Assessing Active Knowledge

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ASSESSING ACTIVE KNOWLEDGE[1]

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The theme we would like to convey is described in a 1971 paper by Robert McClintock entitled “The Place of Study in a World of Instruction.” This discussion admirably conveys the spirit in which the approach to educational assessment based on cognitive research can be framed. McClintock reminded us that classical philosophers from Plato to Erasmus considered education as consisting not so much of instruction, as of study. Diverse forms of study were seen as the driving force in education, a view quite different from that in which instruction supplies students with knowledge and thereby accords them a passive role in learning. In this classical conception, instruction was not sufficient because it left “too little room for human doubt, inquiry, uncertainty and the search for ideas” (pp. 171-172). The world of education did harbor a place for instruction, but it was a subordinate place. Instruction should have the mission of making itself unnecessary; learners should become mindful architects of their own knowledge. The true goal of education was to foster study, or in modern terms, constructive cognitive activity.

Somehow in the modern world, instruction, not study, became ascendant. McClintock dates this reversal in emphasis as beginning in the 17th century, with the influence of Comenius’ message in *The Great Didactic.* As the movement toward educating greater numbers grew, instruction won precedence. Didactic teaching became the near universal approach, and seemingly compatible associational behaviorist theories of learning abetted its dominance or hegemony. Concepts of students’ self-regulation and control over their learning were obscured.

Now, empirical findings on the nature of cognition have opened the black box of study and related mental activities, yielding new understanding of their value to learning. Many investigations inform us that competence is fostered through

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teaching that engenders specific kinds of cognitive activity. In designing curricula and instructional practices, the question is only partially what ought to be learned, important as this is. Equally important is examining the opportunities that students have for working and playing with ideas and procedures, and the effectiveness of the tools and environment used for these purposes. In this context, our remarks are presented in three sections: Conditions of Cognition, Analyzing Cognitive Activity, and Active Cognition in the Classroom.

Conditions of Cognition as a Framework for Educational Practice

Certain fundamental principles of cognition can play a central role in the design of tools for the education community, and also in efforts to secure the strong relationship between research and practice that can guide educational change and support *study* in the classical sense. The recurring theme is that learning is a process of constructing new knowledge on the basis of current knowledge. The pervasiveness of this idea in cognitive science is evident in a trend of three central concepts that have implementations for teaching and assessment: (1) the representation and organization of knowledge; (2) self-regulation, metacognition, or what can be called a change of agency for learning; and (3) the social and situational nature of learning. Just a moment on each.

The representation and organization of knowledge. Extensive research and theory on human problem solving shows that the ways students represent the information given in a math or science problem, or in a text that they read, depends upon the organization of their existing knowledge. As learning occurs, increasingly well-structured and qualitatively different organizations of knowledge develop. These structures enable individuals to build a representation or mental model that guides problem solution and further learning, to avoid trial-and-error solution strategies, and to formulate analogies and draw inferences that readily result in new learning and understanding.

It seems clear that pattern-based retrieval serves as a cueing schema for appropriate action in competent performance. This mechanism reflects the acquisition of well-organized and integrated knowledge and provides a structure for representation that goes beyond surface features. Advanced learners' knowledge is organized around principles and abstractions. These principles are not readily apparent in the original problem statement but are derived from knowledge of the subject matter. In addition, advanced learners' knowledge includes knowledge about the application of what they know.

In contrast, the knowledge of new learners is organized around the literal objects explicitly given in a problem statement or situation. Their knowledge schemas may contain sufficient information about a problem situation but lack knowledge of conditions of their application. These new learners may demonstrate effective problem-solving heuristics; however, the limitation of their thinking derives from the inability to infer further knowledge from the literal cues in the problem statement. For advanced learners, these inferences are necessarily generated in the context of the knowledge structure that they have acquired.

The argument to be made for instruction and the development of competence and expertise is that knowledge must be acquired in such a way that it is highly connected and articulated, so that inference and reasoning are enabled, as is access to procedural actions. The resulting organization of knowledge provides a basis for thinking and cognitive activity. Structured knowledge, therefore, is not just a consequence of the amount of information received, but reflects exposure to an environment for learning where there are opportunities for problem solving, analogy making, extended inferencing, interpretation, and working in unfamiliar environments requiring transfer. These are significant targets for assessment that needs to be further developed for promoting achievement.

Self-regulation and self-agency. With increasing attainment of knowledge and skill there is the ability to interrogate, negotiate, and test a representation so that effective learning activity occurs and new levels of performance are attained. The learner can generate a representation of an encountered situation, where information about the content is integrated with procedural knowledge that allows the selection of actions; this occurs while carrying out evaluation, checking, and reasoning about alternative actions. In the course of learning and problem solving, certain kinds of regulatory performances are apparent, such as knowing when to apply some procedure or rule, predicting the correctness or outcomes of a performance, planning ahead, and efficiently apportioning cognitive resources and time.

