

An International Investigation of Preservice Science Teachers' Pedagogical and Subject Matter Knowledge Structures

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ABSTRACT

The nature and development of an international sample of preservice science teachers' subject matter and pedagogical knowledge structures were assessed as they proceeded through student teaching. Twelve American and 14 Taiwanese preservice science teachers were asked to create representations of their subject matter and pedagogical knowledge structures before and after their student teaching experience. They also participated in a videotaped interview concerning knowledge structure representations immediately following student teaching. Qualitative analyses of knowledge structure representations and transcribed interviews with and between subjects were performed. Initial knowledge structures were typically linear and not coherent. Subject matter representations were stable, while pedagogy structures were susceptible to change, in the American sample, as a consequence of teaching. The American preservice teachers perceived pedagogy and subject matter as distinct and exerting separate influences on classroom practice, while the Taiwanese sample consistently exhibited difficulty in separating subject matter from pedagogy. Differences between the nature and development of the knowledge structure representations of the two groups were related to both cultural differences and differences in approaches to teacher preparation between the two countries. Taken within the context of prior research, the results support the assertion that a clear relationship exists between the complexity of teachers' knowledge structures and subsequent translation into classroom practice. Given that only one teacher preparation program from each country constituted the sample for the investigation, the reader is cautioned against over-generalizing the results to Taiwan and the U.S. in general. However, this initial cross-cultural investigation does raise some questions concerning the differences in approach to teacher education in Taiwan and the U.S.

Key Words: teachers' knowledge structures, teacher education

I. Introduction

Recent concerns about the quality of teacher education programs (Carnegie Forum, 1986; Holmes group, 1986; Kennedy, 1990) and the evaluation of teaching (Shulman, 1986, 1987) have focused attention on the subject matter and pedagogical knowledge of teachers. As a consequence, many states have increased subject matter requirements for admission

to teacher education programs. These increased requirements have taken the form of mandatory degrees in subject matter and/or subject matter competency examinations (e.g., National Teacher Examination) for prospective teachers. Such changes in policy have been made in spite of the fact that prior attempts to relate quantitative-oriented measures of what teachers know (e.g., GPAs, college credit hours, degrees attained) with measures of effective teaching have

rarely produced relationships of strong, practical significance (Brophy & Good, 1986).

The results of previous research, however, have not caused educators and policy makers to abandon the rather intuitive notion that a teacher's subject matter knowledge necessarily influences classroom practice. Rather, it has been recognized that the "older" process-product oriented research paradigms (most of which were quantitatively-oriented) are not sufficient to answer questions concerning teachers' subject matter knowledge, its formation, and its potential impact on classroom practice. Prior research, whether quantitative or qualitative, has yielded little more than relationships among superficial attributes of teachers' thinking and classroom behaviors. Consequently, older research paradigms have yielded to more in-depth qualitative measures of teachers' subject matter conceptual frameworks.

Recent attempts to explore teachers' conceptual understanding of subject matter have used a wide variety of approaches, notably semantic networks, word associations, concept maps, and various versions of card sorting tasks (Baxter, Richert, & Saylor, 1985; Hashweh, 1986; Hauslein & Good, 1989; Hauslein, Good, & Cummins, 1992; West, Fensham, & Garrard, 1985; West & Pines, 1985; White & Tisher, 1985; Wilson, 1989; among others). Although such approaches are often used in concert with interview protocols, respondents are typically asked to organize and/or categorize topics or themes provided by the researcher in order to elucidate underlying subject matter structures. Although the data yielded by the aforementioned techniques are qualitative in nature, the structure imposed on data collection arguably compromises the benefits and purpose of using a qualitative research design. To date, relatively few studies have avoided the pitfalls of limiting subjects' representations of content knowledge to an *a priori* list of topics when assessing development over time.

Although the growth and role of subject matter knowledge within teachers' professional development is presently the source of much research and controversy, the parallel development and role of pedagogical knowledge, with few exceptions (Hoz, Tomer, & Tamir, 1990; Lederman, Gess-Newsome, & Latz, 1994; Morine-Dershimer, 1989), and the interaction of these two domains of knowledge has yet to be systematically analyzed. Furthermore, the nature and development of pedagogy and subject matter knowledge structures among preservice science teachers in different countries is a totally uncharted area of investigation.

