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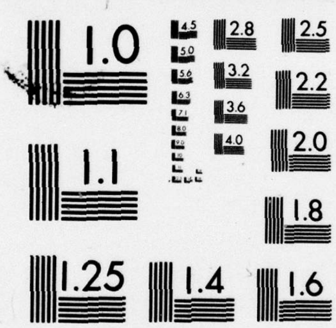

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Research Report

PRESENTATION AND REPRESENTATION IN DESIGN PROBLEM SOLVING

John M. Carroll
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ABSTRACT

Two experimental studies of design problem solving are presented. Eighty-one subjects worked on one of two design problems that were isomorphic in structure: a schedule for stages in a manufacturing process or a layout for a business office. In Experiment 1, a difference between problem isomorphs is obtained: the "spatial" office layout problem obtains better performance and shorter solution times than the "temporal" scheduling problem. In Experiment 2, this difference attenuates when subjects are provided with a graphic representation in both isomorph conditions. The availability of a graphic representation is discussed as an aid for procedural design.

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Introduction

Variables of presentation and representation have received considerable attention in studies of human problem solving. Schwartz (Polich & Schwartz, 1975; Schwartz, 1971) has shown that making a graphic means of representing solutions available improves subjects' performance in deduction tasks. Reed, Ernst, and Banerji (1974) and Simon and Hayes (1976) have shown that subjects' performance can differ for logically isomorphic versions of certain problems, when those versions are presented with different "cover stories".

The present study explores the variables of presentation and representation in a "design" problem solving task environment. Design problem solving belongs to that relatively under-studied area of human problem solving that Reitman (1965) associated with "ill-structured" problems. Problem-solving behavior in this domain characteristically <u>cannot</u> be minutely specified as a set of moves, selected from a small and finite set of possible ones, and applied in sequence to a precisely defined initial state in order to derive a unique final or goal state.

A designer, typically, <u>does</u> <u>not</u> know in advance what the goal state will be, although he usually has criteria to evaluate potential goal states. Indeed, the designer often does not even have a definition of the initial problem-state, or of the allowable moves. Simon (1973) contends that the formal and behavioral analysis of ill-defined problems, such as design problems, can be accomodated by the theoretical apparatus developed already to treat well-defined problems (e.g., Newell and Simon, 1972) -- but little argument and no empirical evidence is adduced to this claim.

The possibility exists, however, that there <u>are</u> substantive differences between well-structured and ill-structured sorts of problem solving. Much of "ordinary" (i.e., real world) problem solving is concerned with ill-structured, and not well-structured, problem situations. Thus, an analysis of human problem solving that treats only the well-structured sort certainly risks being an inadequate analysis. One important task for human problem solving research is to extend the existent analyses of well-structured problems to the domain of ill-structured problems.

The two experiments described here address presentation and representation in a design problem solving environment. Presentation is manipulated in two ways. First, we contrast a "temporal" presentation of the problem with a logically isomorphic "spatial" presentation. Second, we compare three different sequencings in which problem information can be presented to the problem solver. Representation is addressed by comparing performance of subjects who are provided with a graphic means of representing their solutions (Experiment 2) with that of subjects not provided with a means representation (Experiment 1). Subjects in Experiment 1 expressed their design solutions in any way they wanted. Subjects in Experiment 2 solved the same design problems, but expressed their solutions using a prescribed graphic representation scheme.

EXPERIMENT 1

In Experiment 1 subjects were presented with one of two isomorphic variations of a design problem: a temporal isomorph and a spatial isomorph. The various design requirements comprising the problem were presented to subjects in one of three sequencings, varying from highly structured to unstructured. The experiment attempted to test for effects of sequencing and isomorph on the dependent variables of performance success and solution time.

Method

Problem Isomorphs. The design problem was presented to each subject in one of two isomorphic versions. The cover story for the temporal isomorph involved designing a manufacturing process for "widgets", which manufacturing process consisted of seven stages. Each stage was to be assigned to a factory shift, at a particular priority level (if workers get behind during their shift, they do the higher priority work first).

To obtain the spatial cover story, we replaced key content words of the temporal cover story with "spatial" words. The spatial cover story involved designing a business office layout. The office was to accomodate seven employees. Each employee was to be assigned to a corridor a certain number of offices down from a central hallway (workers who are higher in prestige prefer to have their offices nearer to this central hallway).

