How Students Think: Implications for Learning in Introductory Geoscience Courses

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ABSTRACT

Non-major students in introductory geoscience classes exhibit a wide range of intellectual development. Approximately half of these students do not have the skills to understand the abstract scientific concepts traditionally discussed in introductory classes. Many geological concepts will remain unlearned without appropriate activities that build on a foundation of concrete examples. The good news is that these same students can improve their logical thinking skills when they participate in challenging in-class collaborative learning exercises with their more intellectually sophisticated peers. While the exercises themselves are important in promoting the development of higher-order thinking skills, the group interaction also appears to be a significant contributor to the improvement of reasoning.

INTRODUCTION

Surveys of college faculty consistently rank the intellectual development of their students as a primary teaching goal (Trice and Dey, 1997). Faculty value the development of higher-order thinking skills such as critical thinking, problem solving, logical reasoning, and creative thinking (Pascarella and Terenzini, 1991; Pinet, 1992; Angelo and Cross, 1993; Cross and Steadman, 1996; Eljamal et al., 1998; NCPI, 1999). The greatest gains in critical thinking during the college experience typically occur in the first year and in courses related to the student's major (Pascarella and Terenzini, 1991; Cross and Steadman, 1996). Instructors can promote cognitive growth by focusing on teaching and learning strategies that make content relevant and understandable to the intended audience, increase student-student interaction in class, and require construction of student knowledge rather than the recognition of memorized facts (Tobias, 1992; Angelo, 1993; Tsui, 1999). Students in introductory science courses infrequently find themselves in an educational setting where higher-order thinking tasks are routinely assigned and assessed to encourage cognitive development. Instead, learning is often reduced to low-level intellectual skills of listening and memorizing facts for multiple-choice exams (Pinet, 1992; Prothero, 2000). An introductory geology course, often taken during freshman year, represents a great opportunity to help students develop the reasoning skills that are essential for success in college (American Geophysical Union, 1994). Unfortunately, many instructors are unaware of how teaching may impact student intellectual development and hence are ill-prepared to help students cultivate the skills necessary to perform at an optimal intellectual level.

HOW COLLEGE STUDENTS THINK

Developmental and educational theorists have documented sequential stages in the intellectual development of students (Inhelder and Piaget, 1958; Perry, 1970; Baxter Magolda, 1992; King and Kitchener, 1994; Knight and Sutton, 2004). Students do not enter college classrooms as empty vessels to be filled with knowledge, but instead actively work to construct their own understanding and form mental models that integrate new information with previous experiences (Kurfiss, 1983; Redish, 1994). Psychologists recognize multiple stages of intellectual development from infancy through adolescence to adulthood during which a person's mental models and conceptual understanding become increasingly sophisticated (Purser and Renner, 1983; Knight and Sutton, 2004). Two of the later stages, concrete operational and abstract (formal) operational (Inhelder and Piaget, 1958), have been widely recognized as characteristic of entering college students (Chiappeta, 1976; Good et al., 1979; Biggs and Collis, 1982).

All students learn best when exercises are tied to personal experience, either as result of direct hands-on activities or indirectly through the description of familiar events. Students who are identified at the concrete operational stage for a specific discipline may have an inefficient working memory and have difficulty managing multiple concepts simultaneously (Biggs and Collis, 1982). Students' concrete responses to questions will often be based on induction that draws a general conclusion using one or more facts from the question but not necessarily the most relevant facts (Kurfiss, 1983; Table 1). There may be a failure to recognize which concept is best applied to answer a problem. Answers are often brief and incomplete as students may stop taking into account alternatives when they consider that an acceptable response has been identified (Biggs and Collis, 1982). This results in a disorganized response characterized by a scatter of information that is not synthesized into a coherent whole (Table 1). Concrete operational students will often consider a problem to have a single correct solution and will have difficulty identifying responses for open-ended questions that potentially have multiple acceptable answers (Uno, 1999).

