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Intellectual skills in higher education*

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ABSTRACT

The knowledge era has placed new demands on professors and students to analyze and organize information. The intellectual skills required to do this have theoretical forerunners in critical thinking, problem solving, formal operations and creativity. These approaches to intellectual skills are reviewed as well as more recent metacognitive and cognitive approaches. Attempts to teach these skills suggest that they have certain operations in common. A model of intellectual skills is presented which includes the skills of description, selection, representation, inference, synthesis and verification.

RÉSUMÉ

L'explosion des connaissances poussent aujourd'hui les professeurs et leurs étudiants à les analyser et à les organiser avec plus de profondeur. Cela exige des aptitudes intellectuelles dont les antécédents théoriques sont la pensée critique, l'aptitude à la résolution de problèmes et à l'exécution d'opérations formelles, et la créativite. L'auteur examine la question des aptitudes intellectuelles dans cette perspective, de même qu'à partir des approches métacognitive et cognitive. Les tentatives faites pour transmettre ces aptitudes indiquent qu'elles font appel à certaines opérations communes. Un modèle d'aptitudes intellectuelles est présenté; ce modèle tient compte des facultés de description, de sélection, de représentation, d'inférence, de synthèse et de vérification.

The advent of the knowledge era has added impetus to the need to understand how we think and how intellectual skills are taught and learned in postsecondary institutions. As professors we are aware of the effects of the vast increase in knowledge in our disciplines and the concomitant increased demand on our time. We recognize that the learning task of our students has increased substantially as well. The knowledge era has also changed the nature of the professor's task.

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Where before professors were expected to review, present and critically evaluate a particular body of knowledge in their discipline, a considerable task in itself, professors must now go beyond this to create a new synthesis, to determine the means of assembling information within a broader framework, and to teach students strategies or intellectual skills for relating and organizing knowledge.

It is generally assumed that students in postsecondary educational institutions come prepared to organize and synthesize knowledge. University professors expect their students to be capable of independent thinking, to interact in situations demanding clear and rational thought, and to combine that thought with expressive communicative techniques (McKinnon, 1978). Students are expected to think logically and to be able to reason with abstract propositions that they will meet in their courses. Discrepant with this expectation, studies have shown that fifty per cent of the entering student population have not yet reached the level of formal operations where they would be able to think logically, abstractly, and independently (Higgins-Trenke & Gaite, 1971; McKinnon, 1978; Ross, 1973). The assumption that students have these abilities limits the provision of explicit learning opportunities for students to develop logical thought within a course or program. Intellectual skills, if they are taught, are more likely to be taught in remedial courses as writing or study skills offered by student services than in regular courses.

What can be done to provide students with the necessary intellectual skills within the framework of their regular programs, where the learning of these skills is most likely to be effective? The ability to make inferences, which appears to be a prominent intellectual skill, is most likely to be developed in a subject matter area where the student has spent a considerable amount of time (Piaget, 1972). This suggests that intellectual skills are to some extent dependent upon knowledge of a particular discipline. It then follows that courses offered in a discipline are the best place to promote these skills. If the discipline is the optimum place for intellectual skill learning, it is important to study how different disciplines have viewed intellectual skills. It is also important to consider how and to what extent the skills can be taught. The purpose of this paper is, therefore, to review different approaches to intellectual skills and to determine if and in what manner these skills can be taught.

Critical thinking

Probably the oldest and most generally recognized approach to intellectual skills is that of critical thinking. Critical thinking is regarded across disciplines as a reasoned or questioning approach to learning as opposed to a doctrinaire or rote approach. Researchers investigating critical thinking in higher education often refer to the Socratic tradition as the origin of this approach (Furedy & Furedy, 1983). The Furedys suggest that the essential elements of critical thinking are a general disposition for disciplined inquiry, based on a readiness to question all assumptions and an ability to recognize when it is necessary to do so, disinterested scholarship, and the ability to analyze and to evaluate. The first characteristic, disciplined inquiry, requires the examination of premises or first principles. Others have referred to this characteristic as the rejection of arbitrariness (Seigal, 1980).

