The use of hierarchical problem solving subroutines in the solution of exercise science problems

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Abstract:
Hierarchical problem solving strategies employed in solving science problems were examined in this study. Hypothesis testing was used as the theoretical base for the study of differences in problem solving within a computer simulation framework. Undergraduate and graduate students in exercise science were asked to solve a series of problems associated with physiological assessment and exercise prescription formulation. Protocol analysis and the Pitt coding system were used to analyse verbal data, and group differences were examined statistically. Both graduates and undergraduates responded correctly to a substantial portion of the questions. However, graduates displayed the ability to define and delineate the problem better than undergraduates. Both groups used all six problem solving strategies, although the graduates often provided a significantly greater number of responses within subroutines of the strategy. Although the graduates appeared to be more efficient problem solvers, they did not consistently exhibit the ability to extract and summarize critical patterns typically associated with expertise.
Keywords: Problem solving, computer simulation, protocol analysis, physiological assessment, exercise prescription.

Article:

Introduction

Problem solvers may select from a vast number of alternative strategies when attempting to solve complex tasks (Anzai & Simon, 1979). While many strategies are available, it is clear from research (e.g. Greeno *et al.*, 1979; Klahr & Dunbar, 1988; Larkin *et al.*, 1980; Sweller & Levine, 1982) that not all problem solving strategies are equally effective. Strategy differences have been examined in terms of speed in arriving at the solution, the load they place on short-term memory, ... the ease of [strategy retention] or ... the range of tasks to which [strategies] can be transferred' (Anzai & Simon, 1979, p. 124).

The examination of solution strategies selected by learners is important in understanding the progressive development of expertise. Novice problem solvers are more likely to use an information processing theory, such as means-end analysis (Newell & Simon, 1972), when initially confronted with a problem. Within this strategy, they tend to focus on the goal and then work backwards toward the problem statement. As one might expect, the backwards-chaining strategy works especially well for problems in which the goal is clearly stated. However, the novice may experience difficulty when attempting to use this strategy for more sophisticated problems or problems in which the goal is unclear. Because of the product emphasis, the means-ends approach is frequently selected when the problem solving process lacks intermittent corrective feedback. In these situations, it is possible to solve problems correctly without developing concomitant understandings regarding the problem category or relevant rules useful in the solution of future problems (Sweller, 1983). Thus, even though the strategy is technically efficient, it may not lead to the development of expertise (Sweller & Levine, 1982).

In contrast, hypothesis testing theory (Levine, 1975) suggests that individuals solve problems most efficiently by testing a series of hypotheses relevant to a particular category of problems under examination (Chi *et al.*, 1981; Murphy & Medlin, 1985). Problem categorization based on a set of applicable principles or rules appears to activate knowledge structures or schema necessary for success. The schema promote the generation and selection of hypotheses and strategies that are most likely to lead to an effective solution (Sweller *et al.*, 1983).

Problem solving ability within hypothesis testing theory evolves as the individual's knowledge base and experience with a particular category of problems increases (Larkin *et* al., 1980). Advanced problem solvers incorporate a forward-chaining strategy based on the recognition of critical components of the problem, categorization of the problem within the appropriate domain, and utilization of strategies and strategy combinations or heuristics. They work forward from the problem statement to the goal, methodically selecting and refining solution options.

Problem solvers using a hypothesis testing strategy integrate feedback from previous actions to generate or selectively search for subsequent moves. Feedback in the form of correct or incorrect responses to subgoals or previous problems is used as an internal cue to limit the range of hypotheses considered. One of the advantages of the strategy is the opportunity to generate rules from the problem-solving process (Klahr & Dunbar, 1988). Rule induction is viewed as an important component of learning transfer when problems are perceived by subjects to be classified within common categories. Efforts to encourage individuals to increase their problem solving skills within a field of study typically focus on the refinement of strategies associated with hypothesis theory.