Students characterized as learning at an abstract operational level are capable of abstract thought (Purser and Renner, 1983). These students can make predictions

EXAMPLES OF CONCRETE OPERATIONAL AND ABSTRACT OPERATIONAL WRITTEN ANSWERS

Concrete operational response

The scientific method is a term that is used often in many science and social science classes. Observations are that the scientific Method strives on, from there one is to make a hypothesis in hopes that it will one day become a theory. It seems unbelievable that scholars of science would devote their time to the scientific method when it is only an educated guess of an outcome. When something is tentative, it merely means that it still has works to be done. Therefore, it makes all of the time spent into doing research on a project useless. Many people devote their time into proving theories are useless thus, making this method of research merely repetitive. In conclusion, something that is tentative cannot always be a bad thing. It is good to know that theories continue to be observed and scientist update previous findings with newer results, helping to make sure that everything done was worth the time and effort.

Abstract operational response

Because of increasing technology and discovery in science, scientific explanations are tentative. As our technology and knowledge of science in all areas increase, old theories and ideas about them may be refuted or revised. Explorations of the sciences are only as good as our tools to view them, henceforth, our views change allowing theories to change. One example of this would be our original theories on matter and how these things were made. As technology and our views on science changed, the discovery that all matter was made up of atoms was adopted, which too may someday change. As technology increases at blinding speeds as it is now, our sciences are always under scrutiny.

Table 1. Earth Science students were asked to write a 6-sentence paragraph to explain why scientific explanations are tentative. These responses are provided as examples of student work that is representative of concrete and abstract operational stages. Passages were not edited for spelling or grammar. These students scored at the concrete and abstract levels on the 12-item GALT pre-test.

in hypothetical situations that may require that they go beyond their experience to build conclusions on logic and inferences or to design solutions to new problems (Kurfiss, 1983). Students using abstract operations typically have the capacity to manage multiple concepts simultaneously as they have a relatively deep working memory and can keep the question, key concepts, and their inter-relationships in mind together while considering potential answers (Biggs and Collis, 1982). Question responses will identify most or all of the potential combinations of relevant variables and show recognition of how these variables influence each other (King, 1985). Furthermore, abstract operational students can isolate the effects of a single variable when necessary and can readily exclude irrelevant factors (Kurfiss, 1983). Complete answers may relate facts to a general concept and the best responses will show evidence of deduction to explain specific concepts in relation to a general rule that may not be discussed in the question (Table 1).

A significant proportion of high school and early college students do not exhibit abstract reasoning skills (McKinnon and Renner, 1971; Lawson and Renner, 1975; Lawson et al., 1975; Chiappeta, 1976; Good et al., 1979; Berenson et al., 1990; Uno, 1999). King (1985) reviewed twenty-five studies of college students and other adults and reported that 40-70% of the individuals in the populations studied tested at the abstract operational level. In six studies that featured only freshmen or sophomores the average proportion of students scoring at the abstract level was 50%. Students normally progress from concrete to abstract thinkers with increasing age, grade level, and practice (Roadrangka et al., 1982; Purser and Renner, 1983; Bitner, 1991), but the specific timing of this transformation can vary significantly. Student reasoning may be abstract for some domains (topics, subjects, disciplines) but concrete for others (Chiappetta, 1976; King, 1985) and will vary with context and degree of instructional support. This unevenness in student intellectual development presents a challenge to instructors in general education courses designed to serve students of 18-80 years of age with a variety of personal experiences, who bring to class a wide range of academic interests. Much of the traditional high school and college science curriculum is taught at the abstract level, making it difficult for students who are at least partially in the concrete operational level (often the majority) to understand the material (Lawson and Renner, 1975; Lawson, 1980; Uno, 1999).

Research on intellectual development suggests two characteristics that must be present for students to learn science successfully: 1. As many students enter college science classes at the concrete operational stage, concepts must be grounded in examples drawn from students' experiences to provide a foundation for the construction of understanding; and, 2. Students' understanding must be frequently challenged to provide an opportunity to identify misconceptions, to upset the equilibrium of existing inaccurate mental models, and to replace them with improved, more realistic models. We sought to investigate students' grasp of higher-order reasoning skills in several sections of a large introductory earth science course for non-majors. In particular, we hoped to address the following questions: 1. What is the intellectual starting point for our students? 2. Can specific teaching strategies contribute to improvements in students' reasoning?