The second characteristic, disinterested scholarship, suggests maintaining perspective or a dispassionate attitude toward the subject under discussion, in short, a differentiation between the subject under review and oneself. This is also referred to as the rejection of partiality (Seigal, 1980). This characteristic has been described as the Greek way of thinking, in which problems are considered for their own sake rather than in relation to human needs (Burnet, 1930). The third characteristic, the ability to analyze and evaluate, is defined in the literature as the seeking of evidence and reasons, as objectivity, or as the appropriate use of reflective skepticism (Furedy & Furedy, 1982; McPeck, 1981; Seigal, 1980).

The Furedys (1983) argue that few university faculty have systematically reflected on what would constitute an appropriate notion of critical thinking for their field of inquiry. They do, however, suggest and have researched ways of structuring a course so that it would include the elements of critical thinking (Furedy & Furedy, 1979). The suggested methods include active student participation, peer interaction, faculty encouragement, and some form of adversarial interaction. In one form of adversarial interaction, students react to an external adversary such as a mythic editor of a journal. In another form, the professor teaches by setting up opposing positions then examining them in class. For example, a psychology professor could argue from a behavioral point of view, then provide arguments from a cognitive perspective. The methods appear to awaken the critical spirit to examine and evaluate knowledge. A possible shortcoming in applying critical thinking techniques to the classroom is that studies of critical thinking have considered global characteristics rather than specific procedures or operations. A more specific approach to intellectual skills is found in the investigation of problem solving.

Problem solving

The sciences, particularly applied sciences such as engineering and medicine, have investigated problem solving processes because it is the skills involved in problem solving that are considered most critical for graduates of such programs to be able to utilize in their professions. In early studies of problem solving, it was defined as an advanced stage of thinking that involves the individual's need to seek a solution to a situation that has never before been encountered (Wallas, 1945). Rather than being described as a set of characteristics as critical thinking was, problem solving has been regarded as a process consisting of a series of steps or procedures. The classic description of problem solving according to Wallas consists of four steps. The first, preparation, is a stage of familiarizing oneself with the problem and assuming an exploratory attitude which allows different ideas to come forth. The second step, incubation, is characterized by inactivity in which the problem solver does not consciously pursue a solution. In illumination, the third step, there is a sense of insight which leads to problem solution. The last step, verification, is to test the insight empirically or logically. This early description does not break down further the steps of preparation and incubation, but researchers in the area of problem solving have since refined the procedures.

Research on different kinds of learning has yielded some insights into problem solving. In the taxonomy of cognitive educational objectives, problem solving is described as an example of the intellectual skill of application (Bloom, 1956). Application requires steps beyond knowledge and comprehension, but in the taxonomy it is considered to be a relatively simple skill in which relationships between concepts are used without requiring higher order skills such as analysis. For Gagne (1977), problem solving is the most complex kind of learning, preceded in a hierarchy of types of learning by verbal association, discrimination learning, concept learning, and rule learning. Problem solving is defined as combining two or more previously learned rules to form a new capability, for example, solving proofs for geometric theorems. This definition points out the level of abstraction required to problem solving and the role of inference.

More recent attempts to specify the steps of problem solving are goal oriented and heuristic in nature. For example, Nickerson (1981) presents a several step prescription for problem solving which begins with stating the goal in one's own terms. The steps then include listing the given facts; trying to make a picture (a table, graph or diagram) which represents the known facts and relationships, and trying to infer some additional facts or relationships and add them to the list and the picture. The next two steps are inferential processes. The problem solver determines what additional information would be sufficient to reach a solution and sees if that information can be inferred. Then he or she tries to infer something about the solution (for example, it must be positive; it must be less than X; it cannot be Y). Nickerson goes on to suggest alternative strategies if these steps do not lead to problem solution, then concludes with verification. This set of steps is detailed and suggests several skills. For example, listing the statements of facts and producing a picture are organizing steps. Making inferences about the facts, relationships, or solution are part of the hypothetico-deductive method. The steps that Nickerson has described are ones he himself follows. How readily such a detailed series of steps could be taught remains to be answered.