Hypothesis testing theory may serve as a theoretical foundation for designing computer simulations that promote increasingly sophisticated approaches to problem solving. In this study, the Health and Fitness Assessment (HAFA) computer simulation was used to examine the extent to which undergraduate and graduate students utilized hypothesis testing theory when assessing the physiological state of a subject and developing exercise prescriptions to increase physical fitness. It was hypothesized that there would be significant differences between graduates and undergraduates in both (a) the number of problem-solving subroutines used and (b) the selection of subroutine groupings that functioned concurrently. The significance of the research lies in the examination of the role of computer simulation in promoting clinical problem solving within a controlled environment. Because the simulation permits the subject to synthesize professional knowledge with practical expertise, students are better able to provide accurate prescriptions in clinical settings.

Method

Six undergraduate and seven graduate students in exercise science participated in the study. The undergraduates had taken courses in measurement of motor behaviour and exercise physiology. However, their experience in analysing fitness data and developing exercise prescriptions was limited, and they were judged to be novices in these tasks. The graduate students were upper-level doctoral candidates in exercise physiology. They had an extensive background in the basic scientific knowledge necessary to understand the problems at hand.

Small sample sizes were essential due to the extensiveness of the analysis of results needed for this type of study. Ericsson & Simon (1984) noted that large samples are not necessary for comprehensive evaluation, especially if a reasonable strategy is utilized for the selection of subjects. In this study, the subjects were carefully selected. The undergraduates had completed the same academic background and would soon graduate. In the graduate group, only doctoral students who were within a year of completing their degrees were selected. Male and female students were represented in both samples.

Health and Fitness Assessment Program

The Health and Fitness Assessment Program (HAFA) is a computer simulation program that presents two problems to the user. The first problem is to assess the overall physiological status of the subject; the second, to generate an exercise prescription for the subject given his or her fitness status. The problem gives the user the option of interpreting data for either a hypothetical case study or a real subject. The variables are physiological and physical parameters that provide the information needed to describe the subject's fitness status and develop an exercise prescription. The subject is then assumed to follow the exercise prescription for 6 weeks. New data are then presented for the user to analyse, and the prescription is modified if necessary. Two types of feedback are provided: knowledge of results (whether the user selects the right or wrong answer to a problem) and informational feedback (that permits the learner to access data from tutorials and normative tables). The computer program was written using the IBM PC C Compiler along with Assembly language for some of the subroutines. A Toolkit program was used in developing the graphics. The IBM PC-XT computers were configured in a token ring network with an IBM PC-AT serving as the host computer.

A preliminary study was conducted (Safrit *et al*,, 1988) to provide objective evidence of the suitability of the program as a problem-solving tool. In this study, undergraduate students displayed a systematic approach to problem-solving leading to the development of an exercise prescription. Students were provided with a choice between goal and problem materials pathways. In the goal pathway, the question was answered directly without the benefit of additional information. In the problem materials pathway, respondents chose to use materials, in this case tables of norms and tutorials, to guide their decisions. There was evidence to suggest that students demonstrated pathway preferences. The analysis of interpretive statements further demonstrated the extent to which students used problem-solving skills as when interacting with the computer. A substantial percentage of these statements (72%) reflected the understanding or use of problem-solving skills.

Table 1. Components of the model: subroutines (SRs) grouped as heuristic subprocesses and strategies*

