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ABSTRACT

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Joseph F. Follettie

ABSTRACT

Typical prevailing task analysis really is skill analysis whose product is a set of generic tasks considered to exhaust or sufficiently sample a skill domain. This approach yields tasks as the base entities of analysis; any understanding of interrelations of structures in the skill architecture in consequence must occur--if at all--above the level of the task. Taking table-using skill as the illustrative domain, this paper presents a view of task analysis and synthesis as dependent on workspace characteristics and grounding on base operations. An assumption anchoring the presentation is that the approach provides a better focus for instructional effectiveness-efficiency issues and solutions than does the more-molar approach wherein tasks are the base entities of analysis.

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TASK ANALYSIS AND SYNTHESIS AS PRECURSORS OF PRODUCTIVE INSTRUCTION

Joseph F. Follettie

Instruction is productive if effective and reasonably efficient. The determination of a constellation or architecture of skills, subskills, tasks, and information domains pertinent to a given area of instruction heretofore for the most part has addressed the narrow objective concerning what to teach or what to teach to. This orientation comes to grips with instructional effectiveness issues in the banal sense that proficiency in basketweaving or berrypicking is dependent on instruction or other forms of prior experience bearing on basketweaving or berrypicking skill. The intellectual work that results--although necessary--is about as exciting as a bucket of warm spit and as efficient as plowing with a stick.

One problem with the usual prevailing approach to instructional design and development is that it has been long on the use of analysis and short on the use of synthesis when identifying a skills architecture. The units of analysis have been too molar to permit useful synthesis of performance structures. An associated problem is a marked tendency in prevailing instructional design and development to give greater weight--in verbal accounts at least--to effectiveness than to efficiency issues. Based on the verbiage, one imagines a predisposition to favor the proposition that effective instruction can be achieved over a wide range of efficiency levels. This paper argues that such a position is untenable--excepting perhaps where students are quite naive and not yet under the control of the principle of least effort--in that effective instruction must be rather efficient since these two facets of instructional productivity are not--as in economics--appreciably independent.

In prevailing instructional design and development it is usual to analyze a complex skill into tasks but not to analyze tasks into base elements from which all tasks in the skill domain can be derived. What usually occurs is skill analysis and the usual result is subskill and molar task inventories at subordinate levels. This effort is useful as far as it goes; it simply does not go far enough.

Driving is a complex skill consisting of such subskills as shifting and cornering. By definition, any subskill subsumes two or more sequences of operations called tasks. A task is a sequence of operations that is essentially invariant over a specified range of operating conditions. Thus, if a normal-state engine reflects one set of operating conditions and a flooded-state engine a second, then starting an engine is a subskill of driving and this subskill subsumes the characteristic engine-starting tasks that apply when the engine is in the normal and flooded states.

A skill analysis might yield a set of subskills each of which subsumes a set of characteristic tasks. A task analysis--performed on tasks identified in the skill analysis--identifies operation elements of tasks in the skill domain. The unique operations in the analysis--the set of base operations--then ground the synthesis of all tasks in the skill domain giving rise to the task analysis.[1] Herein, a subsuming skill--numerical table-using--is analyzed into constituent tasks. The base operations grounding these tasks are distinguished. The tasks then are derived from the base operations in a way that explicates the interrelations among tasks presumed to bear on the development of productive instruction.

The paper sketches a formalization of task analysis and synthesis within a field of constraining workspaces. The objective is to devise a formalization that concurrently serves as a basis for decisions concerning what should be taught and how it should be sequenced--instructional effectiveness issues--and concerning what should not be taught and how extensively and in what form instruction bearing on the different tasks should be rendered--instructional efficiency issues.[2] Since some will not take on faith the notion that instructional efficiency in certain senses is inextrably intertwined with instructional effectiveness, the paper begins with a discussion of these factors in the context of instructional explication.

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[1] Although "laws" of infinite regress cannot be repealed, they can be circumvented. When specifying base operations, the options are to ground the analysis on a base learner population--e.g., kindergarteners--or on a higher-than-base population for whom the instruction is intended. The issue is whether a higher-level grounding inevitably yields a higher-level portion of a more complete analysis grounding on a base learner population. Whatever the area and level of instruction, it would seem prudent to evaluate the usefulness of grounding the analysis on those base operations that are relative to a base learner population. If this proves unnecessary, all that is lost is a bit of time at the drawing board.

[2] The earliest intent of this paper was to address a different audience--those who develop information-display systems for government (particularly the military) and industry. Such an audience does not find efficiency issues quaint, indulgent, or impossibly thorny. One major concern of such individuals is to render an envisioned monitor-operator productive in a workspace dominated by a given information-display system. This entails that the monitor-operator not be overloaded. To insure this, the system developer has at his/her disposal such options as data reduction and conversion. Exercised, such options eliminate or simplify certain information-processing tasks, but at a cost in fine detail. Task formalization schemes should have a role to play in the identification of work-production tradeoffs that insure acceptable production while falling below an overload ceiling.

EXPLICATION, EFFICIENCY, AND EFFECTIVENESS

One justification for performing a skill analysis is to inventory all facets of a skill requiring instruction. Whatever its form, the resulting analysis incorporates a "checklist" against which the level of completeness or explication of instruction can be judged. Imagine two not unduly hypothetical extremes regarding the explication of instruction relative to implications of the skill analysis. Advocates of one extreme position--e.g., occasional gurus from the programmed learning alliance--attempt to "fully explicate" instruction to deal exhaustively with pertinent information sets and information processing and other cognitive and psychomotor tasks. Advocates of the other extreme position--e.g., a few trend-setters from the discovery-learning commonwealth--selectively reduce or delete elements of "fully explicated" instruction to force students actively to seek "solutions" that can be gained by application of extrapolation, generalization, and similar "higher-order proficiencies." This is not the first time such a contrast has been described. It is repeated here to background this paper's position that level of instructional explication defined on this contrast is a pseudoissue in instructional design and development.