ASSESSMENT OF STUDENT LOGICAL THINKING SKILLS

Reasoning skills were measured for 741 students using the Group Assessment of Logical Thinking instrument (GALT, Roadrangka et al., 1982, 1983) as a pre- and post-test in ten sections of general education introductory geoscience courses titled Earth Science or Environmental Geology with an audience of non-majors at a large Midwestern university. The five 160-student sections that defined the test population (n = 465 completed both pre- and post-test) were taught by two Earth Science instructors (Instructor 1 had one class of 82 students; instructor 2 taught four classes of 98, 89, 108, and 88 students. All students completed pre- and

Pre- vs. Post-GALT Score by Group				
Domain	Pre-GALT	Post-GALT	Gain	p <
Test group (Inquiry Classes, n = 465)				
All	6.9 +/- 2.7	7.8 +/- 2.6	18%	0.001
Concrete	3.1 +/- 1.1	5.2 +/- 2.4	24%	0.001
Transitional	6.0 +/- 0.8	7.2 +/- 2.0	21%	0.001
Abstract	9.3 +/- 1.3	9.6 +/- 1.7	6%	0.1
Control Group (Traditional Classes, n = 276)				
All	6.5 +/- 2.7	7.0 +/- 2.7	9%	0.001
Concrete	3.0 +/- 1.0	4.2 +/- 1.6	14%	0.001
Transitional	6.2 +/- 0.8	6.8 +/- 2.0	11%	0.001
Abstract	9.3 +/- 1.1	9.1 +/- 1.6	-5%	0.25

Table 2. Changes to students' GALT scores by starting cognitive level. Note that these scores only represent students who completed both the pre-test and post-test. Gain is a normalized score represented by the change in average scores/possible gain. For example, a post-GALT score of 7.8 represents a 0.9 point gain over a pre-GALT score of 6.9. The maximum possible improvement was 5.1 (12-6.9). Gain is calculated as (0.9/5.1)x100. Statistically significant (p<0.01 or less) gains occurred for students who were initially concrete or transitional in either group. Students who began the class as abstract thinkers showed no significant gains in logical thinking.

post-tests). The five sections that defined the control population (n = 276) were taught by four instructors. One control section was from a 35-student Earth Science class (n = 26 took both pre-and post-test). Two sections were from 90-student Earth Science classes taught by two different instructors (n = 50, 51) and two sections (one Earth Science, one Environmental Geology) were from 160 student classes taught by the same instructor (n = 77, 72). All students in the control groups took both pre- and post-tests. The majority (~70%) of students in each class were freshmen.

The GALT is a valid and reliable instrument for measuring logical thinking in student populations from sixth grade through college and consistently yields higher scores with increasing grade level (Roadrangka et al., 1982; Bitner, 1991; Mattheis et al., 1992). The questions used in the GALT were taken from other tests with proven reliability and validity (Roadrangka et al., 1983). A strong correlation (0.80) between GALT results and the use of Piaget student interview protocols to determine logical thinking ability supports the validity of the instrument (Roadrangka et al., 1983). Furthermore, higher GALT scores correlate with other measures of academic achievement such as course grades, SAT scores, and grade point average (Bunce and Hutchinson, 1993; Nicoll and Francisco, 2001). Students with GALT scores of 0-4 are considered to be concrete operational, scores of 5-7 are interpreted as indicative of transitional learners, and scores of 8-12 are characteristic of abstract operational learners for the tasks tested (Roadrangka et al., 1982). Success on the GALT test requires competence in five logical operations; proportional reasoning, controlling variables, combinational reasoning, probabilistic reasoning, and correlational reasoning (Roadrangka et al., 1982). The abbreviated form of the GALT survey contains twelve illustrated questions, a pair for each of the five logical operations listed above and another two that evaluate conservation.