Heuristic Subprocesses	Strategies
Definition of the problem	General problem solver (GPS)
SR1. List given information	SR10. Define initial state
SR2. List assumptions	SR11. Define goal state
SR3. List possible questions	SR12. Identify data needed
SR4. Select evaluative criteria	
SR5. Assign priorities	Feedback
SR6. List relevant information/ delete irrelevant information	SR17. Identify feedback
	SR18. Tag new information
	SR19. Organize data
SR7. Formulate hypotheses	
SR8. Define predictions	Pattern extraction
SR9. Select question(s)	SR22. Extract patterns from data
	SR23. Summarize relevant patterns
Data acquisition	
SR10. Define initial state	Hypothetico-deductive
SR11. Define goal state	SR7. Formulate hypotheses
SR12. Identify data needed	SR8. Define predictions
SR13. Identify set of available algorithms	SR20. Match data to predictions
	SR21. Determine truth values of prediction
SR14. Select algorithm	
SR15. Edit algorithm	
SR16. Execute program	Evaluation
SR17. Identify feedback	SR2. List assumptions
SR18. Tag new information	SR4. Select evaluative criteria
SR19. Organize data	SR5. Assign priorities
Interpretation	SR6. List relevant information/ delete irrelevant information
SR20. Match data to predictions	
SR21. Determine truth values of predictions	SR15. Edit algorithm
SR22. Extract patterns from data	Basic heuristic category
SR23. Summarize relevant patterns	SR1. List given information
SR24. Output conclusions	SR3. List possible questions
	SR9. Select question(s)
	SR13. Identify set of available algorithms
	SR14. Select algorithm
	SR16. Execute program
	SR24. Output conclusions

*Reproduced from Pitt, R. B. (1983). Development of a general problem-solving schema in adolescence and early adulthood. *Journal of Experimental Psychology: General*, **112**, 552. By permission.

Pitt problem-solving coding system

Pitt (1983) proposed a coding system that encompasses a variety of strategies used in problem solving. Twenty-four subroutines, listed in Table 1, are organized hierarchically into heuristic and strategic problem-solving processes. The categories range from basic components of problem solving such as recall or *listing of given* *information* (Subroutine 1) to the more complex subroutines involved in *extracting* (SR22), *summarizing patterns* (SR23), and *drawing conclusions* (SR24). Heuristics represent a theoretical hierarchy of subroutines that facilitate problem definition (SR1-9), data acquisition (SR10-19), and data interpretation (SR20-24).

The six strategies in the Pitt coding system, listed in the right column of Table 1, provide a detailed representation of the problem-solving strategies. The Basic Heuristic and the General Problem Solver strategies are described by lower-level subroutines in the hierarchy. The seven subroutines within the Basic Heuristic strategy form the scaffolding for the problem-solving process. The General Problem Solver strategy is a hierarchically more sophisticated strategy than the Basic Heuristic and is used to summarize the problem solver's progress to that point in the solution process. It is a means-ends assessment of the progress to date, and includes a re-examination of the goal and the problem statement in an attempt to diminish the distance between the two. Within the Pitt system, hypothesis testing strategies associated with forward-chaining are evident in the Evaluation and the Hypothetico-Deductive strategies. Consistent with the goals of hypothesis testing, the Evaluation strategy includes subroutines that focus or narrow the domain.

The Hypothetico-Deductive strategy involves the statement and testing of hypotheses. It emphasizes the knowledge and experience necessary to formulate and test hypotheses within a specific domain. The Feedback and the Pattern Extraction strategies emphasize the integration of new knowledge and generation of rules or principles essential for transfer. In the Feedback strategy information may take the form of theoretical knowledge or practical application. The most critical aspect of this strategy is the synthesis of the given data with a supplemental knowledge base. As the synthesis progresses, problem solvers reorient their thinking to accommodate the evolving solution.

The Pattern Extraction strategy facilitates the rule induction/transfer component of hypothesis theory. Central to the approach is the identification of patterns that serve as internal cues to the advanced problem solver. Instead of arbitrarily selecting hypotheses based on knowledge and experience, the problem solver selectively analyzes patterns that have evolved in the process of examining several subgoals or problems. Thus the history of previous interactions, including a *knowledge* of the particular category of problems and the *order* in which the problems have been presented, represent patterns or rules that have a substantial impact on future problem solution. The rule induction strategies employed at this level of problem solving facilitate knowledge transfer, encouraging a dynamic, internally-controlled learning process characteristic of expert problem solvers (Klayman & Ha, 1989).