Both problems were defined by a set of 19 "functional requirements". These consisted of six of each of three types of relation, plus a "compactness goal". In the spatial isomorph condition, the three relations that could occur between entities were: (1) "is compatible (incompatible) with", (2) "has more (less) prestige than", (3) and "uses the accounting records (meets people in the reception area) more than". In the temporal isomorph condition, the corresponding relations were: (1) "uses different (the same) resources than (as)", (2) "is a higher (lower) priority manufacturing stage than", and (3) "should follow (precede)". The following are examples of relations in the temporal isomorph problem statement:

F is a higher priority manufacturing stage than B.
A should follow stage C.

G uses different resources than F.
Subjects were presented with a total of 18 such relations (3 types X 2 polarities -- e.g., precede versus follow -- X 3 of each).

There was one further goal given to the subjects, the compactness goal. In the temporal isomorph, they were told to minimize the total number of shifts in which they organized the stages comprising the manufacturing process. In the spatial isomorph, they were told to minimize the total number of corridors in which they organized the seven offices. Thus, subjects were asked to "compact" their design solutions, restricting the total number of shifts or corridors they posited. (The 19 functional requirements for both isomorphs are presented in the Appendix.)

It is important to note that the 19 functional requirements of the design problem involved "trade-offs". For example, the temporal isomorph subjects were told that "C should precede stage F", that "G uses different resources than F", and that "D should follow stage G". Now, if G uses different resources than F, it ought to scheduled for the same shift as F (for optimal efficiency, see below). And, since C should precede stage F (and therefore stage G) and D should follow stage G, we can conclude that C precedes D. However, our subjects also got the functional requirement "C uses different resources than D". This requirement can be optimally satisfied only if D and C are scheduled for the same shift, which conflicts with the other requirements.

As a result of these trade-offs, there is no perfect solution to the design problems we used -- there is no solution that necessitates only one shift (or corridor) and satisfies all 18 of the remaining functional requirements. In fact, even ignoring the compactness requirement, there is no possible solution which satisfies all of the remaining 18 requirements. There are, of course, better and poorer solutions (see below), but as far as we can tell, there is no unique optimal solution either. This situation is typical of ill-defined problem environments. Subjects were encouraged to find the best possible solution, given the inherent trade-offs of the problems.

Sequence of Presentation. The initial cover story was about one and a half typed pages in length for both isomorph conditions, and comprised the first two pages of a booklet given to subjects to read at their own pace. Following this cover story, the 19 functional requirements were distributed over the next four pages of the booklet. On each page, the subject was presented with 6 of the 18 relations or with the compactness goal. There were three possible presentation sequences for the 19 functional requirements.

In the Hierarchical Presentation (HP) condition, page 3 contained a statement of the overall goals of the design problem. Thus, in the temporal isomorph problem statement subjects were told that the organization of the manufacturing process should be "efficient" and "effective". Efficiency, they were told entailed (1) that the total number of shifts required by the process should be minimized and (2) that processes that could be scheduled for the same shift (i.e., processes that use different resources) should be. Effectiveness, they were told, meant (3) that stages should be optimally sequenced (i.e., stages should follow or precede one another as specified) and (4) that priorities should be taken into consideration in the schedule. Each of the four following pages of functional requirements elaborated one of these goals. (An isomorphic set of goals were presented to subjects in the spatial HP condition.)

The Clustered Presentation (CP) condition was like the HP condition except that the statement of overall goals was not included. Thus, subjects in the CP condition were given no explicit framework for the 19 functional requirements, although their four pages of functional requirements were thematically clustered vis-a-vis these overall goals.

The Non-structured Presentation (NSP) condition, like the CP condition, lacked an overall statement of the goals of the design problem. In addition, however, the 18 relations were "jumbled". Hence, instead of getting all of the six requirements pertaining to the use of resources on a single page of the booklet, subjects in the NSP condition were presented with three requirements pertaining to resources mixed with three pertaining to priority. On a subsequent page the were presented with the three remaining resources requirements, this time mixed with three temporal sequencing (precede/follow) requirements.

Design, Subjects, and Procedure. The design of the experiment was a 3 X 2 factorial, whose factors were "sequence of presentation" (HP, CP, and NSP) and "isomorph presentation" (spatial and temporal).

