Modeling Pedagogical Content Knowledge in Physical Science for Prospective Middle School Teachers:
Problems and Possibilities

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In an effort to help prospective middle school teachers incorporate the development of pedagogical knowledge and skills with physical science content learning, the preservice program at the University of Georgia (UGA) incorporates paired corequisite courses team-taught by the combined efforts of scientists, science educators, and practicing middle school teachers. The scope and sequence of the program is based on the notion of pedagogical content knowledge (PCK), and the primary instructional approach is the modeling by university faculty of teaching strategies and content curriculum appropriate for middle school instruction. The purpose of this study was to evaluate the strengths and weaknesses of our efforts, as viewed by students in one of these pairs of courses during a selected academic quarter, and to identify new ways in which this or other programs may be improved.

Introduction:

Middle Grades Science, Teacher Education, and Collaboration

Numerous studies (*e.g.*, Hurd, Robinson, McConnell, & Norris, 1981) have indicated that the pool of young students interested in science and mathematics and doing well in these subjects begins its steady decline in the middle grades. By the eighth grade, many students are "has-beens" (Berryman, 1983) relative to future options in technically-oriented careers. Additionally, these years are thought to be the beginning of the under-representation of females and minority students in these subject areas.

The problem is compounded by the presence of a significant percentage of science and mathematics teachers under-prepared in content and/or pedagogy at the middle grades level. Teacher education programs geared for the middle grades are an important factor in improving this situation. However, most institutions have no specific program for educating middle grade teachers. Often preservice middle grade teachers are forced to choose between an elementary or secondary program. The secondary route may leave prospective teachers without a sense of what content is appropriate for early adolescents and, at some institutions, may prove too specialized in its science content-area emphasis. The elementary track is typically grossly deficient in both depth and breadth of science knowledge. These teachers frequently have no specific preparation for teaching early adolescents. As a result, the typical middle school teacher's career commitment to teaching is not at the middle grades level (Hurd, *et al.*, 1981).

The original proposal for the development of the type of program currently implemented at UGA (Padilla, Davis, & McKillip, 1986) focused on the fact that many beginning teachers lack both the subject matter breadth and depth necessary to teach science. At the time, a needs assessment by the Georgia State Department of Education (1986) indicated that 49 percent of science teachers in middle grades were not adequately prepared in their content area. One State Department official called middle grades "the area of greatest need in teacher training in Georgia." Thus, this program emphasized an increased number of subject matter courses which stressed content appropriate to teaching in the middle grades.

First, three specialized courses, in physical, earth, and life science, were developed and are taught by faculty from the science departments, with advice and support of science education faculty and graduate students. Second, and most importantly, each new content course was paired and block-scheduled with one of three specialized science education "methods" course which stressed content-specific pedagogy related to its matched science course. These courses were developed and are taught by a team of science educators, scientists, and classroom teachers, with the realities of the latter's current classroom providing the practical focus for the research and development effort. This collaborative team approach has been labeled "triads" (Mason & Huppert, 1992) in recent literature.

Theoretical Background:

Pedagogical Content Knowledge

Teaching in any subject matter area is an extremely complex process in which a successful practitioner must draw on knowledge from a variety of domains (Leinhardt & Greeno, 1986). Empirical research in science classrooms supports the notion that adequate preparation both in science and in pedagogy is absolutely necessary for good teaching (Tobin & Garnett, 1988). Knowledge of subject matter not only influences the way in which teachers sequence and explain science content, but also has a more subtle but pervasive impact on how they interact with students. However, even beginning and prospective teachers considered to have an unusually good knowledge of their content area are often unable to wed this content information to appropriate teaching methodologies (Mason, 1988). An explicit linkage of science content and pedagogical methods is needed.

Shulman (1986, 1987) has developed a useful conceptual framework in which the three major domains of teacher knowledge are described as content knowledge, pedagogical knowledge, and PCK. It is not sufficient, he argues, to have an understanding of the subject matter (content knowledge) and good generic teaching skills (pedagogical knowledge); rather, each discipline requires its own repertoire of teaching strategies (PCK). Shulman defines PCK in various ways, but in all of them the implication is clear that it is a separate and crucial entity: "the ways of representing and formulating the subject that make it comprehensible to others" (1986, p. 9); "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (1987, p. 8); knowledge and skills that are "uniquely the province of teachers, their own special form of professional understanding" (1987, p. 8).