Protocol

As in the Safrit *et al.* (1988) study, the student was seated at the computer and asked to talk continuously while interacting with the computer. Questioning was used in this study to encourage the respondent to explain the rationale underlying the decision. The student was not permitted to answer a question by pressing a key until the rationale for the response was presented. Questions included: What information are you going to use to answer this question? Describe the thinking process you are using to decide the answer? Can you state any rules or principles that are useful in responding to this problem? At critical stages in the program, the student was also asked to summarize information and identify problems that might have occurred in the decision-making process. A tape recorder was used to record all verbalizations.

Data analysis

Protocol analysis, used to examine verbal data, permits the use of an information processing model as a basis for encoding verbal protocols in an explicit and objective manner (Ericsson & Simon, 1984). In analyzing the transcripts of the students' tapes, the primary goal was to identify each response according to the subroutine it represented. First the tape was transcribed in double-spaced non-paragraph form. The written transcript of the tape was then processed to identify relevant data. The statements were put in protocol format, with each statement identified by the student's initials and the statement number. Subroutine numbers were then identified for each statement.

Constant comparison analysis (Glaser & Strauss, 1967) was used to further categorize the subroutine data. Constant comparison is an inductive process that provides a systematic procedure for classifying qualitative data. It consists of a two-part process that involves both scanning and comparing protocol statements to detect embedded commonalities. In this study, statements categorized into subroutines using the Pitt system were then scanned to detect commonalities or properties. Properties for each subroutine were used as rules to further classify the statements. As rules were generated, each statement was tested or compared with the rule to determine category membership. For example, a variety of statements were categorized within the formulates hypothesis subroutine (SR7).

After scanning all statements in this subroutine, four subcategories of properties were articulated that described the information used to generate the hypothesis. These included scientific knowledge from exercise physiology, the subject's personal experience, information from the tables of norms or tutorials, and the subject's prior knowledge of fitness tests. The subcategories provided additional in-depth information that contributed to the understanding of subject's use of each subroutine. Efforts were made to refine the rules to the extent that each subcategory was mutually exclusive. The subcategories and rules emerged from the subjects' thought processes as reflected in the protocol statements and were not imposed through an external categorization system.

Intercoder reliability was examined. The undergraduate and graduate students were compared using chi-squared tests, repeated measures analyses of variance, and t-tests where appropriate. When t-tests were used, the experiment-wise error rate was controlled using the Bonferoni procedure.

Table 2. Summary of responses

Level	Subroutine	Undergraduate	Graduate	Total
I	1	19	23	42
	2	85	113	198
	3	50	67	117
	4	316	513	829
	5	481	613	1094
	6	172	183	355
	7	173	297	470
	8	121	199	320
	9	16	30	46
	Subtotal	1433	2038	3471
II	10	110	227	337
	11	69	133	202
	12	131	184	315
	13	1	2	3
	14	124	262	386
	15	13	17	30
	16	16	99	115
	17	0	2	2
	18	0	10	10
	19	13	0	13
	Subtotal	477	936	1413
III	20	11	10	21
	21	17	53	70
	22	2	1	3
	23	11	23	34
	24	0	0	0
	Subtotal	41	87	128
	Total	1951	3061	5012

Results and Discussion

A summary of the responses given by undergraduates and graduates for each subroutine is shown in Table 2. A grand total of 5012 responses were classified within the Pitt system, with 1951 responses attributed to the undergraduate group and 3061 to the graduate sample.

Problem solving strategies

The range of possible correct responses within the program was 61-68, depending on the number of exercises prescribed for various components of fitness. Both groups had a similar proportion of incorrect answers, with an undergraduates mean of 0.195 and a graduate mean of 0.171. The number of incorrect responses for all subjects are included in Table 3.