A total of 36 students from small local colleges participated in the experiment. The subjects were run in groups and were paid for their participation. Each subject was assigned to one of the six conditions. Subjects were given a booklet, and asked to read the first two pages of general instructions. After studying the instructions, subjects were invited to ask questions concerning the experiment. The experimenter reviewed the contents of the instructions, and then allowed subjects to proceed to page 3 of the booklet. At this point, subjects started work on the design problem.

Subjects worked at their own pace. On each page of the booklet they were presented with additional information (further functional requirements) and asked to "design" a solution to the problem on the basis of what they then knew. Subjects were not instructed as to how their design solutions should be expressed, they could express their solutions in any way they choose. It was emphasized that these "intermediate solutions" were very important to the purpose of the experiment and that they should be taken as seriously as the final solution which the subject would ultimately design when all of the information had been presented. While working on any given page of the booklet, subjects were permitted to turn back to any previous page of the booklet, to review their previous work, to review the instructions, or to check on functional requirements presented earlier. They were forbidden to change any of their previous work or to look ahead in the booklet.

After all of the functional requirements were presented, the subject was asked to give a final solution (page 8 in HP, page 7 in CP and NSP). The final two pages of the booklet consisted of a questionnaire, asking subjects about their strategies, feelings about the experiment, and previous designing experience. (There were no gross differences between subject samples.) The entire experimental session took about two hours.

Scoring. Subjects' solutions were scored for both performance and solution time. Performance was scored by giving one point for each of the 18 functional requirements satisfied. The compactness requirement was scored by giving 4 points if the subject's solution consisted of 2 shifts (corridors), 2 points if it consisted of 3 shifts (corridors), and 1 point if it consisted of 4 shifts (corridors). No subject produced a solution consisting of more than four shifts (corridors). The compactness requirement was weighted in this way in order that it would count about equally with the other three pages of functional requirements which presented six functional requirements each. In general, a good score for the other groups of functional requirements was a 4, more rarely a 5, (out of 6), with scores ranging down to 1, and in a few cases 0.

To measure solution times, the experimenter began timing when the subjects turned to the third page of the experimental booklet and marked the elapsed time as each subject completed the final design solution.

Results and Discussion

One subject failed to complete the experiment and was discarded from the analysis. The summary data for the remaining 35 subjects is presented in Table 1.

Table 1
Mean Performance Scores and Solution Times:
Experiment 1

	Spatial Isomorph		Temporal Isomorph	
	Performance Scores	Solution Times	Performance Scores	Solution Times
Hierarchical Presentation	13.00	42.00	7.17 (8.20)	43.50 (43.20)
Clustered Presentation	11.50	38.83	10.33 (10.33)	44.00 (44.00)
Nonstructured Presentation	11.83	34.60	7.50 (9.25)	51.67 (55.00)
Overall	12.06	38.50	8.33 (9.33)	46.39 (47.33)

Analyses of variance for the 2 X 3 factorial of isomorph by sequence were computed for the performance and solution time measures. We used the Method of Expected Equal Frequencies (Ferguson, 1971, pages 238-239), since there was a missing observation in one cell.[1] This ANOVA is justified insofar as the $\underline{X}^2$ of expected cell frequencies does not depart from chance. In the data to be reported all $\underline{X}^2$ values fail to reject the null hypothesis. In each case, we report the obtained $\underline{X}^2$ in parentheses.

For performance scores ($\underline{X}^2$ (5) = .14), a significant main effect of problem isomorph obtains $\underline{F}$ (1, 29) = 12.99, $\underline{p}$ < .001. This reflects the fact that subjects in the spatial isomorph condition had higher performance scores. The effect of sequence (HP vs. CP vs. NSP) and the interaction effect are both non-significant. For the solution time data ($\underline{X}^2$ (5) = .26), the factor of problem isomorph is again significant, obtaining $\underline{F}$ (1, 28) = 7.01, $\underline{p}$ < .025.[2] Subjects in the spatial isomorph condition obtained shorter solution times than temporal isomorph subjects. The main effect of sequence is again non-significant, but the interaction effect is nearly significant, $\underline{F}$ (2, 28) = 2.47, $\underline{p}$ < .10. Temporal subjects obtained shorter solution times with more structured sequence of presentation (i.e., they were faster in the HP condition than in CP and NSP, and faster in CP than in NSP). Spatial isomorph subjects, in contrast, were <u>slower</u> in the more structured conditions.

