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ABSTRACT

This paper is a progress report of the first phase of a project which essentially seeks to replicate previous studies using the successful/unsuccessful design in an attempt to: (1) corroborate the surface/deep structure conclusion which has become an essential component of an understanding of problem-solving; (2) examine more closely the nature of the categorization procedure and how it is applied; (3) reexamine the similarity of keywords identified by subjects; and (4) extend the research into another content area, enhancing the generalizability of the conclusions. Included are results of a pilot study of how geneticists and biologists categorize genetics problems. Findings (based on five faculty responses) show that: biology faculty members apparently have a detailed mental organizational structure for genetics problems; genetics problems are apparently mentally organized by these individuals in a hierarchical system; the self-report of at least one subject suggests that this organization plays a signficant role in problem-solving; genetics principles used by faculty subjects to organize genetics problems appear to be very similar in most cases; the organizations produced were based on "deep structure"; and the keywords identified by subjects are closely tied to the organization scheme being used. (JN)

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THE ORGANIZATION OF CLASSICAL GENETICS PROBLEMS

BY FACULTY PROBLEM SOLVERS

by

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Introduction

In recent years several studies have suggested that when experts approach a problem they often begin by categorizing it, i.e., recognizing it as one of a given type of problem (c.f. Hinsley, Hayes, & Simon, 19?? ?ole, 1977). This recognition is hypothesized to "activate a ?al schema" stored in long term memory, which includes a set of appro? ?ate approaches for solving this type of problem (Chi, Feltovitch, & Glaser, 1981). Intuitively, and according to the self reports of experts (personal communication), the use of categorization would appear to be a strategy which is vitally important to problem-solving success in the sciences. This position is supported by research such as that of Silver (1979) who found that within a sample of eighth graders the tendency to sort verbal math problems on the basis of mathematical structure was significantly positively related to problem-solving performance scores. Chi and others (1981) also observed that novices categorize physics problems according to the "surface structure" of the problem while experts sort according to "deep structure"--the underlying physics law applicable to the problem. Surprisingly, these researchers also found that their experts attended to the same (if fewer) keywords in the problems. Similarly, Weiser and Shertz (1983) found that the manner in which computer programmers sorted a group of programming problems varied according to their expertise, with novices sorting according to the problem's "more literal features," experts according to "algorithm" (content-specific deep structure), and managers according to the "kinds of programmer to whom they would give each problem."

In many of these studies, researchers have typically drawn their subjects from a pool of novices and a pool of experts and compared the performances of the two. Research (Smith & Good, 1984) has demonstrated that successful subjects generally share more characteristics which distinguish them from unsuccessful subjects than a experts when compared to novices. In that study, a group of moderately successful novices who used powerful "expert-like" strategies while solving a group of moderately difficult genetics problem was identified and the argument was made that if an artificial dichotomization of the subjects was to be made, it should be based on problem-solving success instead of subject expertise. Other researchers have also argued recently for research which contrasts successful and unsuccessful subjects so as to eliminate the variable of experience which confounds the expert/novice research findings (Bodner & McMillen, 1985). Together, these studies support the contention that certain expert problem-solving characteristics (such as automatic processing) may, in fact, be the <u>effect</u> of continued success (experience) and not the <u>cause</u> of problem-solving success. (It must be noted, however, that this approach is not appropriate when relatively simple, algorithmically solvable "problems" are being studied).

These conclusions raise several intriguing questions about the relative roles of expertise and success in mental problem representation or organization and the extent of the generalizability of these conclusions to other fields. This paper is therefore a progress report of the first phase of a project which essentially seeks to replicate these studies using the successful/unsuccessful design to attempt to:

a) corroborate the surface/deep structure conclusion which has become an essential component of our understanding of problem-solving,

b) examine more closely the nature of the categorization procedure and how it is applied,

c) reexamine the similarity of keywords identified by the subjects, and

d) extend the research into another content area, enhancing the generalizability of the conclusions.