Table 3. Proportion of incorrect answers

Undergraduate		Graduate	
JM	0.22	KM	0.23
NG	0.20	RC	0.14
MI	0.13	DB	0.17
TG	0.13	AN	0.18
MD	0.36	BM	0.14
LS	0.13	RG	0.12
		JB	0.22
Mean = 0.195		Mean = 0.171	

The Evaluation strategy, associated with mature problem-solvers (Pitt, 1983), was used most frequently by both groups. Chi-squared tests suggested that graduates exhibited superior ability to select evaluative criteria, assign priorities to specific components of the solution process and utilize relevant data provided in the simulation. Graduates provided more evaluative responses overall, although this difference was not statistically significant (see Table 4). Both groups used hypothesis testing strategies associated with forward-chaining in the evaluative context. In fact, this type of hypothesis testing strategy was used more often than any other strategy by both groups, although the graduate usage exceeded the undergraduate in several subroutines.

The second most frequently used strategy by both groups was Hypothetico Deductive. Graduates appeared to make a concerted effort to examine the *accuracy of their predictions* (Subroutine 21) suggesting the application of hypothesis testing strategies with forward-chaining. Graduates provided more responses within this strategy than undergraduates, although this difference was not statistically significant (see Table 4). Examples of responses categorized within the Subroutine 21 are presented in Table 5.

Table 4. Comparison of problem solving strategies of undergraduate and graduate students

Strategy	Mean Response	t-test[a]
General problem solver	U: 30.8 (17.81) G: 54.4 (22.59)	t = −2.59, p = 0.018
Feedback	U: 2.8 (5.72) G: 2.4 (2.61)	t = 0.14, p = 0.890
Pattern	U: 2.2 (2.64) G: 4.0 (3.41)	t = −1.04, p = 0.322
Hypothetics-deductive	U: 21.5 (23.99) G: 37.3 (40.63)	t = −1.30, p = 0.205
Evaluation	U: 53.1 (79.12) G: 71.9 (97.98)	t = −0.67, p = 0.507
Basic Heuristics	U: 7.5 (9.63) G: 16.1 (21.92)	t = −1.98, p = 0.53

[a] $\alpha = 6/0.10 = 0.0167$

Third in the ranking for both groups was the General Problem Solver strategy. Graduates were better able to discern the critical *characteristics of the initial problem* (SR10), facilitating the development of an image of the solution or *problem goal* (SR11). Students using the General Problem Solver appeared to adopt a means-end strategy to acquire needed data. Graduates again produced more responses. In this case, the differences were statistically significant (see Table 4). Although both groups were expected to use this strategy to acquire data, differences were anticipated based on experience (Pitt, 1983).

The Basic Heuristic strategy represents the student's ability to use an abbreviated process that can suffice for simple, well-defined, familiar problems. Graduate responses in this strategy were almost double those of undergraduates, approaching statistical significance (see Table 4). However, the strategy was not used as frequently as those mentioned earlier and was fourth in the frequency of responses. This may suggest that many subproblems posed in the simulation were not perceived by the graduates to be difficult, and thus could be easily solved using basic heuristics.

Table 5. Examples of subject under Subroutine 21 (Determine truth value of prediction based on deliberate consideration of relevant data)

Undergraduate (response to mile run data)
1 Well I wasn't into running when I was little—am still not, but I did a 12-min run in high school.
2 World record is like 3 or 4 min
3 5-1/2 to 6 would probably be normal for an adult.
4 But for a fifth grader, short legs.
5 I'd say average or below average.
6 Because I don't know how conditioned he is.
7 He may have had to walk.
Graduate (response to cardiorespiratory endurance exercise prescription)
1 In this case, which is slightly different from the previous case, we're dealing with below average [cardiorespiratory endurance].
2 So perhaps slightly lower intensity exercise might be more appropriate for this person.
3 On the basis of this ... and due to the fact she is a little bit on the high side of normal in weight, though certainly within that category [normal] ... and her body composition could improve also.
4 Perhaps a slightly lower intensity exercise but an increase in duration might be better.