Close inspection of the comments of three subjects revealed that they did not properly understand the experimental task. That is, they did not seem to understand the relations, like "priority" and "sequence", upon which the problem's functional requirements were defined. Since all three of these subjects belonged to the temporal isomorph group, this discovery raises questions about the effect of problem isomorph just cited. In order to clarify this matter, we performed further analyses of variance, discarding the data of these three subjects as "comprehension failures".

For the performance data (X^2 (5) = .63), the main effect of isomorph presentation persists, F (1, 26) = 9.35, $p <$ .005. There is no effect of sequence of presentation and no interaction. For solution time (X^2 (5) = .55), we also still obtain a main effect of the isomorph presentation factor, F (1, 25) = 9.70, $p < .005$. There is, again, no main effect of sequence of presentation, but a nearly significant interaction term, F (2, 25) = 3.12, $p < .10$.

In summary, the results of Experiment 1 seem to show a reliable difference between the two isomorphic versions of the design problem: the temporal isomorph is solved more slowly and less successfully than the spatial isomorph. On the other hand, our "sequence of presentation" variable obtained only a marginal effect on solution time and no measured effect on performance.

It is notable that all of the 17 subjects in the spatial isomorph group used a graphic representation (a layout drawing) of the business office in the course of solving the design problem. However, only two of the temporal isomorph subjects used such a representation. Nine others produced a discursive listing of facts pertaining to the final manufacturing schedule, and the remaining 4 (not counting comprehension failures) employed discursive paragraphs. The fact that a graphic representation for problem information and solutions is more readily available in the spatial isomorph condition may be causally related to the fact that subjects in the spatial condition have higher performance scores and shorter solution times. This interpretation is encouraged by Schwartz's (1971) finding that graphic representations can function as problem solving aids.

Alternatively, the isomorph difference we measured might reflect fundamental conceptual differences between time and space. This possibility is encouraged by the fact that all of the three "comprehension failures" we recorded were from the temporal isomorph presentation. (If there were some bias in the materials, the temporal isomorph would have been expected to be more easily comprehended since it, and not the spatial isomorph, was the source pattern for both problem statements.)

EXPERIMENT 2

Experiment 2 attempts to further clarify the basis of the isomorph differences discovered in Experiment 1; in particular, to characterize the role which the availability of a representation might play in creating this difference. In Experiment 2, subjects were provided with and trained to use a graphic representation. If the performance and solution time isomorph differences of Experiment 1 were due to the relative availability of a graphic representation, this manipulation should attentuate the differences. If, on the other hand, the isomorph differences were based in more fundamental conceptual differences between the two problem versions, the isomorph difference should persist.

Method

Design and Materials. Experiment 2 has the same 3 X 2 factorial design as Experiment 1. In fact, the materials for the two experiments were identical with one exception. In Experiment 2, subjects were provided with a matrix representation in which they were to record their intermediate and final design solutions. An example of this matrix is given in Figure 1.

Figure 1
Caption: Example of matrix representation provided to subjects in Experiment 2.

In the spatial isomorph problem statement, the horizontal dimension in the matrix was the office's position with respect to the accounting records and reception area (accounting record at the extreme right, reception at the left). The vertical dimension was defined as corridors containing offices, the very top row of the matrix was defined as bordering the central hallway (near to which higher prestige employees like to have their offices). Thus, within a column of the matrix height represents prestige. In Figure 1, A is closer to the accounting records than B and C. B and C are located on the same corridor, and C has greater prestige.

In the temporal isomorph, the horizontal dimension was a time line -- columns to the right are "earlier" than columns to the left. Columns themselves represented "shifts", and height in a column represented "priority". Thus, in the example A is scheduled two shifts before C and B. C and B are scheduled for the same shift, and C has been assigned higher priority.

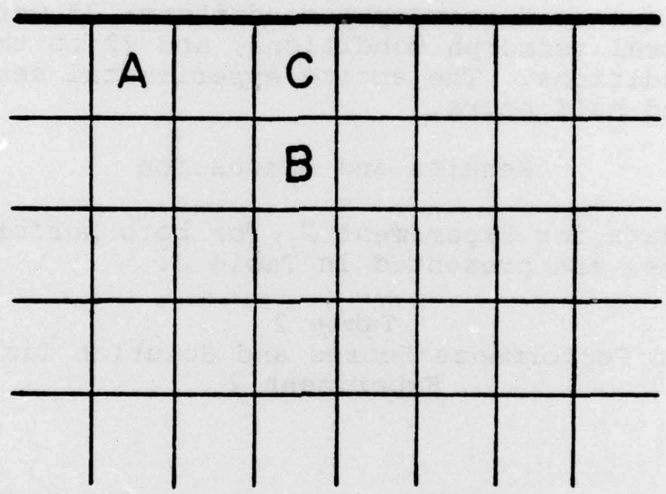

Figure 1

The initial two pages of the experimental booklet were modified to explain and illustrate the use of this representational scheme (adding another half page of material to the instructions). Each succeeding page of the booklet (intermediate solutions and final solutions) had a blank matrix printed out on it. Subjects were asked to record their design solutions in the matrix.