Science's contribution to human knowledge thus far has cost perhaps 100 million person professional years of effort. This testifies to the costliness--the gross inefficiency one might say--of original discovery learning. No doubt there are conditions under which well-conceived discovery learning-centered instruction will prove both effective and efficient. Most current efforts in this area appear effective for some--suggesting that instruction taking discovery-learning form constitutes an excellent selection test for budding scientists and engineers. For many, this form of "reduced explication" simply is ineffective.

"Fully explicated" instruction risks ineffectiveness because unaccountable to the student for ratio of return of investment. Such instruction--exemplarized perhaps by certain programmed learning instructional programs--tends to feature a wooden approach to instructional explication wherein elements of earlier proficiency acquisition are reinstructed. The result is an increase in instructional time with no more positive gain than is inherent in overlearning (and this only if the student can be kept in a receptive state). Wherever the principle of least effort holds, any appreciable decrease in efficiency should be accompanied by a loss in effectiveness.

Instructional inefficiency might be tolerated in a pure novitiate (e.g., a kindergarten class wherein the classroom situation itself provides sufficient novelty to counteract operation of the principle of least effort). However, by second or third grade, the notion that instruction can be effective while appreciably inefficient should be giving way to its obverse--that only reasonably efficient instruction can be effective. By then, a least effort tendency should be taking hold wherein success is in part judged against investment.

If instruction excites a sense of boredom (reticular formation "shutdown"), perhaps because appearing deficient for return on investment, then reception will suffer. Effectiveness then also will suffer, no matter how good an opinion its developers might have concerning the instruction's organization, completeness, etc. Effective instruction either will forestall this form of student passivity or student passivity will defeat instructional effectiveness.

Unbroken small successes probably are insufficient to sustain student interest if these successes sum to very little in light of investment. Instruction that is repetitive in the guise of completeness must harvest ineffectiveness for the inefficiency it sows.

Good novels, interesting speeches, storytelling, and stimulating conversations all are characterized by a certain amount of indirection, Socratic baiting, and the like. Good education might also be spiced up by occasional use of well-constructed invitations to engage in discovery learning. For the most part, though, effective instruction will be the pawn of "compelling explication." Such explication is flexible rather than mindless; its basis in instructional design and development needs to be made explicit. One approach to explicating the explication that the instruction of given content compels is a task specifying formalization that is geared to this requirement.

To summarize, instructional effectiveness must appreciably be influenced by instructional efficiency because students are no more immune to least effort expectations and effects than the rest of society. Instructional explication is an important factor in achieving instructional effectiveness, but if achieved in an excess manner leading to undue reinstruction of elements of previously acquired proficiency, explication must lead to instructional inefficiency, which must erode effectiveness. A task specification mechanism is required that can be used to discern compelling forms of instructional explication that concurrently support the effectiveness and efficiency facets of productive instruction.

MACROFEATURES OF TASK SPECIFICATION

Pursuit of the objective of joint effectiveness and efficiency based on compelling explication using the mechanism of task specification requires an analysis that "molecularizes" at the level of base operations (or perhaps base tasks) rather than "molarizes" indiscriminately at the level of tasks. The required task specification should ground on base components, should differentiate pertinent progressively more extensive or complex task sequences at progressively higher elevations, and should show antecedents to any task structure at any level by the use of appropriate networking conventions.

The anatomy of task specification should be more nearly analogous to chemistry's than to botany's. The specification should accommodate both tasks of immediate interest and many that are presently undefined but might prove of interest when instruction under development is extended. Like the infrastructure of chemistry, that of task specification should ground on basic building blocks that assemble to all higher-order structures that might prove of interest. Such an infrastructure can be indifferent concerning whether a domain of pertinent tasks is finite or infinite. But it will be sensitive to the nature of structural relationships holding between specified tasks or between a specified task and the structures on which it grounds. It is this sensitivity that renders a task specification useful to an instructional designer or developer seeking to minimize reinstruction.

The table-using tasks one could levy in relation to a numerical table having a specified row-column margin structure are not operationally identical to those that are leviable when row-column margin structure is modified. If one views numerical tables as constraining workspaces, then the common different forms of numerical tables constitute a set of workspaces, with any two of these sharing some features and not others. In the next section is sketched a preliminary model of numerical table-using workspaces grounding on a set of base operations from which is drawn a sequence of operations used to process row and/or column margins to determine a pertinent row and/or column.

The present view of constraining workspaces is neither novel nor particular. A basement workshop is a workspace enabling certain tasks and not others. Some that this workspace does not enable are those that a garden workspace surely does--for example, spading and weeding. Like a set of tables differing in structure, the basement workshop is a generalization subsuming a variety of workspaces whose particular configurations and forms of equipment determine what tasks can be performed in them.

Most numerical tables consist of a title, a column margin, a row margin, and an entry field. If one varies title information while holding all else constant, the result is semantic variation. If one varies row or column margin structure, the title information also must be varied and the result is both semantic and structural variation. Semantic variation per se has little effect on task specification. Its principal implication is that an analysis subsuming semantic variation must yield the base operation "Select the appropriate table."

One changes tables structurally by operating on their row and column margins. A row margin might reflect coordinate or hierarchical organization; a column margin, coordinate or factorial organization. Column margins sometimes encompass diverse measures and derivations from these. Both row and column margins reflecting coordinate organization can in addition show lines of sums, percentages, and means. It is possible to construct complex tables incorporating several such complications.

One approach to dealing synthetically with this diversity of possible structures would be to attempt to specify some base forms of tables from which any of the different possible complex structures can be assembled. This approach either will not work or else will prove unduly Ptolmaic. The alternative to be sketched entails distinguishing between base operations of two types--those relating to nonshared elements of workspace structure--row and column margins--and those relating to shared elements--all else.

To summarize, the infrastructure of a task specification accommodating the range of instructional productivity issues must be more analogous to chemistry's than to botany's. Moreover, it will need encompass pertinent variation in workspace structure with sufficient analytic efficiency to avoid bogging down in a morass of potentially infinite complication. One means to this end is sketched in the next section.