Extensive use of the Feedback and Pattern Extraction strategies was not reflected in the data. Feedback is the identification and integration of new information as it becomes available during the problem-solving process. Feedback provided in the simulation through numerous tutorials and norms tables was not incorporated extensively in problem solution. Although it was clear from the verbal protocols that subjects consulted the tables, they did not appear to be able to integrate the information efficiently as part of the solution chain.

Pattern Extraction is the identification of relevant patterns, symmetries, or regularities in the assembled data. A significant difference was found between undergraduates and graduates in the *summarization of relevant patterns in the data* (SR23). Graduates summarized relevant patterns significantly more often than undergraduates. The Pattern Extraction category represents higher-order cognitive processes in the Pitt coding system. It should be noted, however, that even though significant differences were found for one subroutine of this strategy, the total number of responses by each group was small. This suggested that graduates were not able to synthesize the information as well as anticipated. Even with their more extensive knowledge base, the graduate students should probably not be classified as experts.

Heuristic subprocesses

This schema represents a general, broad-spectrum prescription for solving problems. Three heuristic subprocesses were identified in the Pitt system: Definition of Problem, Data Acquisition, and Interpretation of Data. The group differences across all three subprocesses were significant ($\chi^2_{1,2} = 26.5581$, p = 0.0001). In all cases, there were more graduate responses than undergraduate, although the patterns of responses differed. The first heuristic, and by far the most frequently used by both groups, was Definition of the Problem. Graduates tended to provide more responses across most categories, although some of these differences were not statistically significant. In the second heuristic, Data Acquisition, several significant group differences occurred. Graduates averaged many more responses than undergraduates. The third heuristic, Interpretation, was reflected in only a small number of responses. It is worth noting that graduates made a greater effort to examine the accuracy of their predictions. They developed more relationships, with or without a rationale, and generated relevant variable lists. The ranking of responses of undergraduates and graduates by subroutines within a heuristic process was similar across all three processes. The following rank-difference correlation coefficients were obtained: Definition of the problem, $p = 0.967$; data acquisition, $p = 0.842$; interpretation, $p = 0.975$.

Three subroutines under the heuristic process labelled Definition of the Problem displayed significant interactions. These interactions were examined more closely using a simple main-effects analysis to understand better the nature of the graduates' superior problem-solving ability. When *listing possible questions* (Subroutine 3), graduates generated significantly more questions that were content-related. These included questions regarding the protocol of the test, the characteristics of the subject, and the nature of the prescription options offered in the simulation. Graduates also utilized *evaluative criteria* (SR4) based on logic or intuition. At times they appeared to accept their own opinion as a statement of fact without searching further for contradictory evidence. Graduates used anatomical or exercise data more extensively than undergraduates to *formulate hypotheses* (SR7). One additional significant interaction was detected in the data acquisition heuristic within the *selecting algorithms* subroutine (SR14). Graduates were better able to develop rules and algorithms from personal physiological knowledge of exercise physiology and health parameters. Thus not only did the graduate subjects have more information at their command, but they were also better able to retrieve it from memory to generate *questions* (SR3), *criteria* (SR4), *hypotheses* (SR7), and *algorithms* (SR14).

Graduate/undergraduate comparisons

All but one of the subroutines (SR24) were utilized to some degree by both undergraduates and graduates when solving problems related to fitness assessment and exercise prescription. The goal oriented means-ends analysis represented in the Pitt system by the Basic Heuristic and the General Problem Solver strategies was used primarily when subjects were unable to integrate information from tables or tutorials or chose not to use this information (Safrit *et al.,* 1988). Sweller & Levine (1982) reported similar results when subjects did not receive feedback regarding their performances. In these instances the subject had no information regarding the appropriateness of the solution until the final goal was evaluated.

