An Empirical Investigation Of The Cognitive Fit Of Selected Process Model Diagramming Techniques

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Abstract

This paper describes an empirical investigation of the cognitive fit (defined as the degree to which a particular diagramming technique is representative of a problem space) between four process modeling techniques consisting of data flow diagrams (DFD), process maps (PM), flowcharts (FC), and Resources, Events, and Agents (REA) diagrams.

Experimental results indicated some positive associations between three techniques (PM, DFD, and REA) and scores for questions hypothetically pertaining to each, respectively. Contrary to the hypotheses, PM and DFD outperformed FC.

1. Background

The development of information systems modeling techniques has a long history within accounting, information systems (AIS) and engineering. References to the need for a "new symbolism" can be found in Vannevar Bush's "As We May Think" first published in 1945 [Bush]. Early attempts at information systems modeling were based on mathematical graph theory [Martin 67]. Later work consisted of the development of flowchart (FC) techniques [Nassi 73] for software development and systems analysis. Further academic and commercial research resulted in a split into data oriented techniques [Chen 76] known as Entity Relationship Diagrams (ERDs) and process oriented techniques [Gane 78] known as Data Flow Diagrams (DFDs). Some attempts at empirical validation of the techniques were undertaken [Scholtz 73] and [Kammann 75]. However, no comprehensive formal research method was used to determine if these techniques truly added value to either the systems analysis or the software development process [Benbasat 89].

Thus, by the 1980's, three generalized analysis techniques–FCs, ERDs, and DFDs, were generally accepted as useful for systems and software modeling [Mumford 95]. It should be noted that DFDs were developed, along with structured programming as a means of handling system complexity. DFDs were based on the concepts of layering (a multi-level diagram approach), stepwise refinement (downward level movement shows more detail), and information hiding (total system complexity is hidden through layering and stepwise refinement).

In addition, other modeling techniques such as the REA model were developed to incorporate wider aspects of an AIS system. The REA model [McCarthy 82] is a technique for capturing information about economic phenomena. It describes a business as a set of economic resources, economic events and economic agents as well as relationships among them. In the same chronology, the process map technique (PM) was created consisting of flowchart symbols along a functional grid. A process map was a system model that showed functional areas (such as a department) along with the decisions, events, and their sequences [Rummler 86].

This paper describes an effort to empirically examine the cognitive fit between four of the aforementioned modeling techniques, which are typically part of an AIS curriculum. These techniques include DFD, PM, REA, and

Readers with comments or questions are encouraged to contact the authors via email.

FC diagrams. Although arguments are found in some textbooks regarding the advantages of a particular technique over the others, no technique appears clearly dominant. Questions persist as to which of these techniques should be taught and how they should be presented with respect to their relative merits. To date, there appears to be little specific guidance in the research literature that compares degrees of cognitive fit for the full range of graphical models. However, some studies have compared flowchart schemes and process graphs in systems development [Bergstra 93] and the use of flowcharts in program debugging [Brooke 80]. In addition, some work has been done that compares the cognitive fit of graphical and linguistic models. Dunn found that ER diagrams provided significantly better performance (in terms of time) than a linguistic informationally Backus-Naur form grammar [Dunn 00].

This research builds and tests a model based on cognitive fit as a first step in exploring the relative merits of each technique. "Cognitive Fit" is defined as the degree to which a particular diagramming technique is representative of a problem space. Assuming that fit can be quantified by the correctness of a person's responses to questions about the underlying processes as well as the length of time taken to complete a response, then an experiment can be designed to test the subjects' performance in score and time. The technique with the greatest correct response rate or the shortest time to complete the response will have the highest fit.

2. The Hypothesis, Experimental Setting, and Experimental Design

The overall hypothesis is that each modeling technique is inherently best at modeling certain system aspects. For example, the DFD has been thought to be effective in modeling data flows within processes whereas the flowchart was thought to be the best modeling technique for decision-intensive processes. An experiment was designed in an attempt to test this hypothesis. If this hypothesis were true, we would expect that the score will be the highest and/or that the time required performing the task would be the shortest for the model most fitted to the task. A better understanding of the cognitive and model aspects of a system may lead to more effective modeling methods, and thus better accounting systems.

