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ABSTRACT

This review explores the empirical research on nontraditional instruction methods and their effects on reasoning development in college students in introductory biology. A search of primary databases found relatively few empirical studies, but eventually nine relevant empirical studies were identified. Findings suggest that inquiry-based, nontraditional collaborative instruction is more effective than traditional, lecture-based instruction in developing higher order reasoning skills in introductory college biology courses. Gains in reasoning do not appear to be achieved at the loss of content acquisition. Methods that emphasize writing have higher success in developing reasoning than methods that do not. Direct instruction in formal and informal reasoning leads to gains in those reasoning skill areas. Many questions about the strength of effects and how different instructional variables play a role in changing reasoning were apparent, but findings strongly support use of nontraditional inquiry-based collaborative methodologies for the development of student reasoning. (Contains 2 tables and 20 references.) (SLD)

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INSTRUCTIONAL APPROACHES FOR THE IMPROVEMENT OF REASONING IN INTRODUCTORY COLLEGE BIOLOGY COURSES: A REVIEW OF THE RESEARCH

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INSTRUCTIONAL APPROACHES FOR THE IMPROVEMENT OF REASONING IN INTRODUCTORY COLLEGE BIOLOGY COURSES: A REVIEW OF THE RESEARCH

The majority of undergraduates lack advanced reasoning patterns which are necessary for successful achievement in college science courses. The purpose of this paper is to review the studies of various instructional practices in introductory college biology courses that claim to develop reasoning. Most of these were non-traditional, inquiry based, collaborative approaches that were shown to improve reasoning and scientific attitudes but did not adversely affect content acquisition. The inclusion of writing, direct teaching of formal and informal reasoning models, and length of time of instruction were variables that effected positive gains in reasoning development. How the instructional variables play a role in changing reasoning remains a black box.

Although college science faculty purportedly advocate instructional methods that improve student scientific reasoning skills, limited research and change in post-secondary science teaching has been documented (Glick, 1994). This can be attributed to a variety of reasons. According to Glick (1994), college instructors are often scientists who are untrained in instructional theory and practice. As a result, these instructors rely on the methods by which they were taught in order to develop a conceptual framework to guide their teaching. This framework is most often a traditional pedagogy, characterized by a rigorous adherence to content transmission and not the development of reasoning skills (Glick, 1994). Introductory college biology courses tend to have large lecture classes which reinforce passive roles for learners and so a special challenge exists to promote reasoning (Ebert-May, Brewer and Allred, 1997). Also, the undergraduate science laboratories tend to be fact-laden, non-inquiry based, with activities that act in opposition to the development of reasoning skills (Hall and McCurdy, 1990).

Sundberg et al. (1994) cites a fear among college biology educators that content knowledge acquisition would suffer if time were to be dedicated specifically to reasoning skill development during the lecture or laboratory. This has fomented, among science educators, a spirit of antagonism against non-traditional instructional methods that advocate reasoning development. It is also presumed by these instructors that college students, as adults, should be able to use scientific reasoning strategies independently after reading course materials and listening to lecture presentations (Glick, 1994). When students are unable to do this, according to Glick (1994), blame is simply placed on deficiencies in secondary level preparation.

Unfortunately, as many as fifty percent of first year college students lack these advanced reasoning patterns according to Lawson's (1992) review of research on reasoning skills of undergraduates. Perry (1970) and King and Kitchener (1994) found that these entering college students are dualistic (right vs. wrong only) thinkers who are unable to evaluate an argument based on the strength of the evidence. A number of studies of empirical research are cited that outline the deleterious effects of a lack of reasoning ability on achievement in introductory college biology courses (Lawson, 1992; Lawson, 1980). It is thus documented that the ability to judge knowledge claims is critical in understanding science and that a lack of higher order reasoning skills among students should be addressed by the instruction (Glick, 1994). Further, traditional

ERIC

instructional methods such as lecture and textbook assignments alone are not effective in developing reasoning in students, according to Hall and McCurdy (1990). In the traditional lecture-based classroom, Piaget (1970) argues, the teacher is the source of all morality and truth, and "from the intellectual point of view,...[the student] accepts all affirmations issuing from the teacher as unquestionable..." so that the words are dispensed without the need for student reflection (p.179). Thus, a static, unchanging, and factually based way of knowing is perpetuated. Rogers (1967) denounces this method, declaring that it is the recognition by the learner that knowledge is continually changing that should be the goal of education. Piaget (1970) argues that this traditional method of instruction consolidates the egocentrisms found in childhood by simply replacing "a belief in self with a belief based on authority, instead of leading the way toward the reflection and the critical discussion that help to constitute reason and that can only be developed by cooperation and genuine intellectual exchange" (p. 179) to improve reasoning. Thus, a major purpose for this review is to explore the empirical research on non-traditional instructional methods and their effects on reasoning development in college students in introductory biology to determine the truth of the above claims.