TABULAR WORKSPACES

A multilevel column margin typically reflects as many factors as there are levels. The tendency is to process a multilevel column margin from the top down--one factor at a time. A multilevel row margin typically reflects hierarchical organization, with coordinate entities (members) at a first level and class subsumers at higher levels. For example, farming and urban county memberships might occur at the lowest level, farming and urban county subsumers (subtotals) at the next highest level, and an overall subsumer (total) at the highest level. Herein, it is assumed that row margin processing differs from column margin processing in that a multilevel row margin is processed in just two operations--locating the appropriate row set and, if it contains more than one row, locating the appropriate row in the set. Such processing is facilitated by conventional row margin layout, which differentiates row sets (somewhat independently of their level of organization) by spacing, lining, or both.

Few people ever have cause to use a numerical table having more than three levels of organization in row and column margins. The foregoing impressions concerning how row and column margins are processed are given systematic expression in Table 1. Any numerical table must contain at least two entries. The table asserts that such a minimal display will necessitate at least one row or column location operation and that a maximally complex display (herein reflecting three row and three column margin levels of organization) will necessitate three column locating operations and at most two row locating operations. The preliminary typology of tabular workspaces to which Table 1 gives rise is graphed in Figure 1.

A generic entry location task consists of preliminary operations, followed by row and/or column selection operations, followed by entry location operations. When just one table is to be examined, the preliminary and entry location operations will be structure-free. That is, these operations will not vary with variation in workspace structure. Conversely, row-column location operations will be structure-dependent. Table 1 and Figure 1 reflect preliminary impressions concerning how row-column location operations vary with workspace structure.

A definitive model of row-column locating operations should yield operation sequences for which there is covariation between length of the sequence and a measure of processing effort--units of response time, for example. The simplest view of such covariation is that the length/effort relation should be linear.

After formulating the preliminary model, I examined earlier findings for data bearing on the covariation question. A somewhat pertinent study bearing on the column margin processing facet of the perspective (Follettie, 1978, Study 4) featured variation in factorial

Table 1

Row/Column Location Operations When Row Margins are Set-Organized and Column Margins Feature 1-3 Levels

Opn Code	Condition	Operation
1a	Row sets = 1. Rows in rth set = 1.	Do not count Opn 1. Exit row location.
1b	Row sets = 1. Rows in rth set > 1.	Locate ith row. Exit rl.
	OR	OR
	Row sets > 1. Rows in rth set = 1.	Locate rth set (= rith row). Exit rl.
1c	Row sets > 1. Rows in rth set > 1.	Locate rth set. Do Opn 2.
2	Operation 1c.	Locate rith row. Exit rl.
3a	Col levs = 1. Cols at 1st lev = 1.	Do not count Opn 3. Exit col location.
3b	Col levs = 1. Cols at 1st lev > 1.	Locate jth col. Exit cl.
	OR	OR
	Col levs > 1. Flds at 1st lev > 1. Cols at 2nd lev = 0.	Locate jth field (=jth col). Exit cl.
3c	Col levs > 1. Flds at 1st lev > 1. Cols at 2nd lev > 1.	Locate jth field. Do Opn 4a.
	OR	OR
	Col levs > 1. Flds at 1st lev > 1. Flds at 2nd lev > 1.	Locate jth field. Do Opn 4b.
4a	Cols at 2nd lev > 1. Cols at 3rd lev = 0.	Locate jkth col. Exit cl.
4b	Flds at 2nd lev > 1. Cols at 3rd lev > 1.	Locate jkth field. Do Opn 5.
5	Operation 4b.	Locate jklth col. Exit cl.