In designing the experiment, four diagrams representing the four modeling techniques (PM, DFD, REA, and FC) were first developed, based on the same underlying systems scenario, the dispensing of drugs to patients by a pharmacy in a hypothetical hospital. Some short narratives explaining the symbols used also accompanied each diagram. Four sets of five questions aimed at testing an understanding of each of these four modeling techniques were then constructed.

Experimental subjects consisted of 195 undergraduate and 15 graduate students from universities in California and Texas. The subjects had no previous experience in any of the modeling techniques under investigation. The use of naive subjects was considered essential since their experience could contaminate the differences in efficacy among modeling techniques and thereby invalidate the experimental results. Subjects were informed that they could earn bonus points if they achieved an "unspecified" score. During a debriefing session, they were advised that the performance requirement was to induce their best effort. All participants were awarded the bonus points.

It can be argued that a subject might be able to answer the experimental questions based on the scenario context; that is, a subject may know the exact processes in dispensing drugs by a pharmacy without the help of the diagram. This possibility can potentially nullify the experiment. To eliminate this possibility and test the effect of context, we developed another set of four diagrams and four sets of five related questions *with the context removed* (each relevant entity was replaced by an abstract symbol or term).

It can also be argued that the order of the questions can potentially bias the results. For example, it is possible that the subject will pay more attention to and therefore perform better in the first few questions. In such a case, the results will be biased toward the technique related to the first set of questions. On the other hand, it is also possible that the subject will initially perform poorly because of the lack of familiarity with the tasks and will improve as experience increases. Thus, the results will be biased toward the technique related to those questions presented near the end of the sequence. To neutralize the effect of the order in which questions are presented, we used the Latin square design in which four different "blocks" of question orders are presented. Let the original four sets of questions be labeled as 1, 2, 3, and 4. This order was randomly assigned to a portion of the subjects "as is" and was termed block 1. The relative positions of the sets of questions were also switched to form different blocks. Three additional blocks (termed bocks 2, 3, and 4) were formed as follows: (4, 1, 3, 2); (2, 4, 1, 3) and (3, 2, 4, 1). Note, however, within each set of five questions, the question order remained the same. Questions in each set pertain to the same diagram and thus the order within the set should not matter because the same group aggregates the metrics used to measure the performance. To allow the subjects to become familiar with the task, two filler ("dummy") questions were added at the beginning of each block. Thus, each block retained two dummy questions plus four sets of questions totaling 22 questions.

The experimental design included two contexts (with and without), four diagrams, and four blocks of question orders, resulting in 8 treatments presented in 4 different orders (to reduce error variation) or 32 possible combinations[1]. The experiment was conducted using a website. Each subject was instructed to log on the website and answer the 22 questions of a randomly assigned block. Answers to the questions (with the resulting score) and decision time were recorded. When a subject logged on, a random number in the range of 1 and 32 was drawn "without replacement" and the associated context-diagram-block combination was presented to the subject. This was done to attain randomness and ensure an even distribution of subjects among these combinations at the same time. When one cluster of 32 random numbers ran out, another cluster was started. A progress marker for each subject was maintained so that the subject would continue at the same point in the event of an interruption. The design framework is summarized in Table One.