Most of the recent research on the teaching and classification of reasoning in biology courses incorporates the Piagetian theory of intellectual development into the theoretical framework and the analysis of the results (Allen, 1981). The Piagetian model of thought development identifies lower level reasoning (called concrete reasoning) as being limited to merely the describing and ordering of observable phenomena (Allen, 1981; Piaget, 1970). The concrete reasoner needs to reference familiar situations to accommodate and assimilate new information (Piaget, 1970). Thus, only an inductive

ERIC

method of analysis (defined as reasoning from particular facts or situations to general conclusions) is employed to form conclusions (Allen, 1981). This type of reasoner lacks awareness of his/her own thinking patterns and when faced with inconsistencies in evidence, is unable to generate or consider alternate hypotheses and so relies primarily on authority and intuition to draw conclusions (Allen, 1981). In the science laboratory, for example, Allen (1981) describes this student as in need of step-by-step instructions during lengthy procedures.

The higher level reasoner (called formal reasoner), in contrast, is characterized by the ability to generate and test alternative explanations when confronted with ambiguity (Allen, 1981). Reasoning is begun by imagining possibilities so that conclusions are drawn usingthe hypothetico-deductive method (defined as reasoning from a known general principle to the unknown) (Allen, 1981). These reasoners demonstrate the use of formal reasoning patterns, which, for the purpose of this review are defined as the ability to control variables, and use probabilistic, proportional, correlational and combinatorial reasoning (Lawson and Snitgen, 1982). This stage also involves the systematic consideration of alternate hypotheses and evidence to draw conclusions, which for the purpose of this study will be defined as informal reasoning. With such reasoning, individuals possess meta-knowledge and can thus evaluate inconsistencies in their own arguments. Such a reasoner, according to Allen (1981), is an independent thinker and can, for example, develop a workable plan of analysis in a science laboratory given the overall goals and resources of a lengthy procedure.

This development of reasoning is related to the individual's ability to understand the nature and defense of one's own knowledge claims (Allen, 1981). According to

Hofer and Pintrich (1997), the area of philosophy that is concerned with the nature and justification of knowing is termed epistemology, and a body of research exists based on how epistemological assumptions influence the development of reasoning. This includes, for the importance of this review, the manner in which individuals come to know and how this influences and is affected by the cognitive processes of thinking and reasoning (Pintrich and Hofer, 1997).

An epistemologically based developmental scheme exploring how college students make meaning of their educational experiences was developed by William Perry (1970). He was the first to suggest that reasoning in undergraduates was related to epistemologic maturation. The initial work by Perry (1970) on primarily white, male college students has led many researchers to explore reasoning in education. Perry's (1970) two longitudinal studies of undergraduates that began in the early 1950s at Harvard's Bureau of Study Counsel led to a developmental scheme that shows students undergoingepistemological growth in stages that result in a maturation of reasoning ability.

During the initial periods of development, according to Perry's model, students view knowledge and produce arguments in a dualistic manner, with right and wrong as absolute and ultimately determined by authority (Pintrich and Hofer, 1997). Thus, in the biology classroom, such individuals expect instructors to distribute information without ambiguities (Allen, 1981).

The progression of student reasoning abilities should continue, according to Perry (1970), through a series of stages characterized by more pluralistic views, where knowledge and values are perceived as relative. Perry (1970) defines these stages by level of student possession of higher level reasoning strategies that employ skills to interpret evidence to form conclusions. Thus, the student at this level accepts the existence of possibly conflicting, multiple viewpoints and evaluates the evidence, internal consistency, and coherence of each perspective to formulate a conclusion (called relativism) (Pintrich and Hofer, 1997).

According to this model of intellectual development, higher levels of reasoning involve student perception of knowledge and values as contextual and relativistic. Thus, in the science classroom, this informal reasoning translates into skills in interpreting data and observations, evaluating equally valid arguments, and drawing conclusions from experiments. Dualistic, lower level reasoners are uncomfortable with the uncertainties involved in interpretation and evaluation of scientific evidence and so decision-making in science becomes an incomprehensible process when the "right answer" is not provided (Allen, 1981). Thus, Perry (1970) contends, instruction should enhance student reasoning to relate scientific evidence with conclusions rather than simply focusing on memorization of those conclusions.

Comparisons can be made between Perry's model and Piaget's theory of intellectual development. The progression of complexity of thought through the variousstages is propelled by the interaction of the individual with an environment to create the cognitive disequilibrium described by Piaget (1970). Thus, it is the assumption by this review that inquiry-based active learning best develops reasoning, as advocated by Perry (1970) and Piaget (1970).

Although Perry's scheme, influenced by Piaget, addresses general thought development, King and Kitchener (1994) point out that some aspects of scientific

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reasoning are not adequately described by either theorist. Thus, as an extension of Perry's (1970) work, King and Kitchener (1994) propose a model that represents the most recent and extensive work on the development of informal reasoning in college students (Hofer and Pintrich, 1997). The scheme is particularly valuable due to its elaboration of Perry's upper levels of reasoning and will be referred to in classifying the levels of scientific reasoning examined by the authors in the studies reviewed.

King and Kitchener (1994) conducted a fifteen year interview-based study involving the analysis of reasoning in subject responses to ill-structured questions (questions with the possibility of more than one acceptable answer). Through this, King and Kitchener (1994) proposed a seven stage scheme for reasoning development called the Reflective Judgement model, which focuses on the individual's understanding of the nature of knowledge and the process of reflecting on and justifying that knowledge (Hofer and Pintrich, 1997). Table 1 compares the models of reasoning development described by Piaget (1970), Perry (1970), and King and Kitchener (1994).