PCK has been seized upon by some science educators and educational researchers (*e.g.*, Krajcik & Borko, 1991) as an extremely useful organizer, an elegant expression of notions which have previously arisen piecemeal in the reflective practice of science teaching and teacher education. Cochran (1992) has summarized its relevance to science education by distinguishing between the way science teachers and scientists organize knowledge:

> An experienced teacher's knowledge of science is organized from a teaching perspective and is used as a basis for helping students to understand specific concepts. A scientist's knowledge, on the other hand, is organized from a research perspective and is used as a basis for developing new knowledge in the field. (p. 4)

Shulman's differentiation of PCK from content knowledge has recently been challenged on epistemological grounds. McEwan and Bull (1991) contend that all subject matter is pedagogical in some real and important sense. According to their critique, the view that pedagogical content knowledge is an area of teacher expertise separate from content knowledge implies an unreasonably objectivist epistemology.

Tamir (1988) has outlined a further differentiated framework of teacher knowledge consisting of six major categories: general liberal education; personal performance; subject matter knowledge; general pedagogical knowledge; subject matter-specific pedagogical knowledge; and foundations of the teaching profession. He has also pointed out (1991) that the application of any of these aspects of knowledge is so inextricably tied to the personal attributes of the teacher and her or his thought that the growth of expertise in teaching is necessarily extremely idiosyncratic.

Thus PCK may be only one piece of a very large puzzle, or may even be an illusory notion. Nevertheless, the view of a vast majority of the teachers, science educators, and scientists who have shaped the preservice middle school science teacher education effort at UGA is that the notion of PCK is sufficiently justified by the practical value it has had in organizing our thinking and planning during the evolution of the program. Whether or not PCK exists as a philosophical "reality," we have chosen to act as if it does (*cf.*, Gess-Newsome, 1991).

Course Design:

Operationalizing PCK through Modeling

Scientists were recruited to work closely with science education faculty and students in accordance with another of Shulman's (1990) insights, the power of modeling: "How you learn a subject in college affects how you teach it." As might be expected of university science faculty, all were initially most comfortable with using the lecture method almost exclusively when teaching introductory-level undergraduate courses. Given a smaller than usual class size (typically between 25 and 35) and exposure to education faculty, however, science faculty can radically change their approach to college-level teaching over the course of several years. The instructor in the introductory physical science course extensively adopted such techniques as discrepant events demonstration/discussions, non-directive exploratory lab sessions, and various forms of small group work, including a group component in assessment.

Experienced science classroom teachers were recruited to teach the "Tryday" component of the pedagogy courses. Here, the students perform and analyze classroom activities commonly used at the middle school level. The intent is to emphasize the connection between science content, psychological research on learning in specific content areas, and appropriate methods of teaching science topics to middle grades students. For instance, during the week that the physical science course addresses Newton's laws of motion, the Tryday teacher presents sample middle school classroom activities related to qualitative concepts of motion. Examples for this topic might include students pushing and pulling each other on a large cart, engineering balloon rockets for racing on a string track, or a computer simulation of piloting the space shuttle. Each student completes from four to six activities each week during the two-hour class period. At the beginning of each class, the Tryday teacher explains the purpose of the activities, then allows the students to work in groups to complete the activities. At the end of class, a group discussion is conducted to evaluate the activities and discuss the "nuts and bolts" of implementing them in a middle school classroom, particularly on a limited budget or with students of widely varying academic aptitudes.

A third aspect of modeling of science teaching occurs simultaneous with the Tryday sessions. During the middle school teacher's sessions with the prospective teachers, a small number of them each week gain limited field experience by accompanying the science education instructor into the middle school classroom and conducting first a small-group tutoring/interview session and then a whole-class lab exercise with the teacher's (sixth-grade) students. Evaluative and reflective feedback is provided in both the short and long term. As a means of immediate small group followup, students who have visited the school meet with the regular classroom teacher during lunch or a planning period for an informal "debriefing" session later on the same day. As a means of time-delayed whole-group followup, videotapes of these sessions which are judged to be particularly illustrative of either egregious successes or failures of the methods suggested in class are screened and critically discussed in the next class session.