Table 1
Experiment Design

Panel A: Treatments

Model Type	**Context Provided**	**No Context Provided**
Process Map (PM)	**Score** **Time**	**Score** **Time**
Data Flow Diagram (DFD)	**Score** **Time**	**Score** **Time**
Resources, Events, Agents (REA)	**Score** **Time**	**Score** **Time**
Flowchart (FC)	**Score** **Time**	**Score** **Time**

Panel B: Block Randomization of Question Order (Non-Treatment)

Model	Random Block 1	Random Block 2	Random Block 3	Random Block 4	*Total*	Percent
PM	12	12	14	12	*50*	23.9
DFD	14	13	13	14	*54*	25.7
REA	14	15	12	12	*53*	25.2
FC	13	13	15	12	*53*	25.2
Total	*53*	*53*	*54*	*50*	*210*	100

Where blocks of questions were presented in the following order:

Random Block	Questions 3-7	Questions 8-12	Questions 13-17	Questions 1 8-22
RB 1	1	2	3	4
RB 2	4	1	3	2
RB 3	2	4	1	3
RB 4	3	2	4	1

Panel C: Numbers of Subjects in Each Treatment

Model	No Context	Context	*Total*
PM	25	25	*50*
DFD	28	26	*54*
REA	24	29	*53*
FC	28	25	*53*
Total	*105*	*105*	*210*

Since each subject was asked the same questions but only saw a particular diagram, it was hypothesized that subjects would perform better (have a higher score and take less time) in answering those questions which elicited information related to the model type.

A more detailed description of the interaction between the subject and the website is in order. Subjects gain access to the experiment via an ID number and name. In addition, they are asked to identify an instructor (so that proper bonus points could be given). Upon successful login, subjects are presented with a diagram and accompanying explanatory narratives. The choice of diagram is randomized as described earlier. A separate frame contains instructions to the subject about how to proceed and is used to display questions when an onscreen button is clicked. Thus, the subject is able to see the assigned diagram for the duration of the question-answer interaction. The software records the answer and the time taken for a subject response to each question. Again, question presentation is randomized as previously described. Upon completion of the 22 questions, a "thank you" note and additional follow up questions were displayed. The questions solicited the subject's feedback regarding the clarity of the diagram and questions.

3. Results

The overall hypothesis can be divided into four individual hypotheses, each pertaining to an individual technique. Using the full data set consisting of context and no context responses, we tested the following hypotheses based on the questions geared toward each diagramming technique.

H1A: For questions related to process, the process-modeling diagram will outperform other techniques in terms of time.
H1B: For questions related to process, the process-modeling diagram will outperform other techniques in terms of score.

H2A: For questions related to data, the data flow diagram will outperform other techniques in terms of time.
H2B: For questions related to data, the data flow diagram will outperform other techniques in terms of score.

H3A: For questions related to database records and tables, the REA diagram will outperform other techniques in terms of time.
H3B: For questions related to database records and tables, the REA diagram will outperform other techniques in terms of score.

H4A: For questions related to system document flow, the flowchart diagram will outperform other techniques in terms of time.
H4B: For questions related to system document flow, the flowchart diagram will outperform other techniques in terms of score.

4. Time Results

Table 2 shows the mean values of all data of the two metrics cross-tabulated by diagram and by question set. Table 3 shows the ANOVA results of these hypotheses with respect to time. Only the test of the second hypothesis shows significance; that is, those subjects who were given the DFD used significantly less time to answer the questions related to modeling flow of data, as expected. The first, third and fourth hypotheses were not supported.

Contrary to hypothesis H3A, subjects given the FC took significantly less time to answer questions pertinent to the data modeling tasks (Q13-17), hypothesized for the REA diagram to outperform. Also, subjects with PM took significantly less time to answer questions hypothesized for the FC to outperform (H4A; Q18-22). Table 3 also showed that the presence of context was a significant factor in time spent for questions hypothesized for the REA diagram (Q 13-17). Table 3 also shows significance for PM and DFD on "decision intensive" questions hypothesized for the FC to outperform (Q 18-22). PM actually required significantly less time to complete these questions, while the DFD took significantly more time to complete the same. These results are puzzling. Apparently, the time metric alone does not completely predict performance. To gain additional insight into the effect of context, time data were divided into two sets by context and analyzed separately. The results are given in Table 4.