There are three levels within the seven stage model: pre-reflective (stages 1,2, and 3), quasi-reflective (stages 4 and 5), and reflective (stages 6 and 7). In the pre-reflective stages, what is observed or what authority dictates determines truth. As with Perry's dualism, the individual is unable to reflect upon uncertainties in answering an ill-structured question (King and Kitchener, 1994).

During the quasi-reflective levels, there is a growing recognition that the individualcannot know with certainty and that each person is entitled to an opinion. It is during these stages that the belief that knowledge is relative emerges, yet the ability to

ERIC

actively construct arguments and evaluate scientific evidence is absent (King and Kitchener, 1994).

At the reflective stages only, does the role of the knower move from a spectator and receiver of knowledge to an active constructor of meaning. Knowledge is recognized as uncertain and relative so that conclusions made from ill-structured questions include the critical evaluation of different positions. The highest level of reasoning occurs (in science) at this stage when the use of critical inquiry and hypothetical justifications allow for the evaluation and reevaluation of evidence and conclusions for ill-structured questions (Hofer and Pintrich, 1997).

King and Kitchener (1994) feel that reasoning abilities develop by assimilating and accommodating existing cognitive structures through interaction with the environment. The mechanics of this model of change are thus Piagetian and suggest that a major reason for this review should be to determine what instructional variables of the learning environment influence the development of reasoning in a college biology course (King and Kitchener, 1994).

The higher level reflective judgement characterizing stages 6 and 7 has been observed in only a tiny fraction of undergraduates interviewed by King and Kitchener (1994) and has appeared consistently only among advanced graduate students (Hofer and Pintrich, 1997). In addition, although it appears that education is positively correlated with reasoning stages, little development actually takes place during the college years, with less than half a stage during the entire four-year undergraduate experience as reported by King and Kitchener (1994). Thus, studies are needed to investigate what kinds of teaching methods and instructional environments foster the development of reasoning in college students.

This review will attempt to answer the questions: What instructionalmethods/environments foster reasoning development? What are the particular instructional variables within the methods that influence reasoning? Does course content achievement suffer when such methods are employed? What other learning variables are influenced by these instructional methods/environments? and, What are the relationshiips between those variables?

Although each study reviewed operationally defines high level scientific "reasoning" differently, for the purposes of this review, reasoning includes critical thinking, and ability to problem solve and use process skills. Reasoning is also separated into two constructs based on the frameworks presented by Piaget (1970), Perry (1970), and King and Kitchener (1994): formal reasoning which includes control of variables, correlational, probabilistic, proportional, and combinatorial reasoning and informal reasoning which includes the ability to explore nature, raise questions, generate multiple working hypotheses, and evaluate evidence to develop a logical argument (National Science Foundation, 1989).

Methods

The purpose of this paper is to review the research on instructional approaches that has been concerned with improving reasoning skills in introductory college biology courses. The review of the literature has shown that a very limited amount of empirical research has been done on college biology instruction and even less on the development of reasoning at this level.

The process was begun with a preliminary search of the primary databases: ERIC (Educational Resources Information Center), PsychLit (Psychological Abstracts), and Dissertation Abstracts. Upon searching these databases for "reasoning" and "college biology", it became alarmingly clear that very few empirical studies were identified (one was found as appropriate). I broadened the search to include synonyms for reasoning such as "critical thinking skills", "logic", "persuasive discourse", and "argumentation", for college, "undergraduate" and for biology, "science". I found few relevant studies, but then searched all of the work done on undergraduate biology in all of the databases.

Through this, I found a few empirical studies but discovered a review of research by Glick (1994) on "Effective methods for teaching nonmajors introductory college biology" which reviewed four studies. I decided to broaden the search by allowing the definition of reasoning to include both formal and informal reasoning. I also included studies using "process skills" as an outcome variable studied, when described by the authors in a way that resembled a form of reasoning as defined by this study.

When searching the bibliographies, most of the citations were opinion-based and non-empirical, speculative discussions of reasoning in science. The studies which were empirical often explored the lack of reasoning in first-year college biology students but

ERIC

did not focus on instructional methods to develop that reasoning. I searched the bibliographies of all the studies and found that those which were even tangentially related were few in number, including a review by Lawson (1992) on non-majors introductory biology. This review provided more related studies and upon search through the bibliography, found a small number of related studies. The bibliographies acted as a springboard to finding other related work, which finally yielded a total of nine relevant empirical studies.

Personal discussion with Ebert-May (author of "Innovation in large lectures- teaching for active learning", 1997) reinforced the perception that few studies on reasoning in biology courses existed. As a last attempt, I searched recent science education type journals for studies not yet in the databases, including Bioscience, The Journal of College Science Teaching, The Journal of Research in Science Teaching, Science and Education, and The Journal of Biological Education. An indication that the search had been completed occurred when papers alluded to the same sources already identified.

Papers were not selected based on the quality of the study (except publication as a prerequisite) because so few were found. A more complete narrative review should include a comprehensive analysis of study quality in the selection process. However, the studies were selected based on the following criteria:

1. The research subjects were college students enrolled in an introductory undergraduate biology course. Studies including high school students (of which there were many) were eliminated since these subjects are not representative of those who attend college (due to differences in cognitive and intellectual development).

2. The research was empirical in that it addressed a question related to effective instructional methods and evidence to support the conclusions.