In all other ways, the materials for the two experiments were identical.

Procedure. The procedure for Experiment 2 was identical to that of Experiment 1 with the exception that the experimenter also explained the representation in the initial instruction period. A total of 45 subjects participated in the experiment. They were drawn from the local college student population, and were each paid for their participation. Either 7 or 8 subjects were randomly assigned to each of the 6 (sequence X isomorph) conditions: 23 were assigned to the temporal isomorph conditions, and 22 to the spatial isomorph conditions. The entire experimental session took about two and half hours.

Results and Discussion

Summary data for Experiment 2, for both performance and solution time, are presented in Table 2.

Table 2
Mean Performance Scores and Solution Times:
Experiment 2

	Spatial Isomorph		Temporal Isomorph	
	Performance Scores	Solution Times	Performance Scores	Solution Times
Hierarchical Presentation	13.14	65.14	11.25 (12.00)	62.25 (55.67)
Clustered Presentation	12.71	53.14	11.71 (12.00)	67.57 (64.17)
Nonstructured Presentation	12.50	62.29	10.00 (11.00)	71.63 (69.33)
Overall	12.77	60.19	10.96 (11.67)	67.13 (63.06)

We analyzed the data from Experiment 2 by the same ANOVA procedures used to analyze Experiment 1. For the performance data (X^2 (5) = .20), a significant main effect of problem isomorph obtains, F (1, 39) = 5.13, $p < .05$. There is no significant effect of sequence and no interaction. For solution time (X^2 (5) = .18), however, there are no significant treatment effects in the ANOVA.[3]

When we inspected the comments and intermediate solutions of our subjects, we again found cases of apparent comprehension failure. A total of five such cases were detected. Since all five of these cases belonged to the temporal isomorph groups, we performed further ANOVA's discarding the data of these subjects. For performance (X^2 (5) = .50), there are no significant main effects or interactions (for the effect of problem isomorph, F (1, 34) = 1.88, $p < .2$). For solution time (X^2 (5) = .23), there are also no significant effects.

In sum, when subjects are provided with a graphic representational scheme, differences in performance and solution time between the spatial and temporal problem isomorphs diminish. Accordingly, the relative availability of a graphic representation does emerge as an effective difference between the spatial and temporal isomorphs. We base these conclusions, of course, on an acceptance of the null hypothesis, something one generally wants to avoid. However, if an isomorph difference as strong as that we measured in Experiment I had been present in Experiment II, a power analysis estimates that the probability of our finding it would be at least .97.

Providing temporal subjects with a graphic representation does not collapse all isomorph differences. The tendency for temporal isomorph subjects to experience greater comprehension problems than the spatial isomorph subjects, noted in discussion of Experiment 1, is still apparent. In fact, the tendency for temporal isomorph subjects to experience "comprehension failure" is significantly different from chance, $p < .005$, by Sign Test, pooling across both experiments. Five of 23 subjects in the temporal group in Experiment 2 (and 3 out of 18 in Experiment 1) failed to adequately comprehend the problem, while none of the 22 subjects in the spatial group fell into this category.

General Discussion

First, we will comment on the failure of the present study to detect an effect of sequence of "presentation", then we will discuss the effects of isomorph "presentation" and "representation" that were detected. The sequence variable was intended to manipulate the degree to which the implicit goal structure of the design problems were made apparent to the subject-designer. In the HP condition, these goals were explicitly spelled out. In the CP condition, they were implicit in the clustering of the functional requirements vis-a-vis the pages of the experimental booklet. In the NSP condition, the goal structure was obscured.