METHODS

The GALT instrument was administered as a pre- and post-test in multiple sections of courses taught by several instructors teaching in similar classrooms. Classes can be divided into inquiry-based learning (IBL) or traditional formats. IBL sections emphasized processes such as making observations, posing questions, analyzing data, making predictions, and communicating ideas (Brunkhorst, 1996). Students in IBL classes worked together in groups to complete learning exercises that included conceptual multiple-choice questions (conceptests), Venn diagrams, evaluation rubrics, concept maps, and open-ended questions (McConnell et al., 2003). In contrast, traditional classes followed a passive lecture format that did not involve groups and did not incorporate inquiry-based or active learning exercises during class. The contrast between these traditional and IBL learning environments compares with teaching-centered and learning-centered classroom models (McManus, 2002), respectively. In the IBL classes, students were organized into permanent formal groups assigned by the instructor based on the pre-test GALT scores. Each group contained a mix of students with high, intermediate, and low GALT scores. We anticipated that the group setting would provide an opportunity for low scoring students to see effective logical thinking skills modeled by higher scoring students (e.g., Nelson, 1994). The students were not made aware of their GALT scores. Student performance was measured by a combination of exams, homework assignments, and in-class exercises. Exams typically accounted for 50 or 60% of the total course grade. Exams were composed of multiple-choice questions that required either the recall of knowledge or the comprehension and application of concepts. In-class exercises and homework assignments generally required the analysis, synthesis or evaluation of key course concepts (McConnell et al., 2003).

Students in the IBL classes were considered the experimental or test group; students in traditional lecture classes represented the control group. The IBL classes began with 160 students each, except for one class with 36 students. The control population consisted of students taking five similar classes for non-majors from one of four different instructors who used a traditional lecture format. The control classes had either 90 or 160

Student Operational Level Pre-and Post-Test				
	n Pre	n Post	% pre students	% post students
Test Groups (Inquiry Classes)				
All	465	465		
Concrete	101	58	22%	12%
Transitional	144	125	31%	27%
Abstract	220	282	47%	61%
Control Group (Traditional Classes)				
All	276	276		
Concrete	75	62	27%	22%
Transitional	98	90	35%	33%
Abstract	105	124	38%	45%

Table 3. Students at various cognitive levels that were used in this study (raw numbers and % of population).

students with the exception of one class taught on Saturday that had 35 students. The average value of the "overall excellence of teacher" score on student evaluations was 4.0 (out of 5) for faculty teaching the IBL classes and 4.4 for instructors in the traditional classes. Data analyses were completed for students in test and control classes having both pre-test and post-test scores. Mean scores and standard deviations were computed for each class using paired two-tailed T-test analyses. Average score changes were computed for the entire population and for subcategories based on initial GALT score (concrete, transitional, abstract).

AVERAGE GAINS IN GALT SCORES

Data - Pre- and post-test GALT data displayed several interesting trends. The general student population (combined test and control groups) was found to be initially comprised of 24% concrete (n = 176/741), 33% transitional (n = 242/741) and 43% abstract (n = 325/741) thinkers as assessed by the GALT. Student subpopulations (concrete, transitional and abstract) in each group exhibited differences based on initial GALT scores (Table 2). Average pre-test GALT scores for the test group were ~4% higher than those in the control group ($p < 0.05$). The control sections had ~5% more concrete (n = 75/276 versus 101/465) and transitional thinkers (n = 98/276 compared to 144/465) than the test sections (Table 3). There were 9% fewer abstract thinkers in the control group than in the test group (Table 3).

Students in both test and control classes increased their logical thinking skill over the course of the semester. Normalized gains (change in average scores/possible gain) for students in the test classes were higher for all populations (Table 2). Students in the test group average score gains were approximately twice those of the control sections (18% versus 9%). Concrete students displayed the greatest change in both groups; the test group exhibited 10% higher normalized gain than the control group (24% versus 14%; Table 2). Transitional students in the test group also outperformed their control group peers by 10%, but overall gains were less than those the concrete students (21% and 11% respectively; Table 2). Abstract students' gains (or losses) were not statistically significant in either the test or control groups ($p > 0.05$).