One group of researchers attempted to teach a simple problem solving strategy to physics students (Reif, Larkin, & Brackett, 1976). They had previously observed students attempting to solve physics problems and had found that many of them approached the situation in haphazard and ineffective ways. The problem solving strategy they taught consisted of four steps. They began with a description in which the problem solver was to list explicitly the given and desired information, then to draw a diagram of the situation to clearly formulate the problem. In the second step, planning, the student was to select the basic relations pertinent for solving the problem and outline how they would be used, in a specific plan for finding the solution. Implementation, the third step, consisted of executing the plan by doing all necessary calculations. Checking, the fourth step, was a verification of the logic of the steps and that the final answer made sense. To teach the problem solving strategy, the investigators explained the strategy to students, demonstrated it with a few problems, then provided the students with practice and feedback on a variety of physics problems. They found that students had increased success in attaining solutions, and that they did more planning and used more reasoning and steps relevant to solution even when they did not obtain the correct solution. This suggests that problem solving skills can be delineated and can be taught. Although the procedure could be expected to vary somewhat across disciplines, it appears that there are some basic operations which apply overall, such as listing information, diagramming, finding important relationships, and verifying the steps taken. Research is needed on the extent to which the operations found useful in physics problem solving are applicable in other disciplines.

Formal operations

Another approach to intellectual skills which has been applied in the sciences is that of formal operations. The work on formal operations is based on a developmental approach to knowledge. Piaget (1972) divided intellectual development into discrete, qualitatively different stages in which progress from one stage to another was demonstrated by a reorganization and extension of the cognitive structures of the preceding stage. The first stage, the sensorimotor stage, extends from birth to approximately 2 years of age, and is followed by the stage of concrete operations, lasting from 2 to 12. The formal operational stage, characterized by the ability to reason hypothetically and independently, becomes established according to Piaget between 12 and 15 years of age. In this stage the individual has the capacity to reason in terms of verbally stated hypotheses and no longer merely in terms of concrete objects and their manipulation. According to the theory, it could be expected that university students would have reached the level of formal operations before entry into postsecondary education. As studies mentioned previously have shown, fifty per cent of the entering college population have not yet reached this level. We must also note that even if students have reached the level where they can do so, there is no guarantee that they will be prompted to do so or will choose to think deductively.

The Piagetians have been careful to state the specific operations or processes that distinguish concrete and formal thinking. In the concrete operational period, mental operations are designated as concrete because they are tied to concrete experience. The ability to reason inductively, that is, from the particular to the general, is fairly well established, and students acquire the operations known as reversibility and seriation. Reversibility is shown by the ability to add, subtract, multiply and divide, and by the principle of conservation. The ability to seriate involves ordering objects along various dimensions. For example, this ability enables the student to infer that if John is taller than Amy and Amy is taller than Toby, John is taller than Toby. Thus, even if students have not yet reached the stage of formal operations, they can be expected to be able to take instances and form a general concept or rule, that is, to group, or make inferences based on order.

In the formal operational period, students become able to reason from the general to the specific or deductively, and thus to use the blend of inductive and deductive reasoning that characterizes scientific inquiry. This includes the ability to comprehend second-order relations of the kind used in reasoning by analogy, that is, relations between relations. Formal operations, according to Piaget, are based on the knowledge of propositional logic. They include operations such as conjunction, disjunction, implication (if-then), and reciprocity (Inhelder & Piaget, 1955). In theory, the propositional operations, in contrast with the grouping of classes and relations of concrete operations, form a single system such that it is possible to move with accuracy from any one of its elements to each of the others. Although it has proved difficult to show the acquisition of formal operations which are generalizable across different subject areas, students have displayed these operations in specific subjects such as mathematics or physics, after focussed study in the area (Piaget, 1972).

One effect of being able to think logically and reflectively is that it allows escape from the concrete present toward the realm of the abstract and the possible. The period of formal operations is characterized as the first one in which one contemplates not only what is but what might be (Kuhn, 1979). Thus, formal operational reasoning allows one to construct arguments for a position one might not support, an ability similar to that of impartiality, an important characteristic of critical thinking. Formal operations also appear to be necessary to perform the inferential operations of problem solving such as determining what additional information would be needed to reach a solution or seeing what information could be inferred.