Table 2

MEAN Time Used; MEAN Score (All Data: Context and No Context)

Question Set (Model)	Mean Time Used	Mean Score (Percent Correct)	Chi-Sq (Score)
Questions 3-7 (PM)			
PM	40.366	**.66**	45.85
DFD	40.363	.46	
REA	43.772	.31	P < .000
FC	**38.903**	.22	Sig.
Total For Question Group	40.855	.41	
Questions 8 12 (DFD)			
PM	42.603	.38	18.76
DFD	****33.327**	**.49**	
REA	**45.660	.22	P < .000
FC	38.767	.28	Sig.
Total For Question Group	40.021	.34	
Questions 13 – 17 (REA)[1]			
PM	43.678	.35	5.45
DFD	43.372	.31	
REA	43.039	**.41**	P = .14
FC	****37.487**	.26	Not Sig.
Total For Question Group	41.876	.33	
Questions 18 – 22 (FC)			
PM	****34.216**	.52	30.68
DFD	**45.237	**.60**	
REA	39.555	.23	P < .000
FC	37.584	.44	Sig.
Total For Question Group	39.248	.45	

** Statistically significant (See Table 3)

[1] From Table 3 we learn that Context matters for this block of questions.

Table 3
ANOVA Results (Time) (All Data)

	Variable	F	P-Value	Significant?
Questions 3-7 (PM)	Context	.023	.881	No
	PM	.050	.823	No
	DFD	.056	.813	No
	REA	1.921	.166	No
	FC	.860	.354	No
Questions 8-12 (DFD)[2]	Context	2.671	.103	No
	PM	1.521	.218	No
	DFD	11.431	.001	Yes
	REA	7.883	.005	Yes
	FC	.387	.534	No
Questions 13-17 (REA)[3]	Context	4.531	.034	Yes
	PM	.727	.394	No
	DFD	.555	.456	No
	REA	.327	.568	No
	FC	4.672	.031	Yes
Questions 18-22 (FC)[4]	Context	.222	.637	No
	PM	4.576	.033	Yes
	DFD	7.201	.007	Yes
	REA	.018	.892	No
	FC	.538	.463	No

[2] Putting Table 2 together with Table 3 we learn that DFD took significantly LESS time for Questions 8-12 (this supports our ex ante hypothesis) and REA took significantly MORE time for Questions 8-12.

[3] Putting Table 2 together with Table 3 we learn that FC took significantly LESS time for Questions 13-17. It was hypothesized that REA would take less time here. Our hypothesis is not supported but the evidence suggests that FC might be cognitively suited for this type of tasks. Also note that Context is significant here so Table 4 is introduced to tease out these effects.

[4] Putting Table 2 together with Table 3 we learn that PM took significantly LESS time for Questions 18-22 and DFD took significantly MORE time for these questions. It was hypothesized that FC would take less time here. Our ex ante hypothesis is not supported but the evidence suggests that PM might be cognitively suited for this type of task.

Table 4
ANOVA Results for Hypothesis 3, Mean Time and Mean Score: No Context/Context Data

Questions 13-17 Variable	F	No Context Data P-Value	Significant?
PM	.251	.616	No
DFD	3.551	.060	Yes
REA	.448	.504	No
FC	2.994	.084	Yes

Questions 13-17 Variable	F	Context Data P-Value	Significant?
PM	.524	.469	No
DFD	1.281	.258	No
REA	3.044	.082	Yes
FC	1.981	.160	No

Questions 13-17 Chart	No Context Mean Time	Context Mean Time	No Context Mean Score*	Context Mean Score
PM	45.983	41.373	.32	.38
DFD	49.932	36.308	.29	.33
REA	42.199	43.734	.27	**.53
FC	39.292	35.466	.24	.30
Totals	44.387	39.365	.28	.39

* Not significant
** p < .001
Without context FC is significantly LESS time and DFD is Significantly MORE Time. It was hypothesized that REA would be significant here. But the evidence suggests that FC might be cognitively suited for this task when no context is present. With context the results are as hypothesized.