Students progressed from less complex cognitive levels to more complex levels in both test and control groups (Figure 1). Concrete operational students made up just 12% (n = 58) of the test group at the end of the course compared to 22% (n = 62) in the control group (Table 3). Transitional students made up 27% (n = 125) and 33% (n = 90) of the final test and control groups, respectively (Table 3). The final cohort students in the test group were 61% (n = 282) abstract compared to 45% (n = 124) in the control group (Table 3). Results in individual sections varied. Three of the control sections displayed no overall gains in logical thinking scores. One instructor's traditional lecture-based section displayed a ~12% overall gain one semester and no gain the next. Another control class displayed overall gains similar to that in test group (~24%), but only 20% of the initially concrete students remained in that section by the end of the course. Inquiry-based sections displayed statistically significant gains in all sections that ranged from 19% to 21% except one case where the overall gain was 10% during the first semester of the study.

Interpretation and Discussion - More than half the students taking introductory geoscience courses for non-majors were cognitively unprepared for instruction that required them to make abstract connections concerning major concepts. Concrete and transitional thinkers are not adequately prepared to learn material presented at an abstract level. In a lecture course, such students may attempt to cast the information in a quasi-concrete form with which they are most comfortable. These students rely on memorization and commonly fail to comprehend questions that test concepts using applied knowledge. The learning environment for these students must be structured to scaffold learning in a fashion that takes advantage of their natural learning strengths. When the teacher scaffolds learning, such as is common in an IBL format where students work in groups, exercises commonly begin with concrete examples. Abstract thought processes were also frequently modeled by their peers as they complete group exercises. Such activities give concrete and transitional students an opportunity to ask questions and build concepts in a non-threatening environment where students addressed concepts that required them to apply knowledge to new situations. Lastly, in the IBL setting where in-class (formative) assessments are common (McConnell and others, 2003), students can consistently recognize gaps in their understanding and take action to correct them.