Methodology

Pilot Study. Using standard think aloud interview techniques (Easley, 1977; Hutt & Hutt, 1970; Newell & Simon, 1972; Opper, 1977; and Piaget, 1929/1976), two faculty geneticists were asked to organize a group of 24 typical genetics problems. These problems were drawn from a widely used undergraduate genetics text and included problems from most of the chapters on classical genetics. After the categorization was completed, these subjects were questioned at length about what their group labels meant, how the labels were selected, and how a problem was identified as belonging to a given category. In addition, the subjects were asked to report their perceptions of how frequently when approaching genetics problems they initially recognize a problem as belonging to a general type. After the interview, these faculty subjects were also asked to privately solve a set of four moderately difficult classical genetics problems which had been found in a previous study (Smith & Good, 1984) to be useful for meaningfully categorizing subjects as either successful or unsuccessful problem solvers. Based on the results of this study, one of the 28 problems was modified slightly, a specific set of instructions for the task was developed, and plans for the full research project were completed.

Faculty Study. Fifteen college and university faculty biologists from across the nation were solicited to perform the organization task privately. On February 17, 1986, each professor was mailed a packet of materials developed on the basis of the pilot study. These materials included a carefully prepared Instructions Sheet which required recording the total time required for the task, a Consent Form/Participant Profile, 28 3" X 5" cards on which the 28 genetics problems to be organized were typed, and a booklet which included the four problems which were to be solved. The Instructions Sheet directed the subject to "organize the problems based on how YOU would solve them" and to "circle the keyword/s in each problem, i.e., the words which are important in the organization decisions you make." After the task was completed, the subject was directed to "briefly describe your organization on a sheet of paper" and then to solve the four problems (to provide a basis for categorizing subjects according to success). All materials were then returned in a pre-stamped envelope.

A second phase of this study is planned in which a group of student volunteers who have recently completed a college genetics course will be asked to complete the same tasks. Comparisons of the organizations of the two groups will be made. A final phase of the study will ask similar groups of faculty and students to organize a second set of genetics problems modified specifically to accentuate differences identified in the earlier parts of the study. This paper is a progress report of the faculty pilot study and the three faculty responses which have been received to date. These subjects are characterized in Table 1.

Results and Conclusions

The organization schemes of the five faculty participants are provided in Figures 1 - 5. Even with this limited number of subject responses, several tendencies appear to merit attention. First, the faculty organizations typically take one of two forms: a sorting into separate groups or a branching categorization scheme. It was recognized early on that the sorting instructions which had been used in earlier research were too narrowly limiting since they do not provide for the option of multi-level organizations. The frequent use of such organizations by the subjects in this study supports the wisdom of providing for both options. Genetics problems are apparently mentally organized by biologist faculty members in a hierarchical system.

Secondly, each subject produced a detailed and explicit organization suggesting that these individuals have a detailed mental organizational structure for genetics problems. Furthermore, the following comments of subject F01 suggest that this organization plays a significant role in problem solving:

F01: I first look at it to see what I'm dealing with . . . . and you zero in on it. I don't think I think about it, but I'm sure, I must, that's how, I zero in [snaps fingers] on what it is right away. Am I dealing with simple Mendelian; am I dealing with, you know, ah, co-dominance, and right on up the line . . . . And I can look at a problem and see that part of the problem is simple Mendelian inheritance, very simple, the other part, though, since I may be dealing with more than one trait may be an intermediate, trait . . .

I: I heard you say that when you read a genetics problem, one of the things you first do is immediately begin to say "this is

F01: Oh, yeah.

I: this type or this type" and that's one of the things that you typically do

F01: Umhum.

I: every time you solve a problem.

F01: Oh, yeah.

I: OK, are you aware of that?