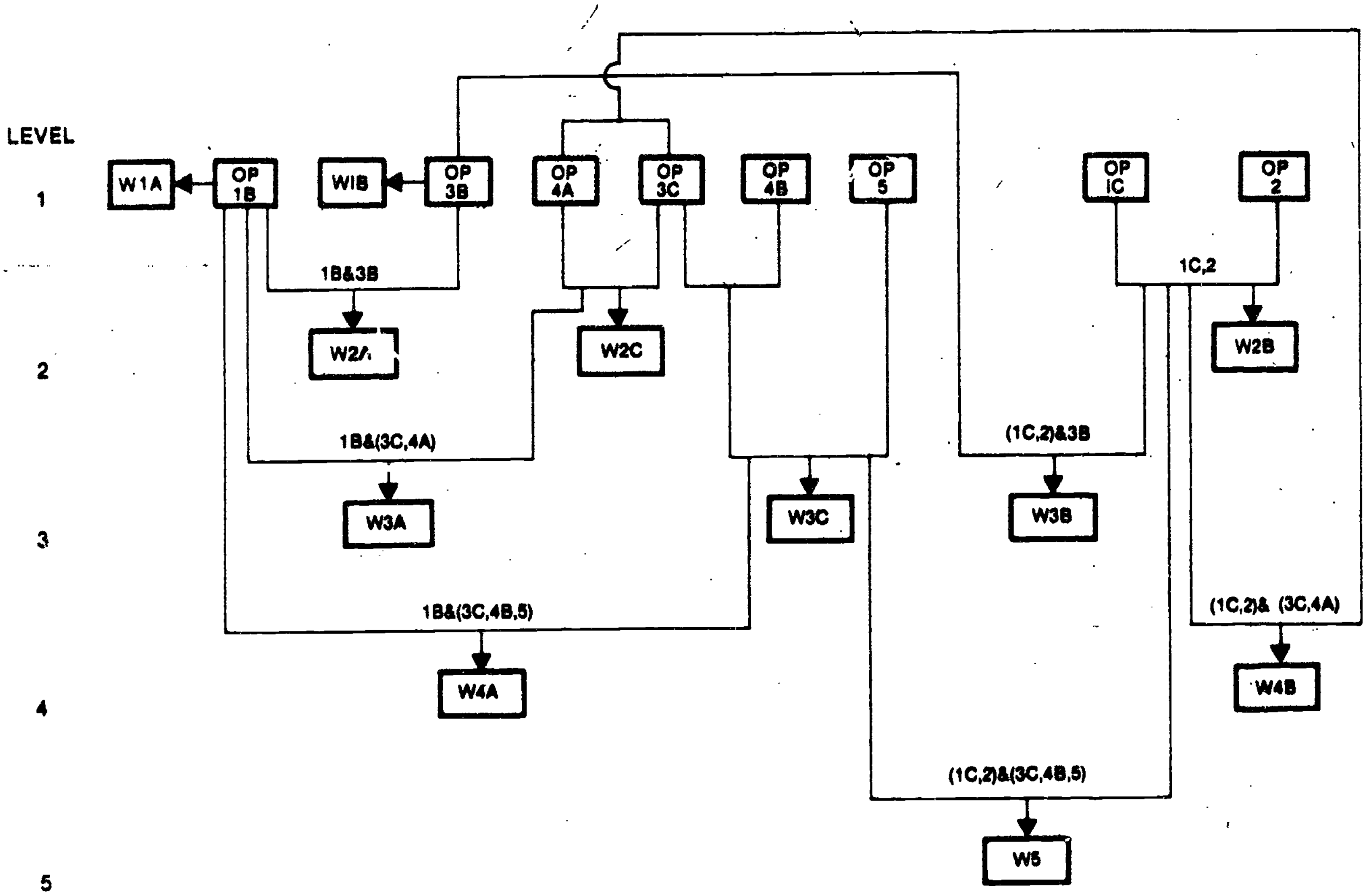


Figure 1. The levelled types of workspaces that inhere in Table 1.

organization of column margins. Twenty 5th-6th graders retrieved entries from tables featuring one-level column margin organization (1x8), 20 from tables featuring two-level organization (2x4), and 20 from tables featuring three-level organization (2x2x2). All tables were equally extensive, consisting of 80 entries in 8 columns x 10 rows. According to Table 1, the number of row-column location operations are 2 for the 1x8 structure (coded W2A in Figure 1), 3 for the 2x4 structure (W3A), and 4 for the 2x2x2 structure (W4A).

The pertinent means are presented in the lefthand portion of Table 2. In the righthand portion of the table, it is shown that mean response time per row-column location operation does not vary appreciably and that mean accuracy divided by mean time divided by number of operations is virtually constant across studied column margin structures. Although the database is inadequate if the objective is to show that response time increments in unit fashion per column-locating operation over the range of Table 1, it does not contradict this proposition.

Table 2

Mean Performance When Retrieving Entries from Tables having One to Three Levels of Column Margin Organization, and Effects on Mean Performance When Response Time is Divided by Number of Row/Column Operations

Col. Margin Org.	Mean Accuracy*	Mean Accuracy/ Time	Row-Col. Loc. Opns.	Mean Time	Mean Time Per Row/ Col. Loc. Opn.	Mean Acc./ (Mean Time/ Opns.)
1x8:W2A	19.6	5.7	2	3.44	1.72	11.4
2x4:W3A	17.8	3.8	3	4.68	1.56	11.4
2x2x2:W4A	16.6	2.7	4	6.15	1.54	10.8

*Based on responses to 20 queries per participant.

Another somewhat pertinent study bears on the row margin processing facet of the perspective (Follettie, 1978, Study 3). Again all tables were equally extensive, consisting of 81 entries in 9 columns x 9 rows. The following three row margin structures are presently pertinent: one featuring nine coordinate rows (1111=W2A), one featuring eight coordinate rows and a total row (1211=W3B), and one featuring two sets of three coordinate rows, their subtotal rows, and a total row (1311=W3B). Students at three grade levels participated. To achieve comparability with Study 4 findings discussed above, only 5th-6th grader data are considered here. Twenty 5th-6th graders retrieved entries from the 1111 tables, 20 from the 1211 tables, and 20 from the 1311 tables. According to Table 1, the number of row-column location operations for the different structures are 2, 3, and 3, respectively. However, these are maximal values for 1211 and 1311 structures. For these structures, the appropriate row set contained just one row 10 times in 20. Hence, the correct row-column locating operations for these structures on the average were 2.5 and 2.5, rather than 3 and 3.

The pertinent means are presented in the lefthand portion of Table 3. In the righthand portion are shown analogous derivations to those shown in the righthand portion of Table 2. These data suggest that Table 1 overstates the number of row operations when there are just two row sets and one contains just one row (1211) and understates the number of row operations when there are five row sets and three contain just one row (1311). It might be that simply adding a total row should not increase the number of row locating operations. Conversely, when the row margin grows more complex, number of row sets might need be taken into account.

Table 3

Mean Performance When Retrieving Entries from Tables Having One to Three Levels of Row Margin Organization, and Effects on Mean Performance When Response Time is Divided by Number of Row/Column Operations

Col. Margin Org.	Mean Accuracy*	Mean Accuracy/ Time	Row/ Col. Loc. Opns.	Mean Time	Mean Time Per Row/ Col. Loc. Opn.	Mean Acc./ (Mean Time/ Opns.)
1111:W2A	19.4	5.05	2.0	3.84	1.92	10.1
1211:W3B	19.2	4.9	2.5	3.92	1.57	12.2
1311:W3B	17.1	3.0	2.5	5.70	2.28	7.5

*Based on responses to 20 queries per participant.

Were one to modify the Table 1 formulation consonant with the negative evidence afforded by Study 3, the resulting formulation would reflect the form that additional empirical work bearing on the formulation should take.

Table 1 and Figure 1 reflect two minimally complex structures--W1B (a one-row or R1 table that does not entail a row location operation) and W1A (a one-column or C1 table that does not entail a column location operation). There are two other types of row margin--one featuring only coordinate rows (Opn 1B) and one featuring multilevel organization that manifests itself as two or more row sets (Opns 1C, 2). There are three other types of column margin--one featuring only coordinate columns (Opn 3B), one featuring two levels of organization (Opns 3C, 4A), and one featuring three levels of organization (Opns 3C, 4B, 5). Some of these types encompass a good deal of variation in structure--variation that is not considered pertinent in the preliminary perspective but might prove so in consequence of further study. Exemplary row structures are shown in Exhibit A; exemplary column structures, in Exhibit B.