The purpose of this international investigation

was to assess the nature, development and changes of preservice secondary science teachers' subject matter and pedagogical conceptions/knowledge structures as they proceeded through their student teaching experience. In particular, this investigation attempted to answer the following questions: (1) What is the nature/form of preservice science teachers' subject matter and pedagogical knowledge structures? (2) What is the source(s) of these knowledge structures? (3) Are these knowledge structures stable during student teaching?, and (4) What is the relationship between these knowledge structures and how do they relate to the act of teaching? In addition to combined data analyses, each of the research questions was used to examine the similarities and differences between the two cultural groups (and distinct approaches to teacher preparation) represented in the sample.

For the purposes of this investigation, "knowledge structure" refers to the knowledge an individual possesses and the manner in which this knowledge is organized. Our research definition is intentionally broad and it is recognized that we might be more accurate in describing our teachers' knowledge as "conceptions" (and at times we use the terms synonymously) of subject matter and pedagogy as opposed to formal knowledge structures. Whether the label "knowledge structure" or "conception" is preferred, such referents should not distract the reader from the primary focus of this investigation: the nature, development, and changes of preservice science teachers' knowledge of subject matter and pedagogy as they proceed through the student teaching experience.

II. Design

1. Sample

Twelve preservice secondary school science teachers (seven biology, three general science, one chemistry, and one physics; seven males, five females) from the U.S. and 14 preservice teachers (seven physics, four biology, and two chemistry; eight males, four females) from Taiwan were studied as they proceeded through their student teaching. The American students were completing a one-year Master of Arts in Teaching (MAT) program and possessed at least a B.S. degree in their subject matter field (two had a M.S. degree and one a Ph.D.). The Taiwanese students were in their final year of a four-year teacher preparation program at a normal university. The Taiwanese preservice teachers possessed the U.S. equivalent of a B.S. plus 15 credit hours in their subject matter specialty. Consequently, all of the preservice teachers

(American and Taiwanese) possessed a level of subject matter knowledge well above that of most preservice teachers. In particular, preservice teachers in the U.S. commonly possess only a B.S. or less within their subject matter specialty. Even with the proliferation of MAT programs, preservice teachers commonly do not possess much more than a B.S. degree within their science specialty. Each of the preservice teachers in this investigation was seeking initial certification.

There were significant differences between the teacher preparation programs undergone by the U.S. and Taiwanese preservice teachers prior to their student teaching experience, which may have contributed significantly to several of the noted differences between the two samples. The duration of the teacher preparation program for the American preservice teachers was one year and consisted primarily of subject-specific pedagogy courses, with subject matter background required as a prerequisite for admission. Student teaching was performed during the third quarter of a four-quarter program. In contrast, the Taiwanese students proceeded through a four-year teacher preparation program in which both subject matter and pedagogy were addressed throughout the four years. Science pedagogy was emphasized in subject matter courses as well as within specific teaching method courses. As a consequence of Changhua University of Education's emphasis on the preparation of teachers, subject matter courses were consistently taught in a context focusing on the ultimate teaching of subject matter to secondary students. Therefore, pedagogy was both implicit and explicit within subject matter courses. Neither the subject matter courses nor pedagogy courses in Taiwan or the U.S. explicitly emphasized or discussed the "structure" of science disciplines or science pedagogy. Student teaching was completed at the end of the fourth year. At the time of student teaching, however, each of the groups of preservice teachers had received instruction in learning theories, teaching methods and strategies, microteaching, and had participated in field-based practica.

The student teaching experiences also differed significantly between the two programs. The American preservice teachers worked full time in a school setting and assumed full instructional responsibility for 3-4 classes (two preparations). Full instructional responsibility was assumed for a period of 10 weeks. The Taiwanese students worked full time in a school setting for only one month, during which time they assumed full instructional responsibility.

The two researchers (one from Taiwan and one from the U.S.) were well acquainted with the preservice

teachers as a consequence of their significant instructional responsibilities within their respective programs. We believe that the rapport between researchers and subjects served to facilitate the gathering of in-depth, accurate data and did not act as a hindrance.