F01: Probably not. I think, when I solve a problem I don't think in terms--but, just, I would imagine sitting here doing this, since I organized it this way, you know, this is a conscious, on a conscious level. I must get this conscious level from something, so probably, subconsciously, I <u>do</u> do it that way.

Figure 1.

Subject F01
6 Years of College Biology Teaching
M.S.: Cytogenetics

Independent Assortment

Linked

Cytogenetics

Biochemical

Figure 2.

Subject F02
19 Years of College Biology Teaching
Ph.D.: Biology

Probability

Classical

Cross-Over

Human

Uniparental

Pedigree

Lethal

Sex-Linked

Figure 3.
Subject F09
16 Years of College Biology Teaching
Ph.D.: Botany

Monohybrid Problems With Dominance

Monohybrid With Incomplete Dominance

Blood Types With No Other Traits

Sex-Linked Traits

Lethal Genes

Dihybrid Problems with Dominance

Dihybrid, With Incomplete Dominance

Dihybrid, With Gene Interaction

Dihybrid, with Lethal Gene

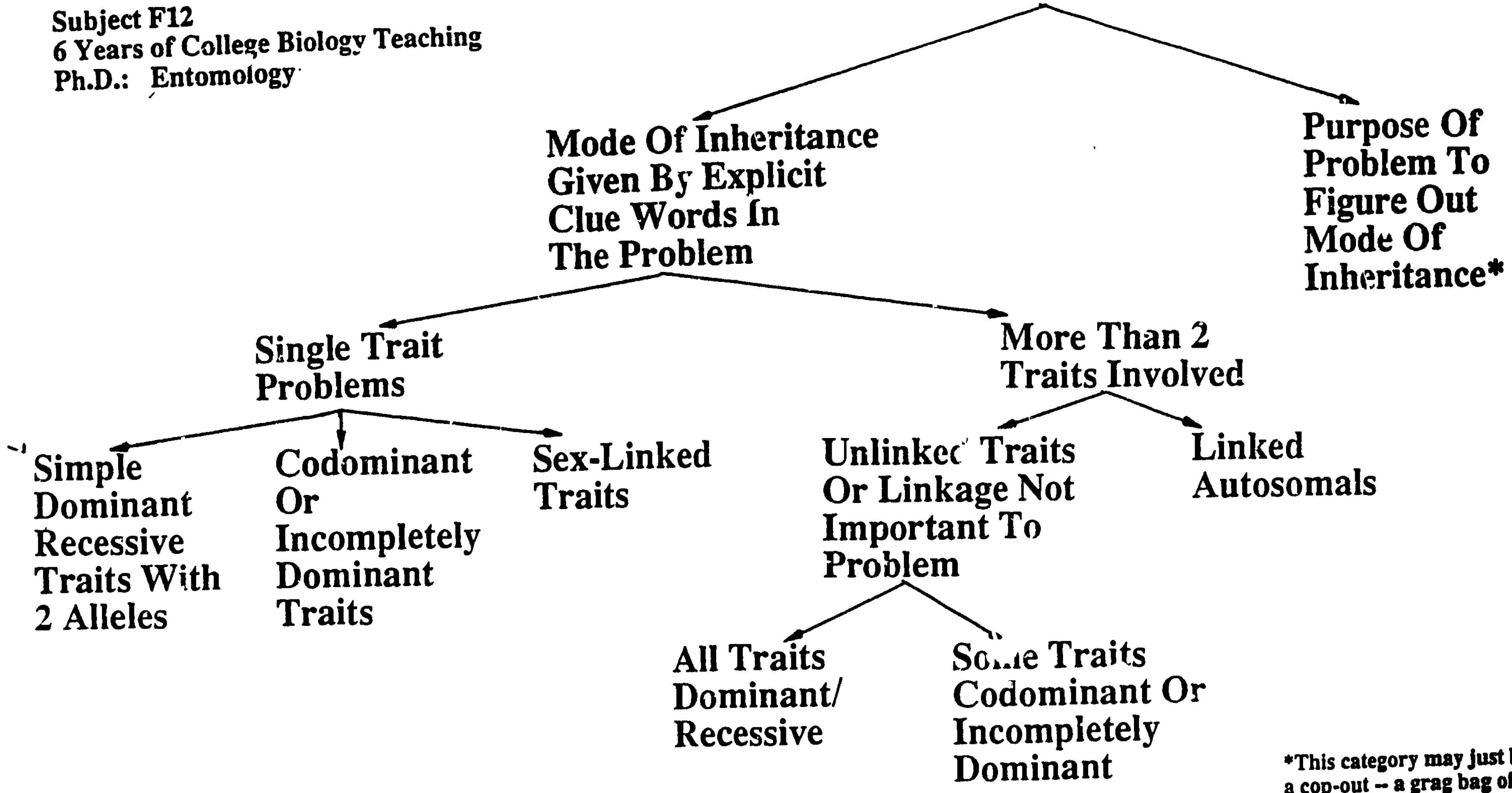
Trihybrid Cross

Linkage Problems

Pedigrees

Figure 4.

Subject F12
6 Years of College Biology Teaching
Ph.D.: Entomology



*This category may just be a cop-out -- a grag bag of things where I didn't immediately perceive the genetics and didn't have time to dig.

