- However, in only one out of seven categories, the SMART Board interactive whiteboard analyses were more similar to each other in terms of the quality of the structure shown as opposed to the paper versions. While the number of elements employed to represent the analysis were comparable – (2), above – the entire set of structural features were not statistically significant. Appendix: Project Graphs, Item 2 shows the plot of these structure-related categories.

- Structural similarity comparisons had initially been composed of nine aspects. Two of the aspects were excluded from the final evaluation. When the diagrammer's analysis was compared with a member's analysis, both failed to the structure. As the items on the assessment instrument were regularly being marked as "not applicable" by the evaluators, their inclusion in the final data set was excluded. (See Appendix: Project Materials, Item 9, Point 6 and Point 7 on the instrument for the exclusions.)

Appendix: Project Graphs, Item 3 shows the averaged performance between the categories of structure and semantics as well as the combined average across all aspects considered.

On time aspects, the diagrammers of the experimental group took almost 50% longer than the diagrammers of the control groups were not significantly different. More so, the members of the SMART Board interactive whiteboard groups when producing the test analyses took 75% longer than the paper-based groups.

The time results of the study showed that members of the experimental groups were taking longer to develop their analyses. The quality results seemed to indicate that the layers provided by the SMART Board interactive whiteboard allowed members of the experimental groups to reach greater semantic similarity. The research hypothesized that the SMART Board interactive whiteboard would help the members to produce graphs quicker and their semantics would be better. In fact, the experimental groups were taking longer to produce their analyses, but their analyses were of a higher semantic quality than the paper-based ones.

This work poses some interesting questions as to the connections between structure and semantics in graphs. The experimental groups' subjects expressed similarity in semantics – in the meaning captured by their diagrams – but not a similarity of structure. Looking at the structure of a diagram may actually be irrelevant to building analysis skills. Good analysts will capture the same meaning, but will chose different structures to capture the meaning. Just as good writers may choose a variety of different sentences in a composition with the underlying meaning of their compositions being the same, good analysts may choose various diagramming combinations with the quality of analysis of the diagrams being the same. Structure – like grammar – may only tell one if the connections of the diagram are legal, but not indicate the ability of the analyst to use those legal structures to adequately represent a situation.

Conclusions

Overall, the SMART Board interactive whiteboard groups were not performing vastly better than the paper-based groups, but a difference was noted. While this study seems to indicate an advantage to offering layers of diagrams in teaching the craft of analysis, further study should be done. Further study is needed (1) to probe the aspects of semantic similarity that are enhanced by provided layers, (2) to confirm the lack of support layers give to structural similarity, and (3) to investigate what aspects of the stored SMART Board interactive whiteboard layers were employed by the diagrammers.

Reference

Bloom, Benjamin S. (Ed.) (1984, 1956). *Taxonomy of Educational Objectives. Handbook 1; Cognitive Domain.* New York: Longman.

APPENDIX: Project Materials

1. Subject Participant Consent Form
2. Subject Participants for System Analysis
3. Instructions for Member Participant Not Using SMART Board Interactive Whiteboard Analysis
4. Instructions for Member Participant with SMART Board Interactive Whiteboard
5. Instructions for Diagrammer Not Using SMART Board Interactive Whiteboard
6. Instructions for Diagrammer Using SMART Board Interactive Whiteboard
7. Scenarios for Diagrammers:
    a. San Juan Sailboat Charter
    b. Spacey Real Estate, Inc.
    c. Thoughts for Tots
8. Scenario Evaluated for Data Analysis:
    a. Morgan and Urdell, Private Investigators
9. ERD Compatibility Assessment

APPENDIX: Project Graphs

1. Structure Comparisons Across Evaluated Aspects
2. Semantic Comparisons Across Evaluated Aspects
3. Averaged Comparisons of Paper-Versions to SMART Board interactive whiteboard Versions