Exhibit A

Exemplary Row Structures of Type 2 (Opn 1B) and Type 3 (Opns 1C, 2)

Type R2 (Coordinate)	Type R3A (Two-Set Hierarchical)	Type R3B (Multi-Set, Hierarchical)
A	A	Total
B	B	Farming
C	C	A
D	D	B
E	E	C
F	F	Urban
G	G	D
H	H	E
I	I	F
J	J	G
K	K	Other
L	L	Mean: All Counties
M	M	Mean: Farming Counties
N	N	Mean: Urban Counties
O	Total	Mean: Other Counties

The Exhibit A row margins are equally extensive; each contains 15 rows. According to the Table 1 perspective, the Type R2 margin entails one operation--selecting the appropriate row from a single set. A type R3 margin entails two operations if the query is to a multirow set, but only one if it is to a single-row set. That is, one first selects the appropriate row set (from two or more). Then, if this set contains more than one row, the second operation involves selecting the appropriate row from it. The negative evidence presented above suggests that Types R3A and R3B should be further distinguished--probably on the basis of number of row sets in the margin.

Exhibit B

Exemplary Column Structures of Type 2 (Opn 3B),
Type 3 (Opns 3C, 4A), and Type 4 (Opons 3C, 4B, 5)

Type	Exemplar							
	1	2	3	4	5	6	7	8
C2: Coordinate	A	B	C	D	E	F	G	H
C3A: Two-Level	People				Personal Income			
	Tot	M	F	<16	Tot	50+Y	30-50Y	<30Y
C3B: Two-Level (Crossed)	Charolais				Hereford			
	1950	1960	1970	1980	1950	1960	1970	1980
C4B: Three-Level (Crossed)	Charolais				Hereford			
	Male		Female		Male		Female	
	2+Yr	<2Yr	2+Yr	<2Yr	2+Yr	<2Yr	2+Yr	<2Yr

The Exhibit B column margins are equally extensive; each contains 8 columns. Based on the Table 1 formulation, the Type C2 margin entails one operation--locating the appropriate column. A Type C3 margin entails two operations--locating an appropriate field of columns at the highest level and an appropriate column in this field. A Type C4 margin entails three operations--locating an appropriate field at the highest level, an appropriate subfield at the next highest level, and an appropriate column at the lowest level. The meager positive evidence presented above suggests that such an analysis of column margins suffices.

One-row tables are as follows: W1A = R1C2, W2C = R1C3, W3C = R1C4. Although rare, these types have received empirical scrutiny (Wright, 1977). One-column tables are more frequently encountered. These include W1B = R2C1 and W2B = R3C1. The remaining structures of Figure 1 are combinations of row and column margin types appearing in Exhibits A and B: W2A = R2C2, W3A = R2C3, W4A = R2C4, W3B = R3C2, W4B = R3C3, and W5 = R3C4.

The perspective does not speak directly to tables having unbalanced column margins, an example of which appears in Exhibit C.

Exhibit C

An Unbalanced Column Margin Table Illustrating a Mix of Assignable Workspaces

County	Area	Population					Personal Income	
		Total	Male		Female		Total	Per Capita
			16+Y	<16Y	16+Y	<16Y		
A	1014	101K	26	20	30	25	$527.3M	$5221
B	653	52K	14	12	15	11	316.9M	6095
.								
.								
.								
N	901	41K	11	8	10	12	255.22	6225

A query to the Area column (1) causes the table to project workspace W2A; one to the population total column (2), W3A; one to columns 3-7, W4A; one to columns 8-9, W3A.

The perspective is silent concerning extensiveness effects. There is meager evidence (Follettie, 1978, Probe 2A) that response time increases somewhat when one goes from a 49-entry (7x7) to a 144-entry (12x12) table. For 5th-6th graders, retrieving an entry from the larger table takes a third longer, and accuracy declines a fifth.

Nor does the perspective deal with row-column labelling semantics. This topic falls outside the structural domain but might influence response time and so might need in some sense be considered in a definitive formulation of row-column selection operations.

Although preliminary, the sketched formulation and accompanying commentary should clarify that workspace features influence task characteristics and lend support to the view that quantification of structural variation of tabular workspaces is a manageable undertaking. The structures of workspaces dominated by gauges and similar indicators might be a bit more challenging. When one adds in CRTs bearing text and diverse graphics, the level of challenge increases appreciably; but if text elements can be handled in such instances, all else surely can.

MICROFEATURES OF TASK SPECIFICATION

The general conditions giving rise to the performance of a task and its completion should take the same form across tasks. Whether one is spading a garden or using a numerical table, the task occurs in a workspace with some conditions on labor. If the task is table-using, the workspace is a numerical table. Form of the performing milieu is as follows:

- A levied task T is a sequence of operations performed under levied conditions Q relating to a specified workspace W to accomplish a levied response R.
- Whether generated by a user or an external source, a task-levying command L takes the general form "Given Q in the context W, 'deduce' and perform T to obtain R."
- The command implies T but does not model it. Whether deduction or some other form of apprehension then must occur, the user must formulate and perform T based on the indications provided by L (or Q in the context W). This the user can do if possessing suitable experience--for example, based on instruction.
- The obtained response R* (signifying, for example, the recording of obtained pertinent information) implies the obtained performance T* (subject to chance error considerations). If R* models R (implying T* models T), then, if chance error is taken into account, T is assumed proficiently performed.

Imagine a numerical table W having a title, a column margin having five coordinate category or membership column headings (Type C2--for example, successive years), a row margin having 10 coordinate category or membership row headings (Type R2--for example, independent producers), and a 5x10 field of numerical entries reflecting the outputs of the different producers in the different years.

Let L1 take the form "How many tons of the product did the ith producer grow in the jth year?" If the data are fictitious, the chance probability that $R^* = R$ can always be set at $1/rc = 1/50$ by rendering each entry unique.