3. The written report needed to be available in published journals, Dissertation Abstracts, or through the ERIC and Psychlit databases. Unpublished dissertations and works-in-progress were not included since they are not readily available to instructors hoping to improve their teaching. Also, unpublished work could indicate a lack of quality in the information contained.

4. An outcome variable in selected studies was reasoning. For the purposes of thisreview, reasoning was classified according the definition presented in the introductory section and is the major variable examined by this review (shown in Table 1).

5. Studies were each analyzed on the following criteria: claims of the outcomes, validity and reliability of the methodology, types of dependent variables studied, and sample size. Characteristics of the studies were compared to provide an interpretation and integration of the results (shown in Table 2).

Results

The following statements can be made with strong support from the empirical research of the studies reviewed, although they are not submitted without contestation. Outcomes for the studies are displayed by Table 1. Several weaknesses were found in some supporting studies and there is not unanimous agreement on all points in this review.

1. Inquiry-based, non-traditional collaborative instruction is more effective than traditional, lecture instruction in developing higher order reasoning skills in introductory college biology courses.

2. The gains in reasoning through inquiry-based, non-traditional collaborative instruction are not achieved at the loss of content acquisition.

(Points 1 and 2 will be discussed together since an argument against reasoning development is the suffering of content).

3. Inquiry-based, non-traditional collaborative instruction emphasizing writing to develop reasoning has higher success at developing student reasoning than those methods not emphasizing writing.

4. The direct instruction of formal and informal reasoning leads to gains in those reasoning skill areas.

5. Gender and Major do not appear to interact with instruction to influence reasoning.

6. Enough instructional time is needed to improve reasoning.

7. Developing reasoning skills improves the general intelligence of students.

8. Inquiry-based instruction that improves reasoning also enhances positive scientific attitudes.

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9. The BSCS (Biological Sciences Curriculum Study) method of inquiry-based instruction produces no significant gains in reasoning ability.

10. The laboratory is an important part of an introductory biology course since it improves reasoning.

(Figure 1 displays the purported relationships among the variables by the review (dotted lines represent possible relationships to be determined by future studies)

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Discussion

The attempt to change instructional methods in undergraduate biology to include the development of reasoning is not a recent phenomenon. The earliest study found, by Barnard (1942), emphasized the need for students to learn more than just factual content. The reform efforts stimulated by "A Nation at Risk" to improve science reasoning have produced most of the studies on undergraduate biology found in this review (Ebert-May, et al., 1997). All of these include a quantitative, experimental design which employs, as independent variables, instructional methods for increasing student involvement in constructing knowledge to improve reasoning.

All of the studies except those using the unmodified BSCS (Biological Sciences Curriculum Study) method demonstrated an improvement in student posttest reasoning scores in the experimental treatment groups. These six studies will be presented together first as support for non-traditional instruction. Some used a control to compare their strategies with a traditional, lecture-based method (Barnard, 1942; Tyser and Cerbin, 1991; Haukoos and Penick, 1983; and Ebert-May, et al., 1997).

Barnard (1942) first showed this in his study using a problem solving method of instruction which emphasized student involvement in the collection of data, forming of generalizations, and evaluation of explanations in science over the lecture method in which students were described as passive acceptors of knowledge in its final form. A pre/posttest quasi-experimental control group design was used with three batteries of tests administered as pretests, midsemester, and posttests. The problem solving group had higher midsemester and posttest scores on problem solving through reasoning than the control group. The author assumes equivalence of the groups based on pretesting and

ERIC

psychological testing and describes the differences in instructional methods in great detail.

However, the results are not convincing due to a number of weaknesses in the study. A modern statistical analysis of Covariance (ANCOVA) should have been done todetermine statistical significance of the differences in the pretest/posttest reasoning development of the subjects in the two treatments. A threat to external validity also exists since it is doubtful that the subjects of over fifty years ago resemble modern undergraduates. Additionally, little information is given about the subjects other than heterogeneity in class years, thus again restricting generalizability.

The tests for problem solving through reasoning also had unacceptably low test-retest reliabilities, with reported pretest, midsemester, and posttests at .67, .53, and .51, respectively. The addition of a midsemester test also increased the chances of a test-retest effect on achievement as well.

Barnard's (1942) study was also the only study in this review which showed a decrease in content knowledge achievement among the problem solving groups. However, the tests on content also had reportedly low reliabilities (averaged at .43) and the addition of a midsemester test increased the chances for a test-retest effect. Thus, supported by the poor statistical analysis of the data, the threats to external validity, and the low reliability of the test batteries, it can be concluded that little can be learned from this study about improving reasoning in undergraduate biology courses today.

A theme emerging from an analysis of the studies in this review is the use of writing during instruction to develop student reasoning. Tyser and Cerbin (1991), Lawson and Snitgen (1982), Moll and Allen (1982) and Ebert-May, et al. (1997) showed that integrating writing as an expression of reasoning during instruction has a positive impact on student reasoning development.

The use of a "Science News Exercises" instructional method in introductory college biology with a pre/posttest quasi-experimental control group design by Tyser and Cerbin (1991) showed improvement in student reasoning skills. This method represents students with a model for evaluating evidence in popular science articles to develop a logically persuasive argument. Students assess 6-7 biweekly scientific articles in terms of guidelinesfor the direct teaching of reasoning through a three step line-of-reasoning model. This is the only study in the review to directly teach and apply a method for informal reasoning. The model gives simple guidelines for the identification and evaluation of evidence and for then persuasively communicating a developed article.