Participants and Procedures

The physical science/pedagogy courses described in this paper were taught by two principal professors, one from chemistry and the other from science education, who rotated daily teaching responsibilities so as to accommodate such activities as discussions, laboratories, or remediation. Both instructors were generally present during class for any discussion that might arise specific to their area of expertise. The consolidated class met every weekday for a total of 12 hours per week.

Students in the class were 27 undergraduates, prospective middle-school science teachers, representing a variety of experiential backgrounds, age groups, and stages of progress in their degree programs. The courses were one of three corequisite pairs required of students intending to teach in the middle grades who had declared science as a major or minor field of subject matter concentration. Other coursework in the program covers Life Science, Earth Science, and their teaching at the middle school level.

The instructors modeled a method of instruction which continually incorporated student thoughts and ideas, helping them to construct their own understanding of the subject matter. For example, student-generated questions were rarely answered directly. Rather, the instructors would take on the role of facilitators, encouraging the students through discussion, demonstrations, hands-on activities, and group work to discover the answers themselves. For this reason, ample time was provided for students to discuss homework problems and do laboratory activities within their groups. Members of the class were divided into six learning groups of four to five students each, and group membership was changed three times during the ten-week quarter. Group work included, for instance, solving application problems in physical science sessions and practicing techniques such as reciprocal teaching (Brown & Palincsar, 1989) in science education sessions.

In order to determine the effectiveness of the program and areas which might be improved, data for this study were collected by a doctoral student in the science education assigned as a graduate assistant. These data were considered to be a source of formative evaluation for the instructors. During group work, all of the authors circulated around the room listening to, and sometimes joining, students' discussions. Fields notes were taken at these times and occasionally the discussions were audiotaped. To gather additional insight, focus group interviews (Patton, 1990) were conducted at the end of the quarter. All students volunteered to participate in the groups after being told that their comments would be used in shaping decisions about how the class would be conducted in the future. In order to encourage frank responses, the focus group sessions were conducted only by the graduate student and audiotaped, with results presented to the professors only in the form of transcripts and on a strictly anonymous basis.

Data analysis involved unit coding and content analysis (Patton, 1990). Recurring ideas and themes in the data led to the construction of conceptual categories and provided insight into the thoughts and motivations of students. The results reported below are structured according to these categories.

Results

Students' responses addressed many issues which we feel have a direct impact on the effectiveness of the courses. These issues include: the prevalence of science anxiety among the students; unfamiliarity with the teaching strategies used by the instructors; the value of group/class discussions as a method of teaching and learning; the interpersonal dynamics of the groups; the merits of demonstration of laboratory activities by instructors versus the hands-on manipulation of materials by the students; and the relative importance of general versus science-specific pedagogical issues.

Science Anxiety

At the beginning of the quarter, it became obvious that the students were demonstrating a considerable degree of anxiety concerning the demanding nature of the physics content covered in the course:

> *Kim*: But I am very worried, because I really felt comfortable in biological science, and I felt fairly comfortable in geology, but I don't feel comfortable at all in physics, and I'm really putting a lot of effort into this class.
>
> *Mary*: I really do not like this, I like science, but I don't know, to me all this stuff is just confusing, and it's very hard for me to grasp this.

A group discussion following the midterm examination revealed considerable frustration and anxiety:

> *Bill*: I would love to be able to do all of that, but I'm just not... and it makes me feel, not dumb, but dumb in a way.
>
> *Jane*: I mean, because you're like "well I can grasp all the other sciences, why can't I get this?"
>
> *Mike*: Yeah, it makes me feel very dumb.

This anxiety level decreased throughout the quarter, however, as students were reassured by the instructors' attempts to cultivate a supportive and comfortable classroom climate. As some students noted later in the term:

> *Kelly*: Yeah, I remember at the beginning of the quarter, I guess I was having that science anxiety, or whatever, but I was having it, I think on a more intense level than most people, and he was so patient with me and so understanding, he said "I will do anything to help you understand this," and that just made me feel so much better.
>
> *Bill*: Yeah, and I really appreciate them sitting there and being patient with those of us who don't understand.