Let L2 take the form "Which producer grew the most (least) product in the jth year?" The chance probability that $R^* = R$ again is $1/rc = 1/50$.

The L1 and L2 tasks can be combined as follows:

- L3 takes the form "Which producer--the i_xth or the i_yth--grew the most (least) product in the jth year?" To perform this task, one performs L1 with respect to i_x and with respect to i_y (in either order) and then performs L2 with respect to the array $E_{i_x j}$, $E_{i_y j}$.

- If the first and second performances of L1 are considered independent--not very tenable--then the change probability that R* = R is $(1/rc)^2(1/2)$.
- More likely, the second performance of L1 will make use of the information that j is the appropriate column and that the first i is to be deleted in the second L1 search. Hence the chance probability that R* = R is (1/rc)(1/9)(1/2) = 1/900.

For most tasks performed relative to moderately extensive tables, proficiency assessment is adequately defensed against chance effects if at most a handful of L-type queries is responded to.

Ignoring certain preliminaries, the base operations underlying the L1 task are:

- 1 Locate the row (Opn 1B of Table 1).
- 2 Locate the column (Opn 3B of Table 1).
- 3 Go right along the row to ij--the locus of entry E_{ij}.
- 4 Go down the column to ij.

Opns 1 and 2 are performed first, in either order (1&2). Opns 3 and 4 next are performed concurrently (3:4). L1 commands the task sequence T1 = 1&2, 3:4.

Again ignoring certain preliminaries, the base operations underlying the L2 task are:

- 2 Locate the column (Opn 3B of Table 1).
- 5 Scan the column array; identify the largest entry.
- 6 Go left along the largest-entry row to the named producer in the row margin.

These operations are performed in order. That is, L2 commands the sequence T2 = 2, 5, 6.

A student having learned T1 and T2 in the context W, what added instruction is required to elicit the T3 response to L3? L3 commands that one perform L1 twice and then L2. One would expect column selection to occur during the first L1 response and to be unnecessary during the second L1 response and the following L2 response. Efficient deletion of repetitive steps seems so natural under such conditions that it is not really necessary to show the T1 T1 T2 sequence as the reduced sequence T1 T1- T2-, since in practice

T1 T1 T2 will be rendered in reduced form without benefit of instruction. In base operations, L3 commands T3 = 1&2, 3:4; 1, 3:4; 5, 6.

All that needs to be taught to render a student already proficient in T1 and T2 also proficient in T3 is the notion that L3 entails the sequence T1 T1 T2. Thirty seconds of exposition followed by a few minutes of critiqued practice should suffice. Any "awesome" complexity that might seem to inhere in T3 relative to T1 and T2 (which occur one level lower in the task specification network) like Everest exists more at the base than nearer the summit.

One could terminate any task sequence on such operations as "Read and momentarily remember the obtained information" and "Record the information (consonant with prevailing record-keeping conditions)." In the foregoing illustration, such operations are left tacit because they do not vary from task to task.

Different tasks conceivably pose different instructional challenges based on their ordering characteristics. A task might be fully ordered (T2 above), semiordered (T1 above), or (a remote possibility) unordered. Tasks vary for length, recursiveness, and other characteristics that might bear on instructional handling. All such features of tasks are potentially distinguishable within the task specification framework being sketched.

To summarize, tasks arise in workspaces under suitable eliciting conditions. We infer proficient performance according to the proposition that the end implies the means. When a higher-level task results from the sequencing of two or more previously mastered lower-level tasks, about all that requires teaching regarding the higher-level tasks is that it is a specified sequence of lower-level tasks that is responsive to a customary command in the context of a specified workspace.

AN ILLUSTRATIVE TASK SPECIFICATION

Exhibit D illustrates an R2C2 (or W2A) workspace--a numerical table whose features were described in the previous section. The commoner tasks that can be levied relative to the use of the table entail responding to the different queries listed below.

Exhibit D

Thousands of Tons of Corn Grown in the Ten Leading Farming Counties of the State of Calvada in the Years 1971-75

County	Year				
	1971	1972	1973	1974	1975
Alturas	7	9	9	14	11
Carson	12	23	19	26	15
Ebbets	50	52	55	51	54
Fricot	2	3	6	5	10
Glenn	38	30	37	32	36
Jackson	28	16	24	40	27
Modoc	44	48	31	18	46
Oakdale	39	25	17	22	41
Placer	42	33	45	35	43
Trinity	21	29	34	13	20

Recall that a task-levying command L consists of a a set of conditions or query Q in the context W. Exhibit D specifies W. Exemplars of representative forms of Q are:

Absolute Retrieval (T1)

- Q10: Obtain Entry. HOW MANY KTONS OF CORN DID GLENN COUNTY GROW IN 1974?
- Q11: Obtain Row Descriptor. WHICH COUNTY GREW 25 KTONS OF CORN IN 1972?
- Q12: Obtain Col Descriptor. IN WHICH YEAR DID MODOC COUNTY GROW 18 KTONS OF CORN?

Superlative Retrieval (T2)

- Q21: Obtain Row Descriptor. WHICH COUNTY GREW THE MOST (LEAST) CORN IN 1973?
- Q22: Obtain Col Descriptor. WHAT WAS PLACER COUNTY'S BEST (WORST) CORN-GROWING YEAR?

Assembly Task (T3 = T1 T1 T2)

- Q31: Obtain Row Descriptor. WHICH COUNTY--GLENN OR PLACER--GREW THE MOST (LEAST) CORN IN 1974?
- Q32: Obtain Col Descriptor. IN WHICH YEAR--1972 OR 1974--DID EBBETS COUNTY GROW ITS LARGEST (SMALLEST) AMOUNT OF CORN?

Arithmetic: Summing Task

- Q41: Obtain Col Sum. HOW MANY KTONS OF CORN WERE GROWN IN THE TEN COUNTIES IN 1973?
- Q42: Obtain Row Sum. HOW MANY KTONS OF CORN WERE GROWN IN JACKSON COUNTY IN THE 5-YEAR PERIOD?