The "Science News Exercises" group performed statistically significantly better than the traditional lecture group on the objective test for evaluating evidence ($t=3.46$, $df=1, p<.01$) and on the lines of reasoning written test ($X2=11.93, df=1, p<.01$).

Content achievement was not assessed, but the authors contend that only 200 minutes of lecture time (10% of the lecture course) were used for Science News Exercises. Thus, the concern for a loss of content should be ameliorated according to the authors.

Although Tyser and Cerbin (1991) used statistical analyses (a paired t-test and Chi square) to compare the means, several weaknesses are evident which cast a doubt on the results. First, there is little subject information offered except that 80% are non-majors. This limits generalizability, especially to courses consisting of a high proportion of biology majors. Second, the teachers for control and experimental treatments differed, thus introducing the possibility of confounding variables. Third, the reliability and validity of both the objective and written tests are not offered by the authors. Despite these flaws, the results do show evidence of positive effects of non-traditional instruction emphasizing writing on reasoning development in college students.

A study by Lawson and Snitgen (1982) on the direct teaching of formal reasoning in an inquiry-based course for preservice elementary teachers also showed positive effects on reasoning development. The course, entitled "Biological Science for the Elementary Teacher" used reasoning modules to facilitate collaboration among students to apply formal reasoning strategies to experimentation. This is the only study in the review to address the direct teaching of formal reasoning. The authors implement Piaget's (1970) suggestion to ground the development of formal reasoning in concrete experiences and socialinteractions. Their method introduces what is familiar to the student and through collaboration, allows for the student to recognize his/her own faulty reasoning. This creates a mental disequilibrium which is then corrected, according to Piaget (1970).

This Piagetian model was pre- and posttested using a quasi-experimental design lacking a control group. Using the dependent t-test, the authors report statistically significant pre/posttest increases in formal reasoning for the subjects after taking the course ($t=9.96, df=31, p<.001$). The Lawson Test for Formal Reasoning was used and verified for face, factorial and construct validity and for reliability according to the authors.

However, the posttest only group scored significantly lower, indicating a possible test-retest effect. In addition, the test for the transfer of reasoning to unfamiliar contexts

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showed no significant pre/posttest improvement among subjects. Thus, the application of reasoning using this method is not demonstrated. In fact, qualitative analysis of the results indicated that students misapplied reasoning strategies even though they could formally reason. A future study should investigate possible negative effects of this method such as confusing established formal reasoning patterns.

Other qualitative data obtained by this study were particularly illuminating. Some formal reasoners found the course "childish and boring" and others dropped the course citing their desire not to conform to the thinking methods called for by the Reasoning Modules. Although the authors cite positive comments for the course on reasoning development, no qualitative analyses were done to draw definitive conclusions in this respect.

A lack of generalizability to a majors course is also seen since all subjects were non-majors. The absence of a comparative group is a flaw in the research design, as it does not allow for an accounting for a maturation increase over the semester.

Thus, although ostensibly demonstrating positive effects of this writing-based inquiry course, it is not prudent to draw definitive conclusions until the flaws in the study arecorrected and it is repeated.

An inquiry method of instruction using videopresentations to guide discussions was used by Moll and Allen (1982) to develop reasoning skills in response to ill-structured questions. This course emphasized student writing to create arguments from an analysis of evidence to develop informal reasoning. The method used was described in detail by the authors as stressing student exploration of ideas, interpretations, and various lines of informal reasoning to improve critical thinking skills. These skills are identified as informal reasoning as defined earlier.

A pre/posttest no control group quasi-experimental design was used to show a significantly higher improvement of reasoning skill and content knowledge ($p<.001$) by the experimental group. The gains were not shown to be related to gender or major. The authors also cite qualitative evidence that students appear to reason better after taking the course.

The weaknesses of the study again cast doubt on definitive conclusions. The lack of a control does not allow for isolation of the effects of maturation of reasoning over the semester, no reliability is mentioned for the tests, the statistical methods used are not given, the number and description of subjects are omitted, and the types of qualitative methods used are not discussed (e.g. questionnaire and survey).

If this information were given, the study would be particularly interesting because it is the only one to explore the interaction of gender and major with instruction to influence reasoning. In addition, since one section in the study was given more content and scored significantly higher on the content posttest but not on the reasoning posttest than the other groups, this implies that content alone was not sufficient for improving reasoning.

An inquiry-based study by Lawson (2001) involved 514 non-major introductory college biology students asked to practice formal reasoning strategies using a series of progressively unfamiliar biological inquiry problems. Students were confronted with ascientific problem and asked to use formal reasoning skills to generate hypotheses, set up experiments, predict results, and answer if/then questions about the activity. The

ERIC

lectures infused an if/then analogical reasoning approach in conjunction with the activities. An exemplary activity required students to use formal reasoning strategies to design an experiment to test the variables influencing mealworm behavior in a box. Writing is infused in this design by requiring student written to responses to the activities.