2. Data Collection and Analysis

The case study design specified by Bogdan and Biklen (1992) was considered most appropriate for this investigation. In this particular instance, the case study focused on two culturally different groups of individuals who were proceeding through two distinctly different teacher preparation programs and student teaching experiences. Data was collected and analyzed in two phases. Of initial interest was whether preservice science teachers possess coherent conceptions and/or structures for their subject matter specialty and pedagogical knowledge. This question was addressed primarily in Phase I. The additional questions proposed by this study were addressed in Phase II.

A. Phase I.

Two weeks prior to the beginning of student teaching, each subject was given approximately 30 minutes to answer the following questions:

(1) What topics make up your primary teaching content area? If you were to use these topics to diagram your content area, what would it look like?

(2) Have you ever thought about your content area in the way you have been just asked to do so?

One week later, each subject was asked to answer the same questions, but with "important elements/concerns of teaching" substituted for the phrase related to primary teaching content area. The preservice teachers were asked to answer Question #1 again immediately following the completion of student teaching. For the second administration of the questionnaires, Question #2 was replaced with: "Have your views changed? If so, how and why?" Naturally, questionnaires were written and filled out in the native languages of the preservice teachers.

It should also be noted that no specific methods of formatting or organizing the subject matter and pedagogy "diagrams" were suggested to the preservice teachers. In addition, the preservice teachers were told that their descriptions of subject matter and pedagogy could focus on topics, themes, processes, strands, etc. and could be "represented" by use of a diagram, concept map, picture, description, or in any manner with which they felt comfortable.

Overall, it was felt that this methodology was superior to past attempts to assess subject matter and pedagogical knowledge structures because it gave respondents the freedom to select their own topics, themes, processes, or strands, etc. (as opposed to card sorts) and to organize these elements of knowledge in any manner with which they felt comfortable (as opposed to artificially forcing representations into categories, hierarchies, dimensions, or particular formats). It was hoped that this approach would provide a clearer portrait of the preservice teachers' conceptions/structures of subject matter and pedagogy. All representations and written text produced by the Taiwanese preservice teachers were translated into English prior to data analysis by the first author.

Qualitative analysis of the data collected during this phase (two administrations each of the subject matter and pedagogy questionnaires) attempted to derive any evident patterns between and within both groups of preservice teachers' stated subject matter and pedagogical structures. This initial analysis (conducted by the first author) served as a guide for additional data collection during a follow-up interview which took place one to two weeks after the completion of student teaching.

B. Phase II.

Within two weeks following the completion of student teaching an attempt was made to assess changes in the preservice teachers' knowledge structures and clarify any patterns elucidated in Phase I. Each American subject was asked to participate in a 45-60 minute videotaped interview conducted by the first author, while the Taiwanese preservice teachers were interviewed by both researchers with the second author serving as translator. The interviews consisted of questions that asked the subjects to describe their current knowledge structures, discuss changes which had occurred and any reasons for these changes, discuss any relationships between the knowledge structures or between either knowledge structure and their teaching, and their feelings about completing the questionnaire. During the interview, the previously completed knowledge structure diagrams/representations were displayed and discussed individually and as a group. Finally, all subjects were given an opportunity to revise the second diagrams/representations produced for subject matter and pedagogy to conform to any changes which might have occurred since its completion.

Importantly, the interview was also viewed as a means to compensate for any confusion created by the

pencil-and-paper questionnaire (either with respect to the respondents' reactions or the researchers' interpretations of responses). The problems associated with researchers' attempts to infer individuals' conceptions, knowledge, and beliefs solely from pencil-and-paper materials have been clearly recognized (Lederman, 1992). All interviews were transcribed (and translated when necessary) for analysis. Data were compared within and between individuals to derive any evident patterns for this particular group of preservice teachers.

Both phases of data analysis were conducted by the first author with the second author independently analyzing both the Taiwanese and American preservice teachers' knowledge structure representations and videotaped interviews. The second author is fluent in both Taiwanese and English. The independent findings of the two researchers were compared, contrasted and discussed. Given the cultural differences between the two groups of preservice teachers and the researchers, this was a critical step in the analysis of the data. There was no attempt to achieve total agreement between the perceptions of the two researchers. Such an attempt would only have served to eradicate the richer understanding which was gained from the different perspectives brought to the data analysis by the use of multiple researchers (Bogdan & Biklen, 1992; Eisner, 1991; Lincoln & Guba, 1985). The result was a clearly more comprehensive and deeper understanding of the preservice teachers' conceptions, while at the same time protecting interpretations from being overly influenced by the perspective of an individual researcher (Lederman & Gess-Newsome, 1991; Miles & Huberman, 1984).