Other tasks involving arithmetic--for example, deriving percentages, means, and differences between sums--can be specified. Although an R2C2 table invites the derivation of sums and other values, wherever these are considered appreciably pertinent, a table developer would use a more complex form of table--one that includes, for example, summing rows and/or columns. Such an approach has the effect of transforming tasks involving computation into simple retrieval tasks.

There are in addition to the tasks specified above some word knowledge and format comprehension tasks one might levy with regard to Exhibit D. Some examples are:

Word-Phrase Knowledge

- Q51: IONE COUNTY IS A COUNTY OF CALVADA, BUT IT IS NOT MENTIONED IN THE TABLE. IONE COUNTY WAS NOT ONE OF THE:
    - FARMING COUNTIES OF CALVADA.
    - CORN-GROWING COUNTIES OF CALVADA.
    - TEN LEADING FARMING COUNTIES OF CALVADA.
    - TEN LEADING FARMING COUNTIES OF CALVADA IN 1971-75.
    - COUNTIES THAT GREW THOUSANDS OF TONS OF CORN.

Format Comprehension

- Q52: THE NUMBERS THAT MAKE UP MOST OF THE TABLE STAND FOR:
  - AMOUNTS.
  - TONS OF CORN.
  - KTONS.
  - NUMBER OF PEOPLE IN THE COUNTIES.
  - NUMBER OF FARMERS IN THE COUNTIES.

Let a display to be processed consist of three parts: instructions, table, query. A student user in a proficiency assessment situation will encounter explicit instructions. A user who initiates usage will do so on the basis of instructions that might not be public. Whatever the auspices under which an information display is used, constraints in the form of preliminary instructions will be present. These take the form of a sequence of preliminary operations that apply to a task without regard to structure of the workspace. A full description of the task-levying command L adds this source of constraint. That is, L consists of Q in the contexts W and P.

One element of the preliminary sequence of operations indicates the form that an overt response--the culminating operation(s) in a task-length sequence--should take. To distinguish between row and response notation, the symbol for the levied response hereafter is ℟. Common forms that the levied response can take when the task involves table-using include:

- ℟1: Circle the descriptor or entry.
- ℟2: Record the descriptor or entry.
- ℟3: Mark the appropriate response alternative.

Terminal uses of such codes in operation sequences need occur only when different codes apply to different tasks. When a task consists of lower-order tasks, the response codes for certain lower-order elements clarify the nature of the higher-order task sequence.

Were it considered necessary to render the levied preliminary operations rather fully explicit, they might take the following form:

- P1: Read the query.
- P2: Examine the table (for title information and layout).
- P3: Reread the query (to refresh memory).
- P4: Respond to the query using form ℟$_i$.

For the set of tasks cited above, 14 base operations can be distinguished. Two of these--1 and 2--deal with row-column location. Two others--10 and 11--are task sequences in arithmetic which are shown here as belonging to the set of base operations simply to avoid developing a parallel task specification for arithmetic. The set of base operations is:

- 1 Locate R_i (Opn 1B of Table 1).
- 2 Locate C_j (Opn 3B of Table 1).
- 3 Locate E_{ij} (an entry in the ith row and jth column).
- 4 Go right along R_i to the intersection with C_j.
- 5 Go down C_j to the intersection with R_i.
- 6 Go left to the R_i descriptor.
- 7 Go up to the C_j descriptor.
- 8 Locate the largest (smallest) number in the C_j array.
- 9 Locate the largest (smallest) number in the R_i array.
- 10 Perform the C_j array-summing sequence.
- 11 Perform the R_i array-summing sequence.
- 12 Locate the row universe descriptor in the title.
- 13 Locate the entry universe descriptor in the title.
- ~~14 Determine the cited individual's status in the universe.~~

The sequences of operations for the different tasks are constructed from the set of base operations and the set of levied response forms. These sequences are responsive to the query forms inventoried above. Thus, T10 responds to Q10 in the contexts W and P; T11 to Q11; etc.

- T10: 1&2, 4:5, R2.
- T11: 2, 3, 6, R2.
- T12: 1, 3, 7, R2.
- T21: 2, 8, 6, R2.
- T22: 1, 9, 7, R2.

- T31: 1&2, 4:5, ℞1; 1, 4:5, ℞1; 8, 6, ℞2 (= T10 T10 T21)
- T32: 1&2, 4:5, ℞1; 2, 4:5, ℞1; 9, 7, ℞2 (= T10 T10 T22)
- T41: 2, 10, ℞2.
- T42: 1, 11, ℞2.
- T51: 12, 14, ℞3.
- T52: 13, ℞3.

Note that the levied terminal response forms conform to the illustrative queries presented above. One could require alternative response forms and indeed could distinguish task sequences differing in just these terminal response forms. There might be pedagogical or other operating conditions under which one would wish to levy tasks featuring several response forms and other conditions under which interest would be confined to one particular response form for a particular task.