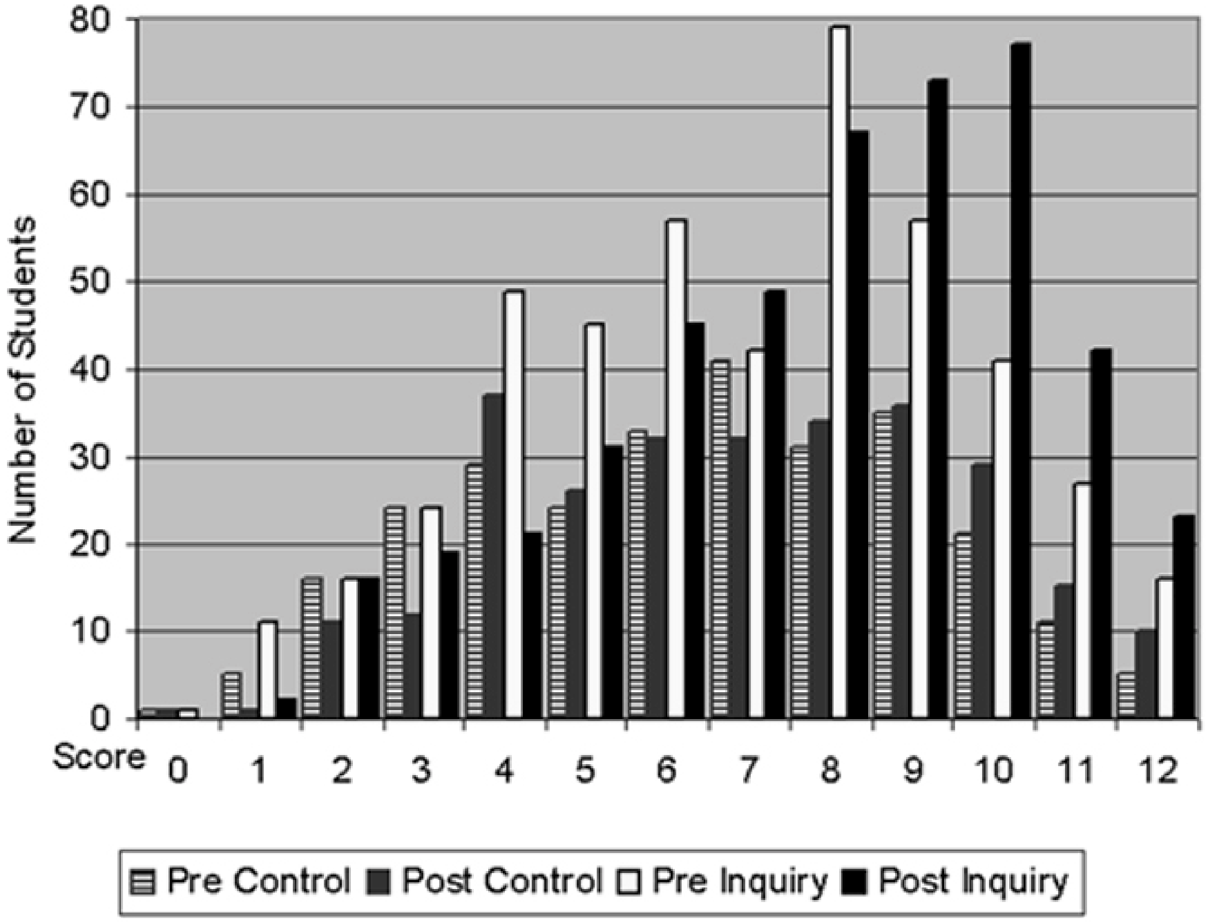

Figure 1. Numbers of students scoring at each level on the GALT pre- and post-tests for control (traditional) and inquiry (test) groups (n =741).

Post-test scores indicated that, although development occurred in both groups of students, students develop more quickly and consistently in an IBL environment. Overall, those students who entered the courses at the concrete level displayed the greatest gains in either teaching format. Those students scoring lowest on the GALT had the greatest opportunity for improvement. The GALT test is designed with questions of varying levels of difficulty from relatively simple (most students answer correctly) to relatively difficult (few students answer correctly). Typically ~4% of students score at either the low end of the scale (0 or 1) or the high end of the scale (12). Normalized gains to logical thinking skills for students in the inquiry-based class were significantly higher than those found in the lecture format sections. Greater improvements to GALT scores might be predicted in the IBL classes due to the nature of the instruction where the student-centered approach forced students to identify and struggle with their misconceptions in class (McManus, 2002). Similar trends in gains were observed for the transitional thinkers (though of a lower magnitude) while no overall gains were observed for abstract thinkers. We attribute the latter result to a cognitive ceiling effect. Students who entered the classes as abstract thinkers were unlikely to be confronted with materials that were sufficiently challenging to improve their logical thinking skills.

GALT SCORES AND COURSE PERFORMANCE

The GALT test provides a measure of cognitive performance but has not been directly linked to student understanding of geoscience concepts. GALT pre-test scores and course grades for 474 students in large IBL Earth Science classes were analyzed to determine if there was any correlation between student scores on the GALT test and student achievement in introductory geoscience courses.

Data - In general, students who began the course as abstract thinkers earned higher grades in the course than students who began as concrete learners (Figure 2). Two thirds (66%) of the students who entered the IBL classes as abstract thinkers earned an A or B in the course compared to just 27% of the initially concrete thinkers (Figure 2). More than a third (42%) of the concrete students were unsuccessful, as defined as a grade of D or F. In contrast, 11% of abstract thinkers were unsuccessful (Figure 2).