With the final examination a few days away, others related their feelings about the classroom "atmosphere":

> *Lavar*: I'm just glad there's good feelings about science going on, most people are worrying about the final, but there's like a good atmosphere...[the instructors] are so energetic about science, and about kids.
>
> *Mary*: Which makes it really interesting for us, it's nice to see something other than the negative attitudes you see out there all the time.

Responses to an Unfamiliar Teaching and Learning Model

The "active learning" model used by the instructors, characterized by hands on activities, group work, and discussions, was unfamiliar to many of the students. Perhaps not surprisingly, the students viewed this experience with mixed feelings. Many students found this teaching strategy extremely useful in increasing their understanding of the subject matter:

> *Jennifer*: I liked the whole thing, and this is the most interesting class I have ever had, you know, like with all the experiments. I can see how that's a better way to learn, I would rather do that than take notes.

> *Mike*: ...the further we got into it, I mean I actually learned a lot, and at the end of the quarter I'm like, "Hey, I really know what I'm doin' [*sic*]"
>
> *Kim*: ...because I have learned so much and it's been so interesting, and the link that you can make to the other sciences, that I really didn't realize was there.

However, some students who were accustomed to the traditional lecture method of college science teaching had difficulty with the transition to the less structured teaching style. During several of the focus group interviews conducted at the end of the term, some students expressed a great deal of frustration with the methods of instruction:

> *Jason*: You can't spend your whole college life learning "this way" and then get thrown into a class where none of that is provided...
>
> *Kelly*: And it *is* a better way of learning, but not just all of a sudden.
>
> *Jason*: That's right.
>
> *Collin*: Yeah, you can't do that.
>
> *Johnny*: You know in every class I have had in college, you take notes, you get a lecture...this is the topic, these are the main points... and you take notes. And man, I take those notes, I can study those notes and I can ace the test, but I got no notes.
>
> *Alice*: Yeah, I don't have any notes either.
>
> *Linda*: I don't have anything, I mean I looked through my notebook before tests and I'm going "what?"...there's nothing.
>
> *Johnny*: And they try to say that notes are bad, that you shouldn't learn by taking notes, but when I study those notes I *learn*...it's not that I'm just memorizing.

The dialogue sets a tone of frustration, suggesting that even though these students are aware that this method of instruction is generally a more effective way for students to learn and create understanding, they themselves are often still more comfortable with the more rigid structure of lecture and note-taking.

The extent of students' previous physical science coursework frequently arose as an issue in group discussions. Many of the more inexperienced students explicitly expressed the desire to be placed in groups with those with a stronger content knowledge background. Most of the students who had a positive experience with this method of instruction had done more extensive previous work in physical science than their classmates, and perhaps were therefore not as dependent on the basic information that others seemed to be missing.

Learning from Discussion

Though there was a wide range of responses to the unfamiliar teaching strategies, almost all students responded favorably to the extensive use of discussion, both within their groups and in the class as a whole:

> *Renee*: I like it better when we have a little more time to discuss...like throwing out a question that we don't have an answer for and giving us time to come up with an answer that everyone hears and understands.
>
> *Karen*: I liked it because it helped me, like I'm very insecure about my background in science, and I think like talking to other people helps out a lot.
>
> *Bill*: I enjoyed that time we had for our homework...to discuss them, to see who got what answer...and figure it out together.
>
> *Tammy*: I loved it! I thought it was great...we got to come in in the morning...we sat down...we went over the homework together.
>
> *Lavar*: If Bill didn't know one, I might know one, or Tammy might know one.
>
> *Tammy*: And if no one knew it, then that was something you asked in class.

Overall, the most positive comments were centered on discussion. Students felt that having the opportunity to work out homework problems and discuss alternative solutions with their group members helped them better to understand the material.