Since we find no effect of sequence, one might want to conclude that the transparency of a design problem's goal structure doesn't matter -- at least in the case of our design problems. Perhaps the design problem is too artificial and the subjects were just manipulating the A, B, C, ... entities formally and ignoring the details of the cover story. However, neither the obtained differences between isomorphs, nor the comments subjects spontaneously rendered are consistent with such an "artificiality" argument. Subjects often wrote notes on their solutions like "B is incompatible with everybody, I'll have to put him off by himself." These observations suggest that subjects were involved with the cover story, and indeed, that to some extent they approached the design problem as if it were a real world problem.

It is also possible that the particular presentation sequences we contrasted are largely ineffective, but that some other sequence manipulations might indeed control performance and solution time variables. For example, it might be the case that sequence of presentation variables are effective when they effectively structure a complex problem into "sub-problems" (Thomas, 1974). Our three sequence conditions equally did not allow the overall design solution to be independently decomposed into sub-problems. Perhaps significant effects would have been found with a sequence manipulation in which subjects could, for example, design the organization of shift number one based on the information they are presented with on page one of the booklet, shift number two based on information they receive on page two, etc. Each shift could be designed (almost) independently of any other shift. Such a sequence manipulation might obtain an effect on performance and solution time measures in contrast to a set of sequencings which force subjects to reanalyze their entire design each time they received new information (i.e., like the sequence conditions in the present study). This possibility remains for further research. (See Carroll, Thomas, Miller, & Malhotra, 1978, for work along these lines.)

Since providing subjects with a representation mitigates the effect of the problem isomorph variable reported in Experiment 1 vis-a-vis the spatial and temporal versions, it seems that the difference between the two isomorphs can be attributed, at least in part, to the relative availability, or accessibility, of representations. Thus, it is argued that a representational scheme is more available to subjects in the spatial condition, and they are therefore able to solve the problem faster and with greater success

(Experiment 1). However, when subjects in both conditions are provided with an equally powerful graphic representation, differences between the two isomorph conditions attenuate (Experiment 2).

Comprehension failures, however, are no less common in the temporal isomorph group of Experiment 2 than they are in the temporal group of Experiment 2. Hence, at least one difference between the spatial and temporal isomorphs is not neutralized by making a representation available. It appears that while the availability of a representation may differentiate the two isomorphs with respect to "problem solution", it does not differentiate them with respect to "problem understanding". That is, having a graphic representation seems to make the problem easier to solve, but not easier to understand (but cf. Mayer, 1976). It is still relatively more difficult to understand the temporal problem (as indexed by comprehension failures) in both experiments.

Some additional perspective on these matters may be provided by pooling data from the two experiments, and analyzing "representation" directly as a factor in an ANOVA. This is justified in that the only difference between the materials and procedure of the two experiments resides in whether or not a representation was provided to the subject (Experiment 2), or not (Experiment 1). A 2 X 2 ANOVA was performed for the performance and solution time data of Experiments 1 and 2 pooled for the factors of representation (Experiment 1 versus Experiment 2) and isomorph presentation.

For performance (X^2 (3) = 1.66), the representation factor obtains F (1, 75) = 7.11, $p < .01$. This result shows that the Experiment 2 subjects, who had a representation provided, attained higher performance scores. Problem isomorph factor obtains F (1, 75) = 17.46, $p < .001$. This shows that subjects in the spatial isomorph conditions attained better performance scores overall. There is a non-significant interaction of isomorph and representation, F (1, 75) = 1.90, $p < .2$. For solution time (X^2 (3) = 1.49), there are also main effects of representation, F (1, 74) = 43.45, $p < .001$, and isomorph presentation, F (1, 74) = 5.31, $p < .05$. These differences reflect the fact that subjects in Experiment 1, who had no representation provided, obtained shorter solution times, as did subjects in the spatial isomorph conditions overall. There is no representation by isomorph interaction.

As before, we have also computed the ANOVA's discarding comprehension failures. For performance (X^2 (3) = 1.62), there is a main effect of representation, F (1, 67) = 6.88, $p < .025$, and of problem isomorph, F (1, 67) = 9.43, $p < .005$. The interaction term is non-significant. For solution time (X^2 (3) = 1.20), the factor of representation obtains F (1, 66) = 29.90, $p < .001$, and the factor of isomorph presentation obtains F (1 ,66) = 2.92, $p < .10$. The interaction term is non-significant.

These analyses argue that availability of a representation does not exhaust the difference between spatial and temporal isomorphs. The factor of problem isomorph obtains significant main effects in the pooled analysis, and does not interact significantly with the factor of representation. Hence, we still cannot rule out the influence of what we referred to earlier as conceptual differences.