This ability for self-regulation and self-instruction enables advanced learners to leave their teachers behind and to profit a great deal from work and practice by themselves and in group efforts. In this context, the significance of skills of selfmanagement, and design of one’s environment in order to optimize learning, where the learner has control, become significant variables. For example, the student can modify the situations presented and obtain feedback for self-analysis. The use of the situation for learning will vary with the friendliness of the environment and the subject matter for providing information. Research on self-managed activities will contribute to understanding competent performance and the capacity for continued learning.

For purposes of assessment, it is important to focus on advanced learners’ ability to observe their activities as if they were outside themselves, to design situations and make predictions and explanations in the context of which self-observation can occur, or to engage in participation with others for this purpose.

Social and situation affordances. The display and modeling of cognitive competence through group participation and social interaction is a pervasive mechanism for the internalization of knowledge and skill in individuals. In a responsive social setting, learners can adopt the criteria for competence they see in others and then use this information to judge and perfect the adequacy of their own performance. Social contexts for learning also enable the thinking of the learner to be made apparent to teachers and other students so that it can be examined, questioned, and realized as an active object of constructive learning.

Assessment in this context can require performance in group efforts where students contribute to community tasks and assist others. Shared performance promotes a sense of goal orientation as learning becomes attuned to the constraints and resources of the environment. Students develop and question their definitions of competence, as they observe how others reason, and receive feedback on their own problem-solving efforts. An important aspect of this social setting is that students develop facility in giving and accepting help (and stimulation) from others.

Analyzing Cognitive Activity in the Assessment of Achievement

The effective measurement of reasoning, understanding, and problem solving resulting from school learning requires framing subject matter achievement in terms of the quality and complexity of cognition that develops in the course of learning. We have proposed a two-dimensional analytic framework for examining the properties and objectives of assessment~~s~~ situations and scoring systems. The two dimensions entailed are (1) levels of competence or the performance dimension, and (2) a content-process space of the knowledge required. Our initial work has been in the context of performance assessment used in school science, so the framework reflects this flavor (Baxter & Glaser, 1998).

Cognitive competence. Based on studies of expertise, the performance dimension of the framework describes Cognitive Components of Competence. Table 1 shows differences between people who have learned to be competent in solving problems and performing complex tasks, and beginners, who are less proficient. General differences in knowledge structure and cognitive activity are summarized in the table. Attention is called to cognitive strategies such as problem representation, strategy use, self-monitoring, and explanation; these issues are intended to focus on the distinguishing features of differential competence in subject matter achievement.

As we know, key among these differences is *organized knowledge*, knowledge that allows students to think and make inferences with what they know, and *usable knowledge*, knowledge that is applied to appropriate situations. A well-connected knowledge structure links concepts and processes with conditions under which those concepts and processes should be used. Integrated knowledge structures, characteristic of competent students, are displayed in the abilities to represent a problem accurately with respect to underlying principles; to select and execute goal-directed solution strategies; to monitor and adjust performance when appropriate; and to offer coherent explanations and justifications for problem-solving strategies and changes or adjustments in performance. In contrast, less competent students are characterized by *fragmented knowledge*, knowledge that remains isolated from

Table 1

Cognitive Activity and Structure of Knowledge

	Structure of knowledge	
Cognitive activity	Fragmented →	Meaningfully organized
Problem representation	Surface features and shallow understanding	Underlying principles and relevant concepts
Strategy use	Undirected trial-and-error problem solving	Efficient, informative, and goal oriented
Self-monitoring	Minimal and sporadic	Ongoing and flexible
Explanation	Single statement of fact or description of superficial factors	Principled and coherent

an understanding of the conditions or situations in which particular conceptual or procedural skills would be appropriately used. These students generate surface-level representations of the task, engage in trial-and-error solution strategies, monitor sporadically and ineffectively, and offer incomplete explanations of task-related concepts.

Content-process space. The realization or activation of the components of cognitive performance stems in part from the content and process demands of the tasks involved. The task demands for content knowledge can be conceptualized on a continuum from rich to lean (advanced subject matter tasks vs. introductory definitions; see Figure 1). Similarly, the task demands for process skills can be conceived along a continuum from open to constrained (exploration and discovery vs. following directions). The location of an assessment task is related to the nature and extent of cognitive activity underlying performance and, as such, provides a useful schema for describing cognitive task demand (Baxter & Glaser, 1998). The Appendix describes examples in each of the quadrants.