Attempts to teach formal operations in the university have met with measured success (see Karplus, 1974; McKinnon, 1978; Lawson & Renner, 1975). In one study, science concepts were taught by activities provided in three phases (Karplus, 1974). In an exploration phase, students manipulated materials and observed results. In an invention phase, symbols and words were introduced to label what students had observed. In a discovery phase, students then applied what they had learned in more general and abstract contexts. In another study, a course was designed to include all the elements of inquiry, listed as questioning, classifying, hypothesizing, verifying, restructuring, interpreting, and synthesizing (McKinnon, 1978). The course used discussion, small-group seminars, and independent library study to develop these elements. The evaluation of learning in the course was based on an increase in the students' ability to think logically. The main task for the students in the course was to form hypotheses about problems, then to discuss alternatives in a small group session. The students in this study showed appreciable gains in moving from the concrete operational stage to the stage of formal operations when compared with a control group. This suggests that it is possible to provide learning experiences at the postsecondary level which will equip students to reason formally.

Creativity

Another approach to intellectual skills which cuts across disciplines is creative thinking. A major investigator of creativity who also suggested ways to nurture it was Guilford (1950, 1968). He began by describing creative behaviors as consisting of inventing, designing, contriving, composing and planning. To measure creativity he designed tasks for four different creative factors (Guilford, 1950). The first factor consisted of three kinds of fluency. Ideational fluency was the rate of generation of a quantity of ideas, for example, a list of all things which are solid yet flexible. Associational fluency was dependent upon a relationship, for example, all the opposites of small. Expressional fluency was the ability to construct words or sentences from minimal clues, for example in crossword puzzles. Another major factor was flexibility, which was a measure of the kinds or categories of responses a person could make. A second kind of flexibility, adaptive flexibility, required changes to be made in the interpretation of a task, in approach or strategy, or in possible solutions. The third factor, originality, was measured by the rarity of occurrence of a good response compared to responses made by others on the test. The last major factor, elaboration, was a measure of the number of details or variety of implications. These factors all describe the ability to produce a variety of responses, with no right or fully determined answer. They were therefore called measures of divergent, as opposed to convergent, thinking.

An important issue for those studying creativity is the question of the relationship between quantity and quality of responses. Brainstorming techniques separate production and evaluation, with the intention of allowing greater productivity due to suspended judgment. Creativity then appears to benefit at some point from non-critical thinking. In the studies reported by Guilford (1968) on the effectiveness of instructions to suspend judgment or to give good responses, thus evaluating while producing, the results were mixed. In some cases of suspended judgment, greater quantity also led to a higher number of quality responses, but in others it did not. Criticism has been shown to have beneficial effects in problem solving, and Guilford points out that the creative person is one who tends to have a high degree of sensitivity to problems and is more apt to notice something wrong or in need of improvement. Observing imperfection is an impetus for the creative person. We thus begin to have a sense of the relationship between critical thinking, problem solving, and creativity. All three require focussing and attention, but critical thinking has different characteristics and problem solving appears to be more systematic than critical thinking or creativity.

Attempts to compare creativity and formal operations have shown less relatedness. For example, in a study of university students' ability to think creatively and to solve those problems which exemplified an understanding of Piagetian formal operations, significant correlations were found between measures of creativity such as verbal fluency, flexibility and originality, but not between measures of creativity and those of formal operations (Ross, 1973). Moreover, the different measures of formal operations rarely correlated among themselves suggesting that formal operations are either discipline or context dependent, or are more specific in nature.

In early attempts to study creativity, it was approached as a personality characteristic (Guilford, 1968; Torrance, 1962). Ideational fluency appeared to be related to impulsiveness and self-confidence, while originality was accompanied by such characteristics as reflective thinking, tolerance of ambiguity, and less need for orderliness. Torrance and his associates hypothesized that certain attitudes would lead to greater creativity, and these attitudes are similar to the characteristics of the critical thinker. The first identified attitude was an urge to search for the answers to puzzling questions, to explore, and to experiment. The second was a critical attitude, the inclination to search for defects and criticize. The third requirement was confidence in one's perceptions and willingness to believe them. These characteristics overlap with behaviors suggested for critical thinking and problem solving, but can be seen to be at a more molar level than formal operations.