Interpretation and Discussion - There is a positive correlation between scores on reasoning tasks and scores on standardized tests, high-school rank, college GPA, and/or course grades (Lawson et al., 1975; Chiappetta, 1976; Lawson, 1980; Marek, 1981). In the current study, in all cases, students scoring in the concrete range did more

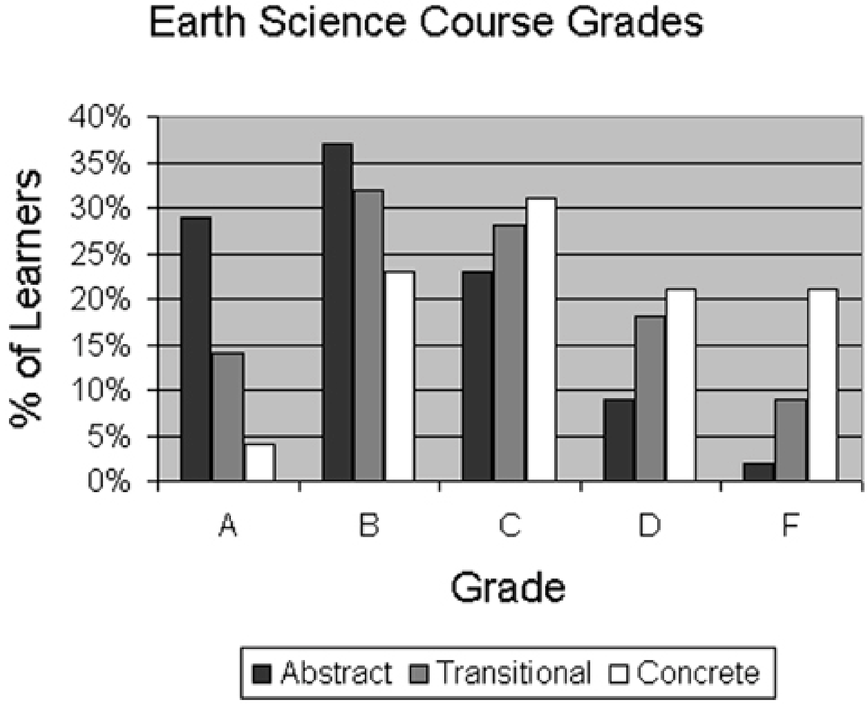

Figure 2. Course grades for concrete, transitional and abstract students in IBL classes as a proportion of students at a particular cognitive level (e.g., 29% of the abstract thinkers earned an A). Those students who stopped attending but did not drop the course are excluded.

poorly on standardized class tests than transitional students, who in turn did more poorly than abstract students.

While cognitive level can account for the broad pattern of grades (Figure 2), it does not readily explain why an abstract thinker might fail the course or why a concrete student might excel. Course success at any cognitive level was at least partially attributable to attendance (Table 4; Moore, 2003). On average, concrete, transitional and abstract level students were equally likely to attend class (Table 4). Students of all cognitive levels who earned an A or B in the class attended ~90% of the classes. Unsuccessful students on average attended between 66-73% of the classes (Table 4). This moderate correlation ($R^2 = 0.41$) between attendance and course grades is to be expected since approximately 30% of the final grade depended on completing group exercises in class. Consequently, we attribute the poor performance of abstract students primarily to attendance.

A comparison of concrete operational students who earned an higher grade (A, B) with those who do poorly in the class (D, F, W) reveals that there was a noticeable difference in their performance on the GALT instrument. Concrete students who earned an A or B performed better on GALT pre-test questions related to the conservation of matter than other concrete students. These high performing students were better prepared to learn and implement the higher-order thinking skills that were necessary to understand abstract concepts such as plate tectonics, atmospheric processes and climate change. This suggests that it may only be necessary to evaluate student understanding of conservation in order to identify students in need of academic interventions to ensure their success in class.

THE EFFECT OF GROUP ACTIVITIES VS. INQUIRY EXERCISES

Our initial results lead us to consider whether students improvement in their GALT scores was a primarily a result of working in groups or was more attributable to working on exercises that required the application of higher order thinking skills. To investigate this question, one instructor taught two sections of the same IBL-style class using the same learning exercises and using collaborative groups in one class but not in the other. Both classes received the identical lectures and class materials. Students in the class without assigned groups were not prevented from working together, though it was not encouraged by the instructor.