Figure 5.
Subject F13
20 Years of College Biology Teaching
Ph.D.: Genetics

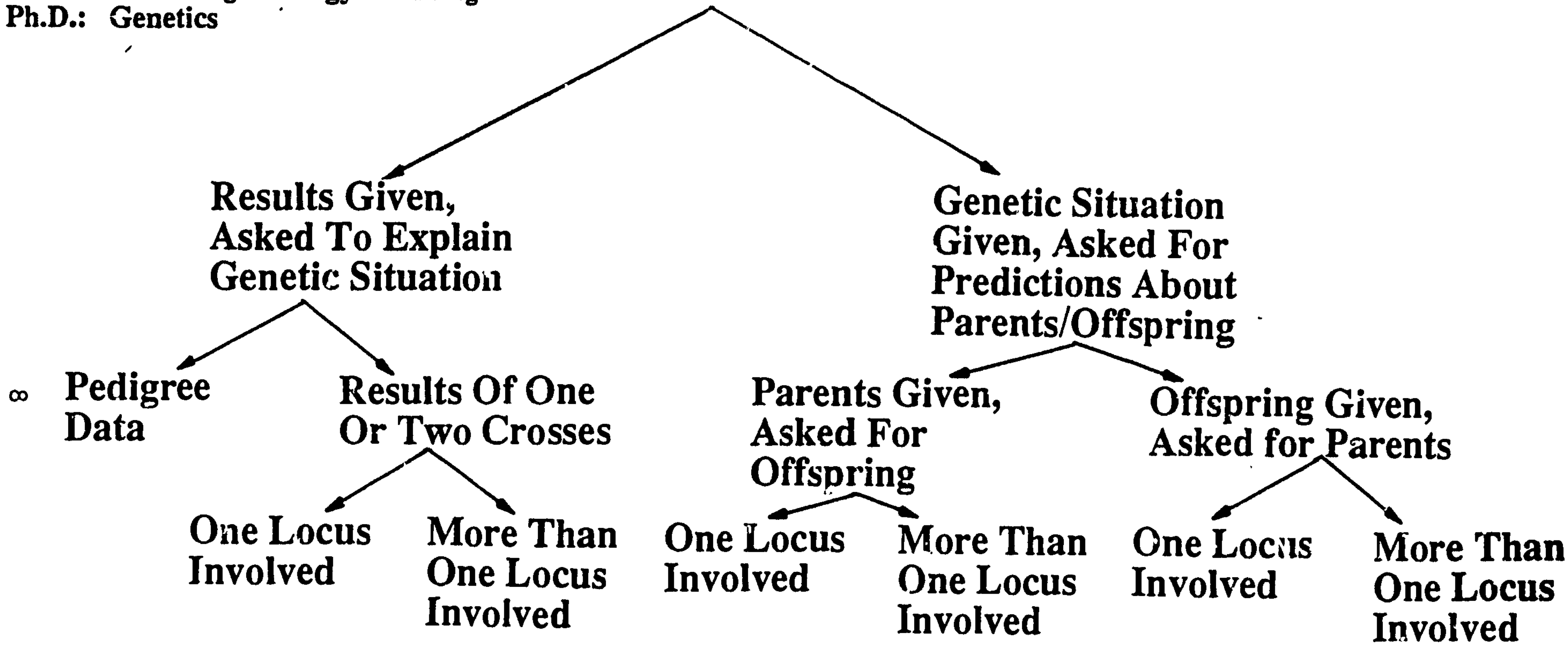


Table 1. Characterization of Subjects

Subject #	Terminal degree: degree	Terminal degree: institution	Terminal degree: area	Semester Hours of Graduate Genetics	Years of College Biology Teaching	Teaches: Intro. Bio.	Teaches: Genetics	Teaches: Genetics Related	Academic Title	Current Institution	Sex	Age
F01	M.S.	MWS-L.A.	Cytogenetics	3	6	X		X	Asst.	J.C.	F	40
F02	Ph.D	Tulane	Biology	0	19	X	X	X	Assoc/Chair	College	M	44
09	Ph.D.	U. of GA	Botany	6	16	X			Assoc.	J.C.	F	47
12	Ph.D.	Cornell	Entomology	4	6	X			Assoc.	Univer.	M	37
13	Ph.D.	Ohio St.	Genetics		20		X		Prof.	Univer.	F	48

In addition, this excerpt highlights that, for experts, the recognition process is very tacit.

Thirdly, the organizations produced were clearly based on "deep structure," i.e., genetic principles, and not on more "surface features." An excellent example of this is the identification by three of the subjects of Problem 5 as a lethal (presumably) based on the atypical offspring ratio and the malformed chicks produced in the problem. The one exception to this pattern is the organization of subject F02 which included a "human" category. Upon questioning, however, this subject acknowledged that he did not view these problems as requiring a solution process uniquely different from that of the other problems. He stated that he had included this category because he tends to teach human genetics problems last as an area of application of principles taught earlier. Furthermore, he stated (as did F01) that it was difficult to perform the task without taking into account the way s/he would organize the problems for classroom instruction.

Although the specific categorization schemes produced by these faculty subjects differ from each other, the genetic principles which lead to these categorizations appear to be very similar in most cases. In decreasing order of frequency, these principles are: mechanism of inheritance (4 subjects), linkage (4), pedigree (3), number of loci (3), and lethality (2). The similarity of the principles used suggests a common organization of genetic problems which, once made explicit, could be taught to novice genetic problem solvers. The principles used provide further evidence of the use of "deep structure" principles for organization. In addition, every subject used at least two of these principles, suggesting that organizations based on deep structure are typical of faculty problem solvers.

In the performance of those subjects whose task included circling the keywords, another interesting pattern appears. The words circled by the subject are very closely tied to the organization scheme being used. For example, subjects typically circled "two gene pairs" in problems which they identified as dihybrid, and "pedigree" in problems of pedigree analysis. This observation not only implies a discriminatory ability to identify words or phrases which are important in the selection of a solution path but also reemphasizes the level of genetic understanding required for this task. The circling of the word "malformed" by subject F09 in a problem identified as a "lethal" is an excellent example of this phenomenon.