In a more recent book by Torrance (1979), the main theme is that the development of creativity requires perseverence, diligence, time and hard work. He links creativity with problem solving and suggests that students need to practice creative problem solving regularly. He provides a variety of suggestions for encouraging creativity which include different approaches to brainstorming, focussing and highlighting techniques, and elaboration, synthesizing, and visualizing techniques. The wealth of examples and techniques suggests the complexity of creativity and the varied possibilities for promoting it. A similar theme is found in de Bono's (1972) writing. In his work on creativity, which he calls lateral thinking, he defines it as moving sideways from established ways of looking at things to find new ways. The moving sideways is not a search for the best way but for alternate ways, as opposed to vertical thinking in which readymade ideas are built upon. He stresses that lateral thinking is not for building on ideas but for restructuring them. The process is thus concerned with perception rather than processing, and we might infer from this that it would be more difficult to teach. On the contrary, it is de Bono's work which has been most readily adapted to educational projects to increase the general intelligence of students (de Sanchez, 1984). Much of this work focusses on developmental exercises which allow the student to form search strategies for recognizing a pattern and organizing information. In this approach, the investigation of creativity and its development have led to more general skill development, particularly representation. The trend in studies of creativity thus has been to focus more and more on trainable skills or strategies.

Metacognition

Recent research on thinking processes divides them into more specific processes, called cognitive, and more global metacognitive processes, also described as executive or self-monitoring processes. Metacognitive processes have a forerunner in study skills but they also encompass the control strategies that are important in decision-making in general, hence the term executive. Metacognitive processes merit attention because they display several of the characteristics of the previously examined approaches to intellectual skills. They also act in conjunction with more specific cognitive strategies and thus form a link between the approaches discussed so far in this paper and most of the current research on cognitive processes.

Metacognitive processes serve three general functions for the learner. The first function is to place a problem in context or decide upon the nature of a problem, thus calling up a repertoire of experiences and strategies and acting as a cueing function. The second metacognitive function is to decide which of the repertoire of strategies to implement in order to accomplish a task. A judgment of best fit or most appropriate pattern is made according to the circumstances. The third metacognitive function is to interpret feedback. The process consists of interpreting external responses to intellectual skills and products. It in some ways resembles the verification process in creative thinking and problem solving.

Training metacognitive skills has received considerable attention from educational researchers because self-monitoring skills are essential for reading. The monitoring process in reading has both preview and retrieval functions. Attempts to teach such operations in order to improve reading comprehension have included instructions to try the strategies of suspending judgment, forming a tentative hypothesis, rereading the previous content, or going to an expert source (Collins & Smith, 1982). The view of researchers in the area is that teaching specific strategies has a limited effect, but that general principles applied over a variety of task domains will allow future transfer. Thus metacognitive skills are not considered to be domain dependent. Those metacognitive skills identified as being necessary for successful performance on general academic tasks include remembering one's place in a long sequence of operations, knowing when a subgoal has been obtained, detecting errors, and recovering from errors by making the necessary correction or by going back to the last known correct operation (Rigney, 1980). It can be seen that these are very general, global skills compared to, for example, making inferences in problem solving or questioning assumptions in critical thinking.

One program that has been designed to develop general learning ability in university undergraduates consists of six executive steps with the acronym MURDER (Dansereau et al, 1979). The steps are to set the *mood* to study, read for *understanding, recall* material without referring to the text, *digest* the material by amplifying it, *expand* the knowledge by self-inquiry, and *review* mistakes made on tests and exercises. Each of these steps has a set of substrategies. Students who completed a program of training on the steps performed significantly better on comprehension tests and reported changes in their study practices. Another program which focussed on metacognitive problem solving skills paired students and had each provide feedback on the other's problem solving steps (Whimbey & Lochhead, 1980). The exercises in this program were focussed on using all the relevant facts, using a systematic, step-by-step approach, not jumping to conclusions, and using an adequate or correct representation of the problem.