The first panel shows that with no context, subjects given the DFD and FC took significantly shorter time to respond to data modeling questions, while the second panel shows that subjects who were given the REA diagram took significantly "different" time length to complete the relevant questions. The bottom panel, however, indicates that the "significance" was in the "wrong" direction; that is, subjects who were given the REA diagram (with context) took much longer time to complete the data modeling questions! Thus, if the time metric is used exclusively to interpret the results, the conclusion would be that the REA model fails the "cognitive fit" test because it takes longer using the REA diagram to perform the tasks that the diagram is expected to perform well.

5. Score Results

However, the rightmost column of the bottom panel of Table 4 offers a completely different perspective. Subjects with the REA diagram were able to score much higher than subjects with other "with context" diagrams. This conflicting evidence raises several interesting questions. How were the subjects with other diagrams able to "achieve" shorter time in responding to questions pertaining to data modeling? Could it be that they could not find clues from the diagrams and therefore they simply guessed? Or, could it be that the REA diagram (with context) is inherently more complex and therefore requires more time for additional "analysis" before the subjects were able to arrive at the correct answers? However, if this were the case, why did the diagram with no context fail to show consistent results in accuracy? (Note that the set of questions pertinent to data modeling do not appear to call for any information that is "context intensive.") Additional research appears necessary and desirable to answer these questions.

Table 5
Panel A: CHI-SQUARE Results (Score) No Context

	Variable	Correct	Incorrect	% Correct	Chi-Sq
Questions 3-7 (PM)	PM	86	39	**69**	80.659
	DFD	57	83	41	
	REA	31	89	26	P < .000
	FC	26	114	19	Sig.
Questions 8-12 (DFD)	PM	43	82	34	19.780
	DFD	66	74	**47**	
	REA	27	93	23	P < .000
	FC	40	100	29	Sig.
Questions 13-17 (REA)	PM	40	85	32	2.576
	DFD	41	99	29	
	REA	32	88	27	P = .422
	FC	33	107	24	Not Sig.
Questions 18-22 (FC)	PM	62	63	**50**	41.359
	DFD	74	66	**53**	
	REA	21	99	18	P = .001
	FC	49	91	35	Sig.

Panel B: CHI-SQUARE Results (Score) All Data

	Variable	Correct	Incorrect	% Correct	Chi-Sq
Questions 13-17 (REA)	PM	87	163	35	13.802
	DFD	84	186	31	
	REA	109	156	**41**	P = .003
	FC	70	195	26	Sig.

Chi-Square tests with all data were run for each question block. The inferences do not change for the other question blocks. But for Questions 13-17, hypothesized to be best suited for the REA model, this hypothesis is weakly supported with all data included but not supported when context data is removed. Suggesting that the REA model, in particular, is sensitive to context and, when context is included, may be best suited for questions type 13-17.

Hypothesis 1, 2 & 3 are supported. Hypothesis 4 is not supported (FC should have outperformed the other models) but the evidence indicates that PM and DFD might be best suited for tasks in Questions 18-22.

Table 5 shows the Chi square results by individual chart. These results clearly indicate that PM and DFD performed as hypothesized using scores as the metric. Consistent with the time analysis, PM scored significantly higher than FC on the “decision intensive” questions (Q18-22; hypothesized for FC). The DFD also outperformed the FC in this respect. The combined time and score results raise questions as to the usefulness of FC for systems analysis. A possible interpretation is that the PM could be used in place of FC in “any” circumstances. An alternative interpretation is that questions designed for FC might have been better handled by the other two techniques. However, although the possibility exists, additional questions remain. With this interpretation, the questions (tasks) could be “jointly” suitable for both the PM and DFD techniques in terms of accuracy. However, no other evidence in this study appears to provide similar clues. Recall that, with the DFD, subjects took significantly more time to complete this set of questions. Why did this technique perform well in one metric and yet poorly in another and what are the implications of these results? These results pose an interesting set of issues for further exploration.