Group Dynamics

Because the successful incorporation of this cooperative method of instruction is contingent on the ability of students to work constructively in small groups, interpersonal group dynamics played a major role in the class. Most students had a very positive experience with their groups:

> *Collin*: I liked it, well, at first I didn't like it, but when we worked in groups...and we *really* worked in groups, I kept up, I read the chapters, I did my homework and stuff, because I didn't want to show up and let my group down, you know, and not have my work done. At first I didn't like that, but then I realized I needed that to help me study.
>
> *Karen*: And if we ever disagreed, and sometimes we did, I'd see things different that what they would see, and I would say "all right, convince me that you're right," and that always worked, and usually they were right.

However, since group work represented such a large proportion of the class activity, when interpersonal conflicts arose, they had the potential to cause problems which would have a highly negative effect on learning:

> *Linda*: ...but there are people that I have now in my group that just annoy me so bad. I just pushed away from the desk and told the professor, "I can not and will not work with her." I just don't know what her problem is.
>
> *Jason*: I've been in a certain group where people wouldn't help each other, and their answer was right and that's all there was to it, and that' s a very bad attitude to have.

> *Alice*: Well, my group is usually arguing with one person, like today..."Hydrogen is not flammable"? Excuse me? I believe it is. We were just sitting there trying to correct her misinformation.

When problems such as these occurred within groups, instructors made an effort to guide the students in a manner suitable for managing similar problems with middle school students:

> *Donna*: Also in this class, I have learned that there are some people that I just can not work with, but I've learned how to deal with that. You go on, you deal with them when you have to, but you don't make a big event of it.

The following group discussion illustrates the instructors' mediating role:

> *Alice*: Our group had problems, and we had to sit and talk to Dr. Smith about the whole thing, and...
>
> *Brenda*: We're a lot better because of that.
>
> *Linda*: And he told us to look at each other and tell each other in our group, what was wrong with each person.
>
> *Jason*: But it helped a lot though...cause we're a lot better.

Accepting the fact that some interpersonal difficulties are unresolvable, the groups were changed periodically in order to maximize the opportunity for each student to be a part of a cohesive, productive group:

> *Jennifer*: I like the way he changed around the groups, I really, really liked my second group that I was in this quarter. The first group was disgusting and my third group was really a lot better than my first group....it's just one particular person in my second group...I'm glad he changed it around because if he hadn't there would have been some *major, major, major* problems.

Unfortunately for the students, however, this sometimes meant moving from a harmonious situation to a discordant one:

> *Mike*: I really liked the first group I was in, really liked it. I worked well with them...the first day...we were all lost and it was a struggle, and we had to kind of get it together. Then we switched off and I didn't really like the group I was in, not anything against the people, but there were two people in particular that were extremely negative.

An unexpected but favorable outcome of changing the groups was that some students who had had very positive group experiences in the beginning felt that changing had created a new and different learning experiences:

> *Tammy*: It wasn't that I didn't like the groups I was in, but just after awhile, the change was good...you got to work with totally new people, to hear new ideas and perspectives. It is a totally new situation and you can learn from it.

Hands-on Versus Demonstration Activities

A major dilemma facing the instructors was balancing the amount of hands-on lab activities with demonstrations (both instructor and student-generated). The students' responses were polarized with regard to their preference for one or the other as learning tools. Some students prefer hands-on activities:

> *Stacy*: Well, I've already had a physics class and it was nothing but plotting in and knowing the formulas. I like this better because this one...is more hands-on, and I like that.
>
> *Kelly*: I like having things that I can see, right there that I can study. I don't like having to take notes a lot to study because a lot of times I miss things.

Others had a strong preference for demonstrations:

> *Johnny*: The analogies that he gives and the demonstrations that he does.... You can understand them because you can really relate things back to them.
>
> *Bill*: The way we go about it in class I don't like. I'm the type that would rather [prepare] one [demonstration] for a while, understand it completely and present it to the class, and then I would just rather sit there and watch everyone else present it to me.
>
> *Jane*: Maybe we should do something like...each [group] do an experiment, and then that [group] be responsible for showing it to the class.