It can be seen that these broad or general strategies for learning provide the student with aids in the form of steps to be taken and the attitude required for successful study. What they do not provide is an understanding of what has to be learned. Why is it that some students can learn well in one discipline and not in another? Why are certain subjects bêtes noires for students? To answer these questions, we need to examine the cognitive skills required to accomplish the learning tasks presented by different disciplines.

Cognitive processes

The study of cognitive processes by educational researchers in North America was spurred by the development of the taxonomy of cognitive objectives (Bloom, 1956). In the taxonomy, intellectual skills such as reasoning, problem solving, concept formation and creative thinking were categorized in terms of increasingly complex behaviors. The categories of intellectual skills were comprehension, application, analysis, synthesis, and evaluation. In the study of these skills, comprehension has been the focus of research on reading, while problem solving has been considered primarily the domain of application. Greatest emphasis in postsecondary education has been on the skills of analysis and synthesis. But early research on analysis and synthesis and their relation to academic performance could not discriminate between these skills in terms of student characteristics (Rokeach & Norrell, 1966). This was probably due to the fact that analysis and synthesis appear to have similar subskills. Analysis, according to the taxonomy, consists in identifying elements, making the relationships between them explicit, and recognizing the organizational principles which hold together the material (Bloom, 1956). Synthesis is defined as putting together elements and parts to form a whole not clearly there before, so it adds new organization to the steps of analysis.

What we appear to need in higher education is some understanding of the analytic processes underlying intellectual skill acquisition in the different disciplines. In a study of the competencies needed at the postsecondary level at Alverno College, researchers defined a series of expected competencies for college graduates (Mentkowski & Strait, 1983). The second listed competency, following communication skill, was the sharpening of analytical capabilities. The competency consisted of six levels ranging from identifying the explicit elements of a work (article, artifact, or process) through identifying implicit elements, identifying relationships, analyzing the structure and organization, and developing new hypotheses, conclusions or relations, to producing a work which demonstrates facility in the analysis of elements, relationships, and organizing principles. We appear to have two stumbling blocks in the teaching and learning of analytic skills: how to identify and represent elements and relations in a subject matter, and how to state the processes necessary to relate and organize the elements.

One attempt to deal with students' acquisition of cognitive skills has been to discriminate between what we see the majority of our students doing and what we would like them to do. It appears to require at least 100 hours of learning and practice to acquire any significant cognitive skill to a reasonable degree of proficiency (Anderson, 1982). Based on this premise, Anderson proposed a two-stage theory about the changes in the nature of a skill over a period of learning. In the early or declarative stage, students interpret facts about a given domain. This stage parallels the knowledge and comprehension levels in the taxonomy of cognitive objectives. In the later, or procedural stage, knowledge in a domain is embedded in procedures for performing a skill. A distinction that many professors make about their students is that a large proportion of the students can give examples of information but they cannot apply or generalize from the information, that is, the majority of students possess the declarative but not the procedural knowledge.

How do students get from one stage to the other? Anderson suggests that there is a compilation process in which skill transits from the declarative to the procedural stage through two subprocesses, composition and proceduralization. In composition, sequences of production are collapsed into a single production, similar to the inductive process of moving from individual examples to the general rule. The second process, proceduralization, embeds factual knowledge into productions, in a manner similar to the production of a schema or organized representation. Once proceduralized, further learning processes operate on the learned skill to make the productions more selective in their range of applications, that is, to refine their use. Thus proceduralization is in large part a process of accurate representation. This approach to learning has been successfully applied both to language acquisition and to mathematical problem solving. The theory supports the need to focus on analytic processes and their representation in order for students to acquire the necessary cognitive skills.