The effects of the representation factor itself suggest some further hypotheses about the role of representation in problem solving. There is a highly significant tendency for subjects in Experiment 2 to take more time in solving the design problem, independent of isomorph presentation. Further, there was a significant tendency for these subjects to obtain higher performance scores.

Perhaps, the longer solution times in the Experiment 2 are merely due to the fact that these subjects had more to learn (i.e., they had to learn to use the representation). We tried to eliminate this possibility by not including the instruction period in the solution time. However, it could be that subjects did not realize their lack of understanding of the representational scheme until after the instruction period, and hence the time they spent learning the representation was actually included in their solution time. On this view, the advantage of the graphic representation lies perhaps in its providing to the subject a recording medium that helps maintain and integrate previous intermediate solutions (see Greeno, 1975).

Another possibility, however, is that the improved performance of the representation subjects is more directly related to the longer amount of time they spend on the problem. In this view, the benefit of the representation resides in its encouraging the subject to work longer on the problem. Indeed, this could be just the sense in which a representation can function as a problem solving aid. In any case, the present experiment does seem to indicate that graphic representations can act as aids in ill-structured temporal design problems -- and thus is a preliminary empirical justification for the use of such aids in real world temporal design task environments like computer programming (see van Tassel, 1974, for discussion of "flow-charting" and related aids).

Summary

The present investigation suggests that the efficacy of graphic representations in solving well-structured deduction problems (e.g., Schwartz, 1971), may generalize to ill-structured problem domains like design. Furthermore, it was suggested, certain presentations of problem information encourage graphic representation and are (thereby) rendered easier to solve (spatial versus temporal in Experiment 1).

This study also elaborates previous analyses of problem isomorphism, distinguishing, in particular, between spatial and temporal isomorphs. The spatial isomorph, in the present study, obtained better performance and faster solution times (Experiment 1), and occasioned fewer comprehension failures than the temporal isomorph. This shows that the intuitive distinction between time and space, like the "transfer" and "change" comparison studied by Simon and Hayes (1976), can be an effective variable in presentating problem information. We have also attempted to clarify the basis of isomorph differences, suggesting that these differences reside in the extent to which a problem statement makes a useful representational scheme available, or accessible, to the problem solver (see Simon and Hayes, 1976).

Finally, we have developed a paradigm which allows for objective assessments problem solving behavior in relatively ill-defined problem solving environments.

Footnotes

* We thank Roger Evans for programming the ANOVA routines used in analyzing the data presented here, Martha McRea for assisting in the data analysis, and Lance Miller and Don Nix for commenting on an earlier version of this report.

[1] We use the Method of Expected Equal Frequencies throughout. We have also checked these results using the Method of Proportional Frequencies (Ferguson, 1971, page 239-241), and find no discrepancies.

[2] One subject failed to signal the experimenter when he finished the problem, and as a result had no solution time recorded.

[3] One of the 45 subjects failed to signal the experimenter upon completion of the problem. As a result, one solution time is missing.

Appendix

1. Functional Requirements for Temporal Isomorph

A uses the same resources as B,
F uses different resources than A,
B uses the same resources as G,
C uses different resources than D,
E uses the same resources as B,
G uses different resources than F,
The total number of shifts required should be as small as possible,
B should precede stage D,
E should follow stage G,
A should follow stage C,
F should precede stage E,
D should follow stage G,
C should precede stage F,
F is a higher priority manufacturing stage than B,
C is a lower priority manufacturing stage than B,
G is a lower priority manufacturing stage than C,
D is a higher priority manufacturing stage than F,
E is a higher priority manufacturing stage than G,
A is a lower priority manufacturing stage than D.

2. Functional Requirments for Spatial Isomorph

A is incompatible with B,
F is compatible with A,
B is incompatible with G,
C is compatible with D,
E is incompatible with B,
G is compatible with F,
The total number of corridors office space is rented on should be as small as possible,
B uses the accounting records more than does D,
E meets people in the reception area more than does G,
A meets people in the reception area more than does C,
F uses accounting records more than does E,
D meets people in the reception area more than does G,
C uses the accounting records more than does F,
F has more prestige than B,
C has less prestige than B,
G has less prestige than C,
D has more prestige than F,
E has more prestige than G,
A has less prestige than D.

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