While some of these students valued first-hand experience with a large number of specific activities as useful in itself, others (such as those above who preferred demonstrations) questioned whether the use of manipulative materials might have been overemphasized. Some suggested that the methods used by the instructors might actually have promoted a more superficial understanding by focusing on the "hands-on" nature of the tasks at the expense of the ultimate goal of "minds-on" experience.

General Versus Content-Specific Pedagogical Issues

Perhaps the most egregious criticism of instructional methods made by the students concerned the time the practicing middle school teacher spent with the students. The time was focused primarily on doing lab activities and discussing what the students liked or disliked about them, but the students interviews suggested that they would have liked to have utilized the time differently:

> *Nancy*: But I want to hear how she *does* it, and sometimes she talks about that, but...[we need] more of how she does the labs.
>
> *Donna*: Well, I want to hear how she handles problems that could go wrong with the lab.... It's great to get the packet and practice the lab, but I want to know the classroom management, things about labs and stuff.... I know you have to learn that

through experience, but I want to hear other people's experiences and the problems that they've encountered.

These comments reveal another notion that recurred often in the data. Many students felt there had been insufficient instruction or discussion concerning general pedagogical methods, especially classroom management, and this caused them significant anxiety about their future teaching experiences. Students felt that the middle school science teacher's time would be better spent addressing the realities of the classroom which are not closely related to particular lab activities or science topics.

Discussion and Recommendations

The middle school years represent the critical point at which students' interest and achievement in science begin to wane, yet many middle school teachers suffer from a lack of subject-specific preparation. Therefore targeting these particular grade levels has great potential to affect change in science teaching and learning that will carry through to high school and college level science learning.

Consistent with concerns over adequate preparation of preservice middle school science teachers in content areas, the students in these classes had a significant degree of anxiety concerning the science content of the course. The support and encouragement, expressed both verbally and behaviorally by the professors, was relatively successful in alleviating the stress level of the students, and thereby increasing the chances of their learning.

Given the level of discomfort of so many members of the class with the method of instruction, it might be advisable to incorporate a small degree of lecture and note-taking into the course in the future. This can be accomplished by having a small portion of daily class time devoted to defining basic terms, etc. In this way, the transition into an unfamiliar method of instruction may not be as unsettling. Students will still receive the benefits of more progressive teaching and learning styles without completely and abruptly abandoning the comfortably familiar lecture format. In an entire program of such courses, this reassuring "scaffolding" may gradually be "faded" (Collins, Brown, & Newman, 1989) until students are comfortable with the increasingly familiar new approach and no longer need the greater structure provided by the old approach. In order to provide students with an explicit rationale for the instructors' practices, instructors should provide specific, research-based arguments for the pedagogical effectiveness of the methods used.

Although there were some negative repercussions of periodically changing group membership, there were clear advantages of this practice. The chance that an individual student might be involved in an ineffective group throughout the duration of the course makes the notion of static groups doubly inadvisable.

Some of the most positive remarks about the course concerned learning through discussion, and the many students would have liked more time for discussion. It follows that the daily schedule should provide for more of these types of activities.

While the discrepancy in preferences for hands-on activities versus demonstrations likely represents a natural difference in learning styles of students, we recommended that a reasonable balance be struck between these approaches.

Nothing clearly and explicitly concerning science-specific pedagogical content knowledge was mentioned by the students. Despite many students' positive reactions to the instructors' conscious efforts at modeling appropriate teaching and curriculum practices, the notion of pedagogical content knowledge was not readily apparent to the students, who seem naturally to view knowledge of pedagogical methods and knowledge of content as separate entities. We suggest that science and education instructors make explicit to their students the philosophical commitment to the value of modeling which is implied by the design of their courses and programs. Students who are conscious of the subject-specific nature of many curriculum and teaching issues should be more likely to transfer their experiential learning in preservice courses to the many specific decisions they will be required to make in their future practice as science teachers.

Implications for Teacher Education

The results of this study speak to several issues in teacher education. Stofflett and Stoddart (1994) contend that science instruction remains primarily didactic, dominated by lecture, demonstration, textbook readings and memorization. Most successful college students have spent their school careers in lecture/note-taking situations, a scenario in which they thrive. With such an extensive grounding in these teacher-dominated pedagogical methods, it is not surprising that students feel adrift when they are given the opportunity to learn in a non-directive setting. It follows that students having a negative experience with the less directive pedagogical perspective modeled in university courses might be less likely to implement it in their own teaching practice. Working on this assumption, isolated efforts at this type of instruction are likely to be unsuccessful in affecting change in science teaching.