A comparison of the student pre-test and post-test scores on a test of formal reasoning skills indicated that student reasoning improved significantly as a result of the course (dependent $T = 29.6$, $df = 513$, $p<.001$). Test reliability and validity had been established by other studies (e.g. Lawson, 1992). However, Lawson's (2001) design lacked a control group and does not address the effects of the course on content acquisition. The study does not describe the amount of time dedicated to formal reasoning development and how it compares with a traditional non-majors introductory college biology course. A test-retest effect is also not addressed as well as affect effects of the course. Nonetheless, this study offers significant evidence that practicing formal reasoning patterns improves the ability to apply formal reasoning patterns. Possible future studies using this design would improve the study's significance.

The final inquiry-based approach emphasizing writing to develop reasoning skills was conducted by Ebert-May, Brewer, and Allred (1997). Care was taken to control variables in instruction in this pre/posttest quasi-experimental control group design. The experimental lectures in non-majors introductory college biology were based on a modified learning cycle (BSCS) model of instruction in which there a high level of student involvement and a risk free atmosphere to facilitate student collaboration in constructing answers to biological questions. The writing assessment included one page papers and group work to answer ill-structured questions. The comparison lectures were traditional and factually based.

Results from an Analysis of Covariance indicated that students in the experimental groups scored significantly higher on process/reasoning questions (identified as informal reasoning for the purposes of this study) on an NABT exam ($N=283, df=3,274, p<.05$).

Also, in support of the view that such non-traditional inquiry based teaching does not negatively affect content achievement, no significant differences were found between the groups in terms of content questions on the NABT exam. Ebert-May et al. (1997) contend that the amount of material covered in the activity based classroom in the end is equal to material covered in the traditional classroom. Considering the importance of content coverage fo student progression to established professional programs (i.e. medicine, dentistry) future studies should replicate such a design, paying particular attention to those standards set forth by pre-professional advisory committees, professional school entrance exams, and professional school admissions.

Qualitative data obtained through random selection of students for interviews and written responses indicated that students were changing the way they viewed the acquisition of knowledge. "Students began questioning the nature of the scientific evidence before them" (p. 606) and "were more likely to apply their understanding of biological concepts to personal, public, and ethical issues than if they had experienced the traditional lecture format" (p.606) showing the development of informal reasoning as defined in this review. A well constructed qualitative analysis such as this can reveal

ERIC

information that quantitative designs cannot. The use of both appropriate questionnaires and interviews in a risk free environment characterize a good qualitative study.

Thus, the research design by Ebert-May et al. (1997) represents the strongest evidence presented so far in support of inquiry based, collaborative instruction as a means of improving reasoning and not weakening content acquisition. It was a mixed method approach, which employed both quantitative and qualitative techniques which together allow for a broad exploration of the variables. Unlike the previous studies described, thisresearch design includes comparison groups, control of instructional variables (e.g. same lecture notes and instructor), statistical analyses mentioned, a heterogeneous, large sample size (559 subjects), and an appropriate qualitative methodology.

There are, however, some unanswered questions remaining with regard to testing (e.g. the reliability and validity of the NABT exam are not given). This is not problematic, if it is assumed that such a national exam has sufficient reliability and validity. However, it is a high school exam and so prior achievement not related to this college course, which is not addressed, could have influenced the results. Also, although the authors mention a Process Skills Instrument to develop reasoning, results on reasoning are only obtained from NABT process questions. As a future study, an exam more appropriately measuring college biology achievement should be implemented. A demonstration of reasoning development other than vague "process skills" should also be used in such a future study as a measure.

The increase in attendance with the experimental groups, possibly due to the daily quizzes, could have also had an impact on increasing reasoning and content performance. Additionally, an interesting future study based on Ausubel's could show the effects of the

ERIC

use of concept mapping to organize the material to make more meaningful connections to improve reasoning. Future studies could isolate the variables within such methods to determine what particularly impacts student reasoning.

The final study supporting the view that inquiry based learning improves student reasoning used a pre/posttest control group quasi-experimental design by Haukoos and Penick (1983). It is the only study in the review that treats the community college level. The effects of a Discovery Classroom Climate (DCC) were compared with a Non-Discovery Classroom Climate (NDCC) in terms of student achievement in biology and the learning of reasoning skills. There were seventy-eight subjects divided into two sections of 10 week long NDCC courses, one section of a 10 week DCC, and one section of a 5week DCC course.

The classroom climates are described in detail by the authors. In general, the differences were based on the directness of teaching. In the DCC, teaching is indirect, with content dialogued and discovered through ill-structured questioning. Thus, knowledge is constructed by the students as in the other studies shown so far. In contrast, the NDCC was the traditional lecture similar to the comparison methods seen in Bernard (1942) and Ebert-May et al. (1997). An ANCOVA showed that students in the 10 week DCC group scored significantly higher on the reasoning skills exam ($p<.01$) as compared with the other groups. There were also no significant differences found between groups in terms of the learning of biological content. Face validity and reliability were given for the tests measuring reasoning (Science Process Inventory) and achievement (Biology Achievement Test).

Haukoos and Penick (1983) are the only researchers in this review to explore the interaction of time and instruction on reasoning and achievement. Since the 5 week DCC does not show significantly improved reasoning as compared with the 10 week DCC, this implies that enough time must be available to develop reasoning.