One unexpected finding is the use by two faculty subjects of the problem goal in the organizational scheme produced. In her branching scheme, Subject F13 (one of the most successful subjects in this study; see Table 2) used as her first level of dichotomization whether "Results [were] given, [solver is] asked to explain genetic situation" or "Genetic situation given, asked for predictions about parents/offspring." Similarly, the first level of dichotomization used by Subject F12 was "Purpose of problem to to [sic] figure out mode of inheritance" vs. "mode of inheritance given by explicit clue words in the problem." This finding suggests that the problem goal is an important factor in the mental representation of these problems and thus

Table 2. Success of Subjects

Subject #	Problem #* 1	2	3	4	Total Y or (Y)
F01					
F02	(Y)	(Y)	(Y)	Y	4
F09	(Y)	N	(Y)	Y	3
F12	N	N	N	Y	1
F13	Y	Y	N	Y	3

*Y=Yes, N=No, (Y)=Essentially Correct

in the problem-solving approach which would be selected by these individuals. Such an organization would be logically consistent with individuals who use means-ends analysis as a principal problem-solving method, but extensive prior research (c.f., Larkin, 1980; Simon, 1980; and Smith & Good, 1984), has clearly demonstrated that this approach is typical of unsuccessful novice subjects and not of successful expert subjects.

Subject F12 provides some insight into this phenomenon in two notes included in the explanation of his organization scheme. He writes: "I began by keeping track of a) type of inheritance and b) type of response demanded, but decided to abandon the latter as a system of classification . . ." Thus, this category was not important throughout the organization task. Furthermore, he notes that the "Purpose of the problem . . ." category "may just be a cop-out--a grab-bag of things where I didn't immediately perceive the genetics and didn't have time to dig." This contention would be consistent with the fact that two of the three problems included by F12 in this grouping were identified by other subjects as either sex-linked (but the mode of inheritance was not explicitly stated) or uniparental or parthenogenic (a category consisting of only a single member).

The relative importance of the problem goal for Subject F13 is not so readily explained, and she does not provide any helpful notes as did Subject F12. In the absence of any evidence to the contrary, we must therefore consider this to be a valid observation. This raises two major questions. First, is this a commonly used criterion of organization in successful problem solvers, and, if so, how can this fact be reconciled with the lack of means/ends analysis? Secondly, if the problem goal is commonly used in the mental organizations of successful subjects, it may be necessary to call into question the basic assumption of this research that the organizational schemes produced in grouping problems accurately reflects the internal mental problem representation. The stated difficulty which instructors have in developing an organizational scheme based on how they would personally solve problems and not on how they would teach those problems might support this position as well.

Summary and Implications

The organization schemes produced by the five faculty subjects who have responded to date suggest several initial conclusions:

1) biologist faculty members apparently have a detailed mental organizational structure for genetics problems;

2) genetics problems are apparently mentally organized by these individuals in a hierarchical system;

3) the self-report of at least one subject suggests that this organization plays a significant role in problem solving;

4) the genetic principles used by faculty subjects to organize genetic problems appear to be very similar in most cases;

5) the organizations produced were clearly based on "deep structure," i.e., genetic principles, and not on more "surface features;"

6) The keywords identified by the subject are very closely tied to the organization scheme being used implying that the recognition of

these keywords is an essential component of the process by which the problem is recognized as being typical of a class of similar problems.

These results are, of course, only preliminary and will be tested on the responses of the remaining subjects as they are received. The remainder of the project which will be completed at the end of this semester will consider the organizations produced by a group of undergraduates who will be completing their first course in genetics. Present plans also provide for including four medical students, two family practice residents, and two members of the medical school faculty. Trends in the differences noted in comparing these groups should be most instructive.

In spite of the incompleteness of the data at this time, it seems appropriate to propose that developing an internal organizational scheme of problem types based on "deep structure" and subsequently learning to recognize problems as representatives of their appropriate categories are valuable skills which will contribute to problem-solving success. Little or no instructional time is typically spent either in recognizing the value of this mental structure or in practicing the skill of such recognition. In addition, for researchers interested in this topic, it also appears to be important that the research protocol allow for subjects whose mental organization is hierarchical and not longitudinal.

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