The implications for teacher education may be summarized by two suggestions. First, science educators should make an effort to forge ongoing working relationships with instructors of introductory-level science courses with the goal of incorporating into these courses sound practices based on the principles of modeling and reflective practice.

Second, science teacher educators should include themselves, not just the scientists with whom they collaborate, in their application of Shulman's (1990) dictum, "How you learn a subject in college affects how you teach it." We should include in our own *methods* courses as many student-centered, constructivist-based activities as possible related to *pedagogical* issues. Lecturing to our students about the benefits of group work is not only likely to be ineffective but is ironic at best and hypocritical at worst. Students should be provided with ample opportunities for independent critical examination of specifically suggested "exemplary" materials and methods so as to develop confidence in making their own decisions about their value. Only then will they be likely to transfer an appropriately contextualized version these practices into their own future classrooms.

References

Berryman, S.E. (1983). *Who will do science?* New York: The Rockefeller Foundation.

Brown, A.L. & Palincsar, A.S. (1989). Guided, cooperative learning and individual knowledge acquisition. In L.B. Resnick (Ed.), *Knowing, learning, and instruction.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Cochran, K. (1992). Pedagogical content knowledge: Teachers' transformations of subject matter. *Research matters...to the science teacher* (NARST Monograph), *5*, 3-10.

Collins, A., Brown, J.S., & Newman, S.E. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics. In L.B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Georgia Department of Education (1986). *Needs assessment: Mathematics, science, foreign languages and computer learning.* Atlanta, GA: Georgia Department of Education.

Gess-Newsome, J. (1991, April). Pedagogical content knowledge: A domain of teacher knowledge or an issue of transfer? Paper presented at the annual meeting of the National Association for Research in Science Teaching, Fontana, WI.

Krajcik, J.S. & Borko, H. (1991, April). Pedagogical content knowledge: An important construct for science education. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Fontana, WI.

Leinhardt, G., & Greeno, J. (1986). The cognitive skill of teaching. *Journal of Educational Psychology, 78*, 75-95.

Hurd, P.D., Robinson, J.T., McConnell, M.C., & Ross, N.M. (1981). *The status of middle school and junior high school science.* Boulder, CO: Center for Educational Research and Evaluation, Biological Sciences Curriculum Study.

McEwan, H. & Bull, B. (1991). The pedagogic nature of subject matter knowledge. *American Educational Research Journal, 28*, 316-334.

Mason, C. (1988). A collaborative effort to effectively evolve pedagogical content knowledge in preservice teachers. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO.

Mason, C.L. & Huppert, J. (1992, March). Triads: A collaborative approach to the preparation of science teachers in the United States and Israel. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Cambridge, MA.

Padilla, M.J., Davis, E.J., & McKillip, W.D. (1986). The University of Georgia middle grades teacher education project. Proposal submitted to and funded by the National Science Foundation under the Middle Grades Teacher Preparation solicitation. NSF Grant # TEI-8652036.

Patton, M.Q. (1990). *Qualitative evaluation and research methods.* Newbury Park, CA: Sage.

Shulman, L. (1990). *Aristotle had it right: On knowledge and pedagogy* (Occasional paper No. 4). East Lansing, MI: The Holmes Group.

Shulman, L.S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*, 1-22.

Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Stofflett, R. & Stoddart, T. (1994). The ability to understand and use conceptual change pedagogy as a function of prior content learning experience. *Journal of Research in Science Teaching, 31,* 31-51.

Tamir, P. (1991). Professional and personal knowledge of teachers and teacher educators. *Teaching and Teacher Education, 7*, 263-268.

Tamir, P. (1988). Subject matter and related pedagogical knowledge in teacher education. *Teaching and Teacher Education, 4*, 99-110.

Tobin, K. & Garnett, P. (1988). Exemplary practice in science classrooms. *Science Education, 72*, 197-208.