Two attempts in different disciplines to promote cognitive skills at the level of proceduralization are worthy of note. In the first, a physics curriculum was examined for its basic elements, with the idea that a conceptual element or schema must consist of a concept and the ancillary knowledge needed to make the concept effectively usable (Reif, 1983). The knowledge necessary to interpret or specify a concept was considerable. It consisted of a definition of the concept, a listing of its salient features, a step-by-step procedure specifying how to identify or exhibit the concept including its operational definition, a statement of how it would be measured, and the independent variables (the conditions, context or frame of reference) that affect the concept. In addition, to make the concept usable in practice, Reif called for the identification of particular instances of the concept and warnings about misuse or limitations of the concept. The process involved in the specification of a concept can be seen from this outline to be a highly demanding one, but one that is probably necessary if clear procedural knowledge of a concept is required. How many concepts could be specified in this manner and in which disciplines remains a question.

The other attempt at proceduralization was developed to measure the effect of a liberal arts education on the development of thinking skills (Winter & McClelland, 1978). A test was designed to judge students' ability to form and articulate complex concepts and to use them in drawing contrasts among examples and instances in the real world. A scoring system, which measured the procedures used to analyze different sets of stories, awarded points for procedures such as making direct comparisons between the sets of stories, declaring exceptions and qualifications, and using an analytic hierarchy. The test discriminated between liberal arts first and senior year students, and was also found to be more highly correlated with majors in mathematics, physics, and engineering. This suggests that analytic skills are learned during university years and that some programs tend to promote these skills more than others.

Comparison of approaches

The different approaches to intellectual skills reviewed here reflect disciplinary perspectives. Most approaches have, however, paid attention to certain aspects, for example, description or context. In critical thinking, one examines assumptions; in problem solving one lists facts. Exploration, questioning, and goal stating help to establish the general context or parameters in various approaches. All of the approaches refer to intellectual skills at greater or lesser degrees of generality. Several include different kinds of analysis: of elements; relationships; groups; or structures. Logic or reasoning is referred to frequently as inference, inductive reasoning, deductive logic, or hypothesis formation. The suspension of judgment and impartiality appear to be adjunct skills. One of the most frequently found skills is representation or visualization, where concepts, systems, problems, or procedures are designed, elaborated, restructured or invented. Finally, some process of verification is recommended in the form of seeking evidence or reasons, providing instances or examples, stating qualifications or limits, and using feedback.

A variety of skills are found in the different approaches reviewed here, but they all appear to use some process of analysis and some form of representation. In recent research we have adapted Bloom's (1956) description of analysis as a model for what is to be learned in university courses: the elements, the relationships between them, and the overall organizational structure of material (Donald, 1984). Our premise was that what is to be learned as an intellectual skill in a given subject matter can be task analyzed, that the task analysis will yield a representation, and that the representation will, in turn, suggest the intellectual skills necessary to master the subject matter.

Analysis and representation

In research on knowledge structures in courses, we studied ways of analyzing course content to determine the learning task and what kinds of knowledge students would need to be successful in the different courses. We began by studying the elements of a course, major course concepts, whether they consisted of a word or a phrase (Donald, 1983a). The concepts ranged from terms such as *temperature* in the chemistry course studied or *damage* in the law course, to phrases such as *eclectic approach desirable in practice* in the educational psychology course or *principles of stratigraphy* in the geology course. In the sixteen courses in the study, selected from across disciplines, it was possible to determine a set of concepts relevant to the course, and within that set to delimit a smaller set of key concepts. We pursued our study with the caution that the concepts were an attempt to clarify rather than absolute or immutable entities. The set of concepts chosen by each professor was tested as a representation of the learning task in the course. We found in a later study that the key concepts were useful in measuring student learning in the courses and that there were differences across disciplines in how useful they were (Donald, 1983b).

We also found that the concepts could be used as a basis for testing the kinds of relationships which are present in courses. As part of the study, the professors developed a tree structure showing the strongest relationships among the key concepts in their course. The professors were asked to describe the relationships and over the sixteen courses a total of 252 relationships were described. Analysis of these relationships showed that they were one of two kinds. Sixty per cent of the relationships were based on similarity, that is, the two related concepts had something in common. In forty-two per cent of the relationships, the most frequently found kind of relationship, the similarity was structural: the concepts had a hierarchical relationship of inclusion or kind or part, reminiscent of Ausubel's (1963) subsumers, which act to group other concepts. In the remaining eighteen per cent which were similarity relationships, the concepts were associated as parts or kinds of a larger whole or had a similar function.