Writing is not mentioned by Haukoos and Penick (1983) as a part of instruction and yet positive results on reasoning improvement occurred. Perhaps other variables in their instruction exist to explain the positive effects. This could be explored by future studies. The BSCS method used by Leonard (1983) and Hall and McCurdy (1990) are the only other studies that do not incorporate writing in their instruction and they demonstrate no positive effects on student reasoning. In contrast, Lawson and Snitgen (1982), Tyser and Cerbin (1991), Moll and Allen (1982) and Ebert-May et al. (1997) incorporate writing in their instruction and show the development of reasoning through their methods.

For each of the aforementioned studies in this review, it would be interesting to explore the relative contributions of different variables within the instruction that led to the successful development of reasoning by the authors' methods. For example, although allof the studies employed both collaborative and inquiry methodologies, what were the relative contributions of each these variables to elicit change. If a non-collaborative approach were used, how would the results on reasoning develop change, for example? Also, how would the introduction of a more intimidating, yet non-traditional classroom environment that harms positive attitudes change the results?

This move to isolate instructional variables was attempted, for example, by Lawson and Snitgen (1982) and Tyser and Cerbin (1991), who discovered the positive

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effects of varying the instruction to include the teaching of how to reason. The other studies assume that improved reasoning patterns emerge as a result of student participation in an inquiry-based instruction. One wonders whether Roger's (1967) fear of routinized methodologies can be applied to such direct teaching of reasoning. The student could merely learn the model for reasoning, but not actually be at a more sophisticated level. Evidence for this was seen as described earlier by Lawson and Snitgen (1982), who do not demonstrate the transfer of reasoning improvement to non-familiar topics and an actual decline in reasoning quality.

This raises an important point--is the teaching of reasoning even possible? Students could be intrinsically locked into a Piagetian developmental stage of reasoning. The ability to change their predisposed abilities before natural development allows for it may not be possible. It is the contention of this review that instruction can affect reasoning ability, but the evidence given by the six studies favoring this view do not address the mechanism of change in reasoning--it remains a black box. Thus, although empirical results show increases in reasoning levels through the instruction suggested, no specific instructional variables are explained as to why they are causing change.

The improvement of scientific attitudes was explored by Barnard (1942) and Ebert-May et al. (1997). Although the problems in Bernard's (1942) study weaken the conclusions, the inquiry group means showed better scientific attitudes than the comparisongroup means. The more convincing results emerge from Ebert-May's et al. (1997) study, citing statistically significant increases in self-efficacy for the experimental lecture groups as compared with tradition groups ($N=283, df=3,274, p<.05$). Self-efficacy is defined by the authors as confidence in doing science, analyzing data, and explaining

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biology to other students. Both studies show increases in reasoning and increases in attitudes, showing possibly a relationship between the two varibales. According to Rogers (1967), the effects of attitude improvement on learning are positive. However, from the studies in this review, this cannot be established.

Based on the research describing the successful improvement of reasoning, the fear that non-traditional methods take too much time and detract from content knowledge acquisition should be reduced. Ebert-May et al. (1997) and Haukoos and Penick (1983) cite no loss in content achievement with their experimental groups. Also, Tyser and Cerbin (1991), although not assessing content achievement, contend that lecture time is not significantly impacted since only 200 minutes are used by the "Science News Exercises". Barnard's (1942) study is the only one showing a decline in content achievement with increased reasoning. However, the many extreme weaknesses described earlier may discount these results.

The one study offering information on the improvement of general intelligence through instruction to develop reasoning was by Lawson and Snitgen (1982). Admittedly, intelligence is a vaguely defined construct. It was measured by the authors using the Raven Standard Progressive Matrices test (reliability and validity not mentioned). The pre/posttest differences show statistically significant increases in general intelligence among the experimental subjects ($t=2.42, df=28, p<.05$). Such results indicate further support for the incorporation of reasoning activities in instruction.

The two studies showing no significant subject improvement of reasoning were by Leonard (1983) and Hall and McCurdy (1990). Both used an inquiry oriented Biological Sciences Curriculum Study (BSCS) developed by Leonard (1983) that engaged the student in collaborative activities in the laboratory such as planning and conducting experiments and drawing and evaluating conclusions. The comparison method used by both groups was a traditional laboratory program that was directive and less inquiry oriented. Both used a quasi-experimental control group design and Leonard (1983) found that on a combined content/reasoning posttest, the experimental groups performed significantly better ($t=3.81$, $p<.005$). Also, in both the experimental and control groups, formal reasoning increased by 15% over the semester, giving support for the importance of laboratories in a time when many are being cut due to economic reasons.

Although Leonard (1983) takes great care to establish equivalence of the treatment groups and states the internal reliability and validity of the tests, the results do not isolate a dependent variable on reasoning--only that content and reasoning are improved together.

Thus, the results by Hall and McCurdy (1990) determine more clearly what the effects are. An ANCOVA on the data show that the BSCS laboratory group scored significantly higher on content achievement ($F(1,114)=4.07$, $p<.05$) but that no significant differences in reasoning ability were found.

The result is surprising insofar as the inquiry-based methods of the other reviewed studies showed improvement in reasoning over the comparison group. In addition, Hall and McCurdy's (1990) research design was strong, with validity and reliability of the tests reported as high, a heterogeneous sample size, equivalence of groups, and appropriate statistical analyses used. Upon closer examination, however, there is a major difference between the other studies and this one--although the BSCS instructional method stresses the evaluation of evidence, raising questions, and generating hypotheses for scientific experimentation (informal reasoning), the pre- and posttest on reasoning assess only formal reasoning. Thus, since the instruction appears to not have matched the assessment, Hall and McCurdy's (1990) results could be misleading.