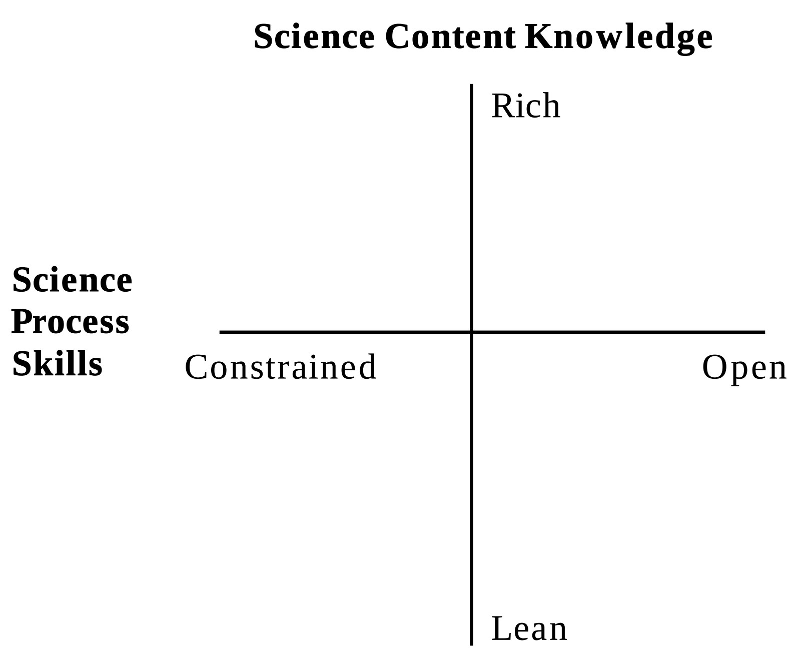

Figure 1. Continuum of task demands for content knowledge.

Examination of current assessment practice can illustrate the correspondence between the content and process demands of the task and the kinds of cognitive activity that are likely to be observed. The position of a task in a particular quadrant specifies task features, which influence performance. It does not imply the relative merits of that task form. Using a framework such as this for various subject matters, we can examine certain aspects of the design of assessment situations such as (a) the match between the intentions of test developers and the nature and extent of cognitive activity elicited and (b) the correspondence between the quality of observed cognitive activity and performance scores.

The results of a trial analysis of science assessments using this framework reaffirm the difficulty in translating learning goals into test objectives and into assessment situations that maintain the integrity of these intentions. There need to be more specific procedures, rules, or heuristic structures that usefully constrain the design of performance assessments or provide guidance for evaluating their effectiveness in eliciting targeted performances. Conceptualizing student competence in appropriate situations with respect to the quality of cognition that develops during learning is a critical first step in attempting to assess active knowledge and its growth in the course of increasing competence.

Science Notebooks and Active Cognition in the Classroom

Along with our attention to a framework for analyzing assessment situations, we have been working in science classrooms where writing can be an important tool for assisting reasoning and active knowledge during the conduct of science inquiry. The use of notebooks in science classrooms can encourage and make apparent the nature of student activity and knowledge development (Baxter, Bass, & Glaser, 1999).

However, the contents of science notebooks are sensitive to teacher influence, particularly in elementary science classrooms. We observed in our study that aspects of science instruction that teachers attended to (such as carrying out procedures and reporting results) appeared in some detail in student notebooks. However, the use of data recording as a platform for thoughtful reflection, hypothesis generation, and the synthesis of ideas was too often absent. This latter active knowledge is what we wished to observe.

The challenge for the future is how notebooks might be conceptualized, implemented, and assessed in a manner that most effectively integrates the doing of science with writing about it. What is needed is a guiding structure than can make visible the relationship among various investigations within a unit of study, and the requirements for process skills and content knowledge in different contexts. In particular, assessment situations will necessitate attention to variation in problem representation, legitimacy of procedures, nature of evidence, and the quality of explanations as appropriate targets for teaching, learning, and reflection.

Concluding Comments

The translation of knowledge about human cognition into frameworks for professional activity and for the design of tools for learning and assessment is an essential endeavor for teachers and their students. As efforts proceed, we need to better understand the kind of learning that fosters connected knowledge and increasing complexities of structure that incorporate abstracted representations and procedural availability. We have seen how easily poorly integrated "multiple-choice" type knowledge is readily transmitted in many instructional settings, and we need to examine closely how the environment helps develop structure as students acquire high levels of cognitive competence.

Finally, we note that the mode of research and development is changing. In the past, much of our attention was devoted to moving from basic research findings to applications. However, in the future, we can contribute best to both science and practice if we take on significant applications and ask how they test what we know, and how they correct and generate new frameworks and heuristics for designing situations that promote active knowledge.