The other forty per cent of the relationships were dependency or contingency relationships. Of these, eighteen per cent were of logical inference (if-then), twelve per cent were causal, and ten per cent were procedural, that is, one followed the other in time. All of the courses had structural relations between concepts and all courses employed at least two kinds of relationships between the key concepts, although certain courses favored particular kinds of relationships. For example, eighty-three per cent of the procedural relationships were found in the science courses, while sixty-two per cent of the logical relationships were found in the social science courses. To illustrate the major kinds of relationships, *risk* and *causation* were structurally related as parts of the legal concept *liability for fault;* and *liability for fault* was logically related to *recovery of damages*.

The representation of the key concepts in the tree structures also yielded information about organizational principles in the course. For example, the physics course concepts were organized in a tight hierarchical pattern with many links among the concepts. In contrast, the concepts in the educational psychology course formed a web with a pivot concept, *socialization,* in the center, and theories and supporting concepts fanning out from the center. One could hypothesize that the learning pattern in the physics course would be all-or-none, with students learning all the concepts or not understanding the pattern, while in the educational psychology course, if students were to realize that *socialization* was a pivot concept, they could use that concept to relate other concepts or instances in the course.

The study of these courses allowed us to see that the learning task in a course could be specified in terms of a representative set of elements and relations. The representations of the course content suggest the kinds of processes needed to acquire an understanding of a particular subject matter. For example, the knowledge structure of a course not only reveals the elements and relationships that are necessary for the intellectual skills of comprehension and analysis, it suggests what kinds of categories, perspectives, or inferences must be learned in order to proceduralize or apply this knowledge. The intellectual skills suggested by the representations appear to be those which are analytic or inferential in nature rather than the contextual or verification skills. This could be expected since the most important course content, which is what was chosen for the content analysis, would be the most central or focussed material in the course. More externally related material could be expected to suggest the context and verification skills that link the central knowledge in the course to other subject matter or empirical substantiation.

A model which would account for the intellectual skills suggested by our research and by researchers into critical thinking, problem solving, formal operations, creativity, and metacognitive and cognitive processes could be expected to consist of sets of skills which are interdependent. One set would consist of descriptive processes. From the review of different approaches to intellectual skills, the descriptive processes might be expected to include such operations as stating the context, listing conditions, listing facts or functions, and stating goals. Another set of skills would include selection processes such as choosing relevant information and ordering that information in importance. Representation processes that are found throughout the literature on intellectual skills would include recognizing organizing principles, organizing and modifying elements and relations, and illustrating them in some manner. The set of inferential processes would include such steps as discovering new relations between elements or relations, discovering equivalences, ordering, categorizing, changing perspective or hypothesizing. Synthesizing processes would include combining parts to form a whole, elaborating or filling gaps, and developing a course of action. Finally, a set of verification skills would consist of operations such as comparing alternative outcomes, judging validity, and using feedback. We thus have six sets of interlocking skills: descriptive, selective, representational, inferential, synthesizing, and verifying. Use of the sets of skills could be expected to follow a linear pattern but would also be potentially reiterative. For example, one could move from representation to inference and then create a new representation.

Which of these skills would professors deem it critical for students to know? How many of the skills do students have when they enter university or college? How many can be taught and evaluated? If the skills are found to be essential, and students do not enter college or university equipped with them, what change will be necessary in our teaching methods to aid students in acquiring them? The research to answer these questions could have far reaching effects on our institutions of postsecondary education. If small group problem solving situations are necessary for the development of these skills, courses may require considerable change in their design to provide such an opportunity. The role of students as active researchers rather than passive information storers is another potential change. Attention to intellectual skills could certainly be expected to increase the level of dynamism in colleges and universities. Would we be asking more of students than they are willing to expend? The report on excellence in American higher education (Mortimer et al, 1984) suggests that students will need encouragement to develop academic skills. A host of critical questions lie waiting to be answered.

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