As previously discussed, with context, the REA model scored higher than other techniques. The same results were not obtained with the "no context" data as shown in Table 5, Panel A. However, the Chi square analysis Panel B shows that the combined data (with and without the context), this model still significantly outscored the other techniques on the questions relevant to data modeling (Q13-17). Apparently, the results were sensitive to the context. The possible causes for such an effect call for additional research.

6. Conclusion

This paper describes a first attempt to empirically examine the efficacy of four popular accounting information system diagramming techniques. The primary objective of the study was to measure the relative value of the techniques in a controlled experimental setting. The experimental design contained treatments consisting of diagramming techniques and the presence (or absence) of a context narrative.

The results indicated that the process mapping technique (PM) appears to be suitable for the tasks requiring an analysis of process as measured by score. These were the strongest results in this study; with a 66% correct response rate on the process analysis question block. The data flow diagram (DFD) appears to be suitable for data relevant tasks as measured by both time and score. The REA model significantly outscored other techniques on database records and tables related tasks when the problem context was present. However, the reasons why the context had an effect were not clear. Perhaps an equally interesting question is why context did not matter in the other models and question blocks. Additional research is needed to provide further insight. The flowchart (FC) was outperformed by either PM (in time) or both PM and DFD (in score). A preliminary suggestion is that either PM or DFD can be used in place of FC. Alternatively, the suitability of those questions used in the experiment may need additional examination.

Perhaps, the most puzzling results came from the time analysis for the REA model. Subjects who were given the REA diagram (with context) took significantly longer time to perform tasks related to database records and tables but achieved significantly higher scores. Without context all four models performed about the same on this block of questions. Absent other evidence, we believe the score is a more reliable metric since it measures the subjects' accuracy in performing the relevant tasks. However, it does not mean that time is not a reliable metric because it appears to show consistency with respect to measuring the performance of other techniques. Perhaps, the inherent complexity of the REA diagram was the cause for the additional time. Additional empirical work with follow up questions that focused on this aspect might provide further insight.

The use of a website as the experiment and data collection instrument is an interesting aspect of this study. Its use eliminated the need for many manual tasks in encoding and assembling the data, especially when the subjects were in separate geographical locations. It also allowed the subjects the flexibility of performing the experiment at their convenience. The subjects were told to complete the experiment within a few days after the instruction was given. However, there might be some "experimental control" issues unknown to the researchers and yet deserving their attention. It is difficult to know with certainty that the subjects were novices, a critical component of this research[2]. To the extent that a subject was familiar with one or more of the models a confounding variable is introduced that may make it difficult to interpret cognitive fit.

7. Suggestions for Further Research

In addition to the above various hints for additional research, this study can be extended in several ways. Previous research has found learning effects for a more complex technique [Wang 96]. The REA model appears to be more complex than the other diagramming techniques. It will be interesting to investigate the effects of learning on the relative performance of these techniques. Also, this current study allows the subjects to respond to questions under an uncontrolled environment. A study with a controlled setting can help to identify issues not known in that study and may yield additional insight. Finally, the finding that the flowchart (FC) was outperformed by PM and DFD may suggest that the three techniques belong to the same type of system development methodology. According to Vessey and Glass [94], system development methodologies can be classified into process-based, data-based, and object-based. They argue that each type of methodology fits better for its respective application domain. Additional empirical study to test these techniques' substitutability for each other can be of great interest. 🕮

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Endnotes

[1] Note there are not 32 treatments. We do not measure or hypothesize any effect due to variations in presentation order. Rather, questions are presented in different order as a randomization technique to reduce error variation that might be caused by fatigue or similar, nuisance variables. Thus, there are only 8 treatments (4 models, context versus no-context).

[2] While, in practice, most users would be familiar with these modeling methods, experience on the part of users would introduce a confounding effect that would make it impossible to measure cognitive fit. The use of naive student subjects is viewed as an important asset of this research.

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