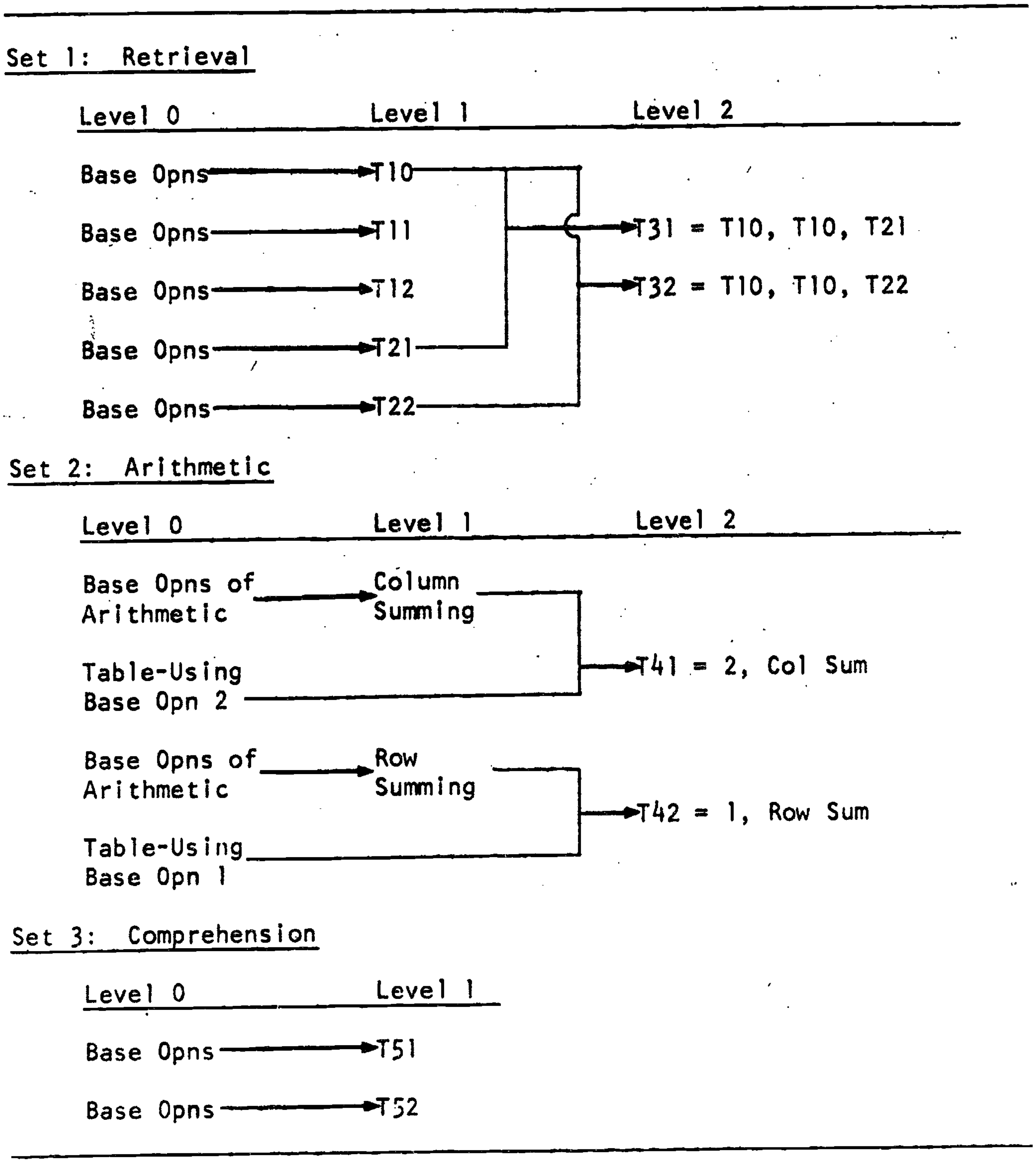
Row-column distinctions in the foregoing analysis stem in part from the Table 1 perspective and in part from bits of data supporting the view that upper elementary schoolers are not always equally effective when selecting row and column descriptors, scanning a row or column of entries, etc. For some individuals, summing a row array necessarily involves first transforming the row array into a column array. The present view is that it would be counterproductive to simplify the analysis by setting aside the row-column distinctions.

Noted earlier, Opns 10 (column summing) and 11 (row summing) are not base operations but effects descriptors of sequences of base operations specified in arithmetic. It is assumed these sequences are a few levels above the base operations of arithmetic, but that 4th graders either have mastered them or are near doing so. Hence, Opns 10 and 11 can be treated schematically like first-level tasks more customary to table-using--T10 and T22, for example--if instruction in the use of R2C2 tables does not occur before 4th grade and cause is found to levy column and/or row summing tasks.

The tasks inherent in Exhibit D fall into three sets in terms of task antecedents. The diagrams of these sets appear in Exhibit E.

Exhibit E

Antecedents of Tasks Leviable in the Context of an R2C2 Numerical Table



Once the base tasks at Level 1 are mastered, Level 2 tasks that are assemblies of base tasks require as instruction only the information concerning how base tasks are sequenced to form the higher-level tasks--for example, T31 = T10, T10, T21.

All of the R2C2 tasks transfer to other tabular workspaces, except that the row-column location operations of R2C2 (Opns 1 and 2 above) give way to other subsequences of operations; these are specified in Table 1. It is to be expected that some of the more complex workspaces will invite the levying of some tasks not discussed in this section and that any such task might feature one or more base operations not inventoried in this section.

To summarize, useful tasks in R2C2 context include several that require the retrieval of specified information, a few that require the use of proficiencies instructed under a mathematics heading in conjunction with locating a specified row or column, and a few entailing the understanding of title semantics (based on word-phrase proficiencies instructed elsewhere--in reading instruction, for example) and table-formatting conventions. Except for row-column locating operations--which are unique to a given form of tabular workspace--the R2C2 tasks in general can be viewed as generic to numerical table-using. These tasks are structure-free except with regard to row-column location.

The base operations underlying any set of tasks specified, it becomes possible to level the tasks according to some rational scheme. Herein such a scheme involves the sequential assembly of base operations into base tasks and of base tasks into higher-order tasks. Conceivably, useful tasks at the third level could be specified in an R2C2 context. If so, these would consist of previously specified second- and perhaps first-level tasks in appropriate sequence. Where the lower-level components of such aggregations are previously instructed, however high the level of aggregation, the instructional task simply is to convey the sequence of the components in the aggregation.

CONCLUDING COMMENT

There is nothing particularly new in the analytic-synthetic views that ground this presentation. Even the notion that workspaces constrain leviable tasks has a long history in skill and task analysis. The principal merit of the present exposition is that it takes seriously the notion that systematic attention to various percepts of task-analytic lore could result in much clearer views concerning the design and development of instruction that is sufficiently efficient to deliver on promissory effectiveness.

When the objective is to design productive instruction, choice resides in instruction-engineering options. The sketched approach also could be exploited in an information system design context, where the objective is to present and package information consonant with rendering a suitably-trained monitor-operator productive. In this situation, operator performance parameters and system objectives are given (and, hopefully, specified), with choice residing in workspace engineering options.

References

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