Appendix

Examples of Tasks in the Content-Process Space

Content Rich-Process Open

"Exploring the Maplecopter" is a good example of a content rich-process open task. High school physics students are asked to design and carry out experiments with a maple seed to explain its "flight to a friend who has not studied physics" (Baron, Carlyon, Greig, & Lomask, 1992). The flight of the maple seed "represents a delicate equilibrium between gravity, inertia, and aerodynamic effects" (Seter & Rosen, 1992, p. 196). For this task, identification of the causal variables involved requires substantial knowledge of physics concepts of force and motion, the ability to design and carry out controlled experimentation, and the effective employment of model-based reasoning skills.

Given that the problem does not have a clean simple solution, it is rich with opportunities for high school physics students to apply their subject-matter knowledge and in-school experience to develop an understanding of an everyday phenomenon--the flight of the maple seed. In this context, successful performance is dependent on an adequate representation of the problem, sustained and systematic exploration strategies (observation and experimentation), monitoring progress toward describing the flight of the maple seed, and explanation of the causal relationships observed and tested. The quality of problem representation, strategy use, monitoring, and explanation reflect the depth of knowledge and process skills students bring to the situation.

Content Lean-Process Constrained

In contrast to the maplecopter task, tasks that are knowledge lean-process constrained require minimal prior knowledge and limited school experiences with subject-specific concepts and process skills for successful completion. Rather, students are guided to carry out a set of procedures and then asked to respond to questions about the results of these activities. For example, consider a task that asks eighth-grade students to study the effects of a train derailment and the resulting chemical spill on the surrounding environment (California Department of Education, 1993). As part of their investigation, students replicate potential chemical reactions from that situation. They are explicitly *directed* to add specific amounts of the relevant substances in a *specified* sequence to set up three chemical reactions. Following this, they are *prompted* to observe each of these reactions for temperature, color change, and "other changes observed." A table is provided to *guide* recording of the specified observations. Students are then posed a series of questions that, for the most part, can be answered by *rereading* data from the table of observations or other information provided. For tasks of this type, generative opportunities for problem representation, strategy use, and monitoring are precluded by the step-by-step procedures.

Content Lean-Process Open

Assessment tasks of this type require students to coordinate a sequence of process skills with minimal demands for content knowledge. For example, the Mystery Powders assessment asks fifth-grade students to identify the substances in each of six bags from a list of five possible alternatives (Baxter, Elder, & Shavelson, 1997). Students are presented with vinegar, iodine, water, and a hand lens to test each substance or combination of substances. Two of the bags have baking soda and cornstarch in them. Each of the others contains either baking soda, baking soda and salt, cornstarch, or cornstarch and sugar. Students are told they can use the equipment in any way they wish to solve the problem.

With these instructions, students represent the problem in terms of actions that follow from what they know about the properties of substances and ways to identify them (i.e., tests and relevant observations). They then implement a strategy such as adding vinegar to a substance, and revise that strategy, if necessary, based on task-feedback (no fizz, try iodine to test for cornstarch). As they monitor their progress toward problem solution, students attend to and coordinate multiple pieces of information including knowledge of task constraints, knowledge of critical aspects of their previous investigations, and interpretations of current trials.

In this situation, processes are open in terms of test selection (number and type of test) and test sequence that can be carried out more, or less, efficiently as a function of effective monitoring and students' knowledge of the relationship between substances and their identifying tests. The content knowledge requirements for successful task completion are lean. Students need to know how to replicate previous investigations and how to match current trials with records of in-class observations of test-substance outcomes.

Content Rich-Process Constrained

Tasks that are content rich-process constrained emphasize knowledge generation or recall. For example, high school students were asked to “describe the possible forms of energies and types of materials involved in growing a plant and explain fully how they are related” (Lomask, Baron, Greig, & Harrison, 1992). A comprehensive, coherent explanation revolves around a discussion of inputs, processes, and products such as: “The plant takes in water, light, and carbon dioxide. Through the process of photosynthesis, light energy is converted into chemical energy used to produce new materials such as sugar needed for plant growth; in addition oxygen is given off.” In developing their explanations, students make decisions about which concepts are important and how these concepts are related thereby reflecting their conceptual understanding of the topic. Although the opportunities for explanation are apparent, opportunities for other activities such as planning, selecting and implementing appropriate strategies, or monitoring problem-solving procedures are less so.

In summary, specifying cognitive activities in the context of the subject matter demands (i.e., content and process) provides a framework for anticipating the impact of assessment features on student performance. With this framework in hand, tasks can be designed with specific cognitive goals in mind, and task quality can be judged in terms of an alignment with the goals and purposes of the developers.

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