Thus it can be seen that the studies discussed in this review would allow for stronger conclusions to be drawn if repeated, with their respective weaknesses ameliorated. Also, the many questions that arise when considering the studies more critically, show the gaps in explaining what and how different instructional variables play a role in changing reasoning. However, it is clear that the successful studies effecting reasoning improvement cited in this review, when taken together, strongly support use of non-traditional, inquiry-based, collaborative methodologies for the development of student reasoning.

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Figure 1: Relationship of the variables

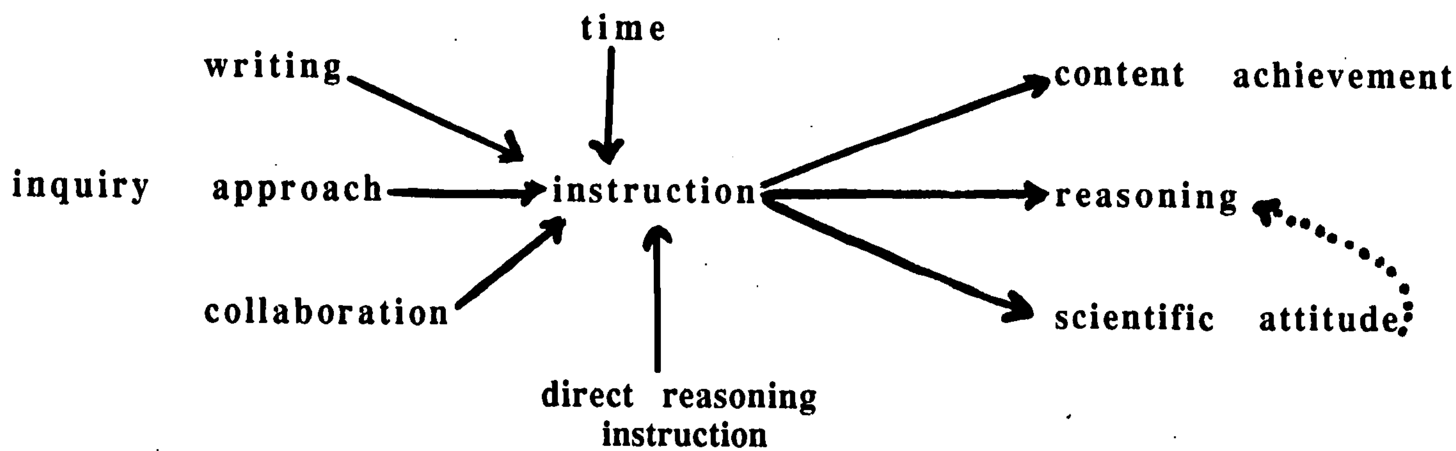

Table 1: Models of Development of Reasoning in Late Adolescence and Early Adulthood

reasoning level	Piaget	Perry	King and Kitchener
low	concrete	dualism	pre-reflective
medium	transitional	multiplicity	quasi-reflective
high	formal	commitment within relativism	reflective

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ɔle 2: Summary of Data from Instructional Approaches for the Improvement of Reasoning

Study	Sample	Dependent Variables	Method	Outcomes
Bernard, 1942	282 students (67 % upper-content classmen)	informal reasoning, achievement, scientific attitudes	comparison of means	problem solving groups had higher reasoning and attitude scores but lower content scores
Ebert-May, Brewer, & Allred, 1997	559 college non-majors biology students	informal reasoning, content achievement, scientific attitudes	ANCOVA descriptive, interview and survey	active learning groups scored statistically significantly higher on reasoning and attitudes but no sig. differences were found on content achievement
Hall & McCurdy, 1990	119 college lab students	formal reasoning, content achievement, scientific attitudes	ANCOVA	BSCS lab groups scored sig. higher on content but not on reasoning and attitude
Haukoos & Penick, 1983	78 community college students	informal reasoning, content achievement	ANCOVA, Duncan's Multiple Range Test	The DCC group scored sig. higher on reasoning but no sig. differences on content test. sufficient time for instruction needed to influence reasoni
Lawson & Snitgen, 1982	72 pre-service teachers	formal reasoning, general intelligence, non-specific transfer	t-test descriptive, observation	students in course had sig. higher formal reasoning and and intelligence development but no sig. increases in transfer of reasoning
Lawson 2001	514 college students	formal reasoning	t-test	students in course had sig. higher formal reasoning scores in pre/post test comparison
Leonard, 1983	426 college students	content/informal reasoning	t-test	BSCS groups scored sig. higher on combined content/reasoning posttests compared with control

l & Allen 1982	not given	informal reasoning, content achievement	statistical not given descriptive	with comparison of pre- and posttest scores, sig. improvement in content and reasoning. content increases not sufficient for reasoning development. No sig. interaction of gender and major on reasoning
Tyser & Cerbin, 1991	60 college students	informal reasoning,	t-test descriptive, survey	science news exercises groups scored sig. better on reasoning on objective and written tests and on survey

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