Analysis of protocols indicated that undergraduates were more likely to use means-ends analysis when the goal was evident and when they lacked professional knowledge or expertise necessary to formulate an hypothesis. In these instances they relied on a personal knowledge of how well they had performed in these situations, sometimes attempting to remember a previous performance over a span of 15 years. Their inability to reference the knowledge base and their reliance on inaccurate, limited examples from their own experiences contributed to their ineptitude when selecting appropriate algorithms. Undergraduate algorithms were less sophisticated than the graduates. In addition, undergraduates used fewer calculations and thus were less likely to manipulate the given data to reach the goal.

In the strategies associated with hypothesis testing, graduates produced significantly more solution-oriented responses than undergraduates. When attempting to utilize the Evaluation strategy, undergraduates guessed more often and were forced to reconsider their decisions more frequently than graduates. This appeared to be associated with the undergraduates' limited knowledge and experience critical to the selection of rules and to the assessment of the information. Within the Evaluation strategy, graduates selected criteria based on logic, intuition, and factual recall significantly more often than did undergraduates. Again it appeared that some of the responses categorized within these subroutines were made at the automatic level with little rationale given for the correct decision. Graduates appeared to be especially adept at selecting relevant information from case histories and test data. However, they did not exhibit equal facility for deleting irrelevant information, sometimes selecting and emphasizing aspects of the case history that were unrelated to the prescription process.

Graduates evaluated the *accuracy of their predictions* (SR21) significantly more often than did undergraduates. They developed relationships between the characteristics of the test subject, the environment in which the test subject was most likely to exercise, and the theoretical knowledge base significantly more often than did undergraduates. They were also able to generate a list of variables relevant to the prediction process. The sophistication of this synthesis process suggested that the graduates were ready to employ more advanced levels of problem solving strategies.

Hypothesis-testing strategies associated with synthesis of new knowledge and rule induction were not used effectively by either undergraduates or graduate students. Neither group was able to *identify feedback* (SR17) or *integrate new information* (SR18); critical subroutines in the rule induction process (Klayman & Ha, 1989). Although there was some indication that undergraduates attempted to *organize the data* (19), the relatively few instances of this subroutine (n = 13) were not considered indicative of the use of the subroutine by this group.

The Pattern Extraction strategy also included subroutines in which the subject *extracts patterns evident in the data* (SR22) and then *summarizes the patterns* (SR23) for rule induction. Although several of the investigator's questions focused on pattern extraction, neither undergraduates nor graduates were able to extract scientific principles and patterns embedded in the problem statements. However, graduates were able to summarize patterns evident in chains of correct responses to particular questions. When a response was repeated several times over the course of the simulation, graduates commented on the centrality of the underlying concept and included it within hypotheses tested in future subgoals.

Conclusions

There were no significant differences between undergraduates and graduates on five of the six strategies used to respond to the computer simulation problems. However, group differences existed within strategies. In the Evaluation strategy, graduates were superior in the ability to select evaluative criteria, edit algorithms, and utilize or delete information. No differences between undergraduates and graduates were detected in the ability to list assumptions and assign priorities.

Within the Basic Heuristic strategy, graduates were more effective than undergraduates when listing possible questions, identifying algorithms, and executing the programme. The groups were similar in their ability to list given information and select questions. In the Hypothetico-deductive strategy, both undergraduates and graduates could formulate hypotheses, define predictors, and match data to predictions. Graduates, however, could better predict the accuracy of their hypotheses. As General Problem Solvers, graduates defined the initial state and the goal state more often than undergraduates, but both groups could identify the data needed. Both undergraduates and graduates used all six strategies, but graduates frequently provided a significantly greater number of responses within many of the subroutines of the strategies.

Graduates, however, did not routinely demonstrate the use of several subroutines that are typically associated with expertise. Specifically, they did not match data to predictions or extract patterns from the data, critical factors in formulating rules or principles useful in the solution of more complex problems. In fact, they rarely summarized patterns that existed in the simulation and were either unwilling or unable to state conclusions associated with rule induction. Thus, although the graduate subjects appeared to be progressing deliberately toward expertise, their inability to focus on patterns or basic principles suggested they should not be categorized as experts.

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