Data - Abstract thinkers in both sections had the highest overall course averages and concrete thinkers scored lowest (Table 5). Overall course grades for students in the section using assigned groups were 5% higher ($p<0.01$) than in the section that employed active learning without the benefit of groups (Table 5).

Interpretation and Discussion - The advantage gained by using groups appears to help all students, but the effect is most profound on the formal students (Table 5). The overall result was not unexpected since the group work concept has been shown to be successful in many situations (Nelson, 1994; Paulson, 1999; Lord, 2001). Students in structured groups learn from one another and are more likely to get their questions answered as they strive to meet common goals and objectives. They become more socially connected and have more opportunities to address their misconceptions. This is

Attendance Rates for the Test Group (n = 465)				
Cognitive Level	**Grade**			
	AB	C	DF	Avg.
Concrete	92%	88%	73%	83%
Transitional	91%	84%	67%	82%
Abstract	90%	82%	66%	85%
Average	91%	85%	69%	

Table 4. Comparison of attendance and grade distribution as a function of cognitive level.

Group Learning Stategy vs. Cognitive Level				
Learning Strategy	Concrete	Transitional	Abstract	Overall
Group Inquiry	74%	77%	84%	80%
Individual Inquiry	70%	74%	79%	75%
p <	0.08	0.07	0.01	0.0005

Table 5. Course averages as a function of cognitive level when comparing sections that employ group exercises compared to those where the exercises were completed as individuals (n = 119).

particularly true in large format sections where individual attention from the instructor is at a premium. Students' logical thinking skills show the greatest improvements in science courses that integrated concrete experiences and social interactions, and that posed questions that caused students to examine their existing knowledge (McKinnon and Renner, 1971; Batt, 1980), or that emphasized the development of process skills (e.g., forming hypotheses, interpreting data, generating experiments; Padilla et al., 1983)

The outcome that only abstract students improved their overall grades (statistically, Table 5) as a result of group activities was unexpected. Perhaps abstract students fare better in the group environment because they have more advanced metacognitive skills that allow them to readily recognize and address their misconceptions as they attempt to explain concepts to peers. This interaction then reinforces the concept for the abstract thinker and better prepares them for later assessment opportunities. In contrast, the exposure to the learning exercises themselves may be the more significant factor for concrete and transitional students with a history of learning strategies that rely heavily on memorization and recall. Further study using qualitative methods such as surveys and interviews may clarify and inform our findings.

SUMMARY AND CONCLUSIONS

The results obtained from the GALT instrument provide valuable information for students and teachers of introductory geoscience courses. Most students will not know their own level of cognitive levels and even the weakest students assume that they are of average ability (Kruger and Dunning, 1999). As such, students are not likely to recognize that the study techniques and methods with which they are most comfortable may not lead to success. Abstract problems and scenarios are most accessible to abstract thinkers and many instructors will frustrate concrete learners who are accustomed to solving problems using highly structured approaches (memorization or non-intuitive formula-based). Additionally, most instructors do not know the cognitive level of students in their courses and may incorrectly conclude that all college students operate at the highest cognitive level, when there is a wide range of cognitive development in adult learners. Activities or lectures should be designed to serve the entire spectrum of thinkers from highly structured concrete learners to abstract thinkers.

In this study, GALT test results reveal that:

1. A majority of students entering introductory geoscience courses for non-majors had not been prepared to think consistently at an abstract level. Instructors must introduce concepts with concrete examples and provide scaffolding activities that assist students in developing an understanding of more sophisticated ideas.
2. Gains on the GALT post-test were greatest for students initially classified as concrete and were almost non-existent for abstract learners.
3. Improvements in GALT scores were more significant for students in active learning environments such as inquiry-based learning classes than for passive learning settings similar to traditional lectures.
4. Course grades were higher for abstract students than for concrete students.
5. Student performance decreased at all cognitive levels as attendance and the number of completed assignments decreased.
6. Classes using structured groups outperformed classes where students worked on similar assignments individually.

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