III. Results and Discussion

The reported results represent the culmination of several rounds of data analysis, by each of the two researchers, and have been organized in terms of the initial questions guiding the investigation.

1. What is the Nature/Form of Preservice Science Teachers' Subject Matter and Pedagogical Knowledge Structures?

Interview responses indicated that the preservice teachers were quite hesitant while completing the first (and sometimes the second) subject matter questionnaire. Many felt tentative or uncertain about what to write. They indicated that they had no problem understanding the question or task at hand, but rather

were hesitant about the content (and quality) of their responses, as indicated by the following representative comments:

I knew what I was supposed to do. Still, you don't want to look like you don't know what you're talking about. I know my subject matter well, but I worry about communicating my knowledge to others. (American Preservice Teacher)

Knowing your subject matter is important. It would be very bad if a teacher did not know his subject. I did not want you to think I did not know my subject. (Taiwanese Preservice Teacher)

In short, both groups of preservice teachers were concerned that the questionnaire was a test of their subject matter understanding. No similar hesitancy or concern was expressed with respect to the pedagogy questionnaire, but the Taiwanese preservice teachers expressed much difficulty in conceptualizing or discussing pedagogy apart from their subject matter.

I am to become a physics teacher. So, I do not know how to think about teaching separately from physics. (Taiwanese Preservice Teacher)

This was a lot easier than the other questionnaire. I've seen so many teachers in my life, it's pretty easy to figure out what it's about. (American Preservice Teacher)

Initial subject matter representations were primarily listings of discrete topics or science courses taken at the university. The Taiwanese group, however, consistently included various pedagogical concerns (e.g., teaching approach, level of students) within their subject matter representations. The inclusion of pedagogical concerns within the subject matter representations of the Taiwanese preservice teachers was a consistent pattern throughout the investigation, serving to further reinforce the inability of the Taiwanese group to separate conceptions of subject matter from the teaching of the subject matter.

The pedagogical structures were primarily listings of the teacher-oriented components of instruction. Student-oriented components of instruction (such as motivation, prior knowledge) were given little or peripheral attention by the American group while the Taiwanese preservice teachers consistently took students as a focal point. The presence of integrative curriculum themes (e.g., nature of science, S-T-S) or connections between or within the components of either subject matter or pedagogical structures were not

commonly noted by either group of preservice teachers. Again, it is important to note that the oral instructions provided with the questionnaires explicitly emphasized that the word "topics" need not be taken literally and that respondents should feel free to include topics, themes, processes, or strands, etc. In addition, it was also emphasized that representations need not be "diagrams," and could take whatever form most accurately portrayed each individual's conceptions.

Organizational patterns were quite traditional with respect to subject matter. In general, subject matter structures were presented in three general formats: discrete (Fig. 1), simple hierarchy (Figs. 2 and 3), and web-like (Fig. 4). The Taiwanese group overwhelmingly presented subject matter in the form of simple hierarchies (again, with pedagogical factors included) while their American counterparts could be primarily characterized as striking a balance between discrete formats and simple hierarchies. The web-like format was clearly not common within either group of preservice teachers. Naturally, the labels used to

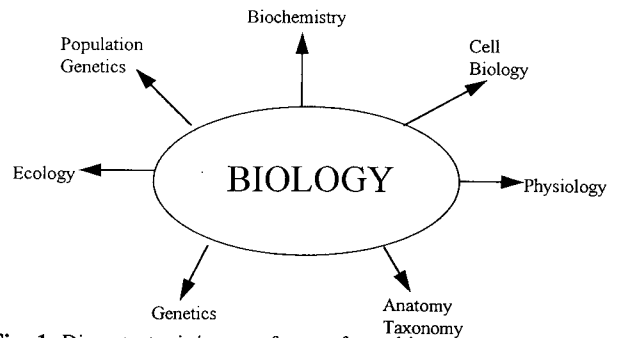


Fig. 1. Discrete topic/course format for subject matter structure. (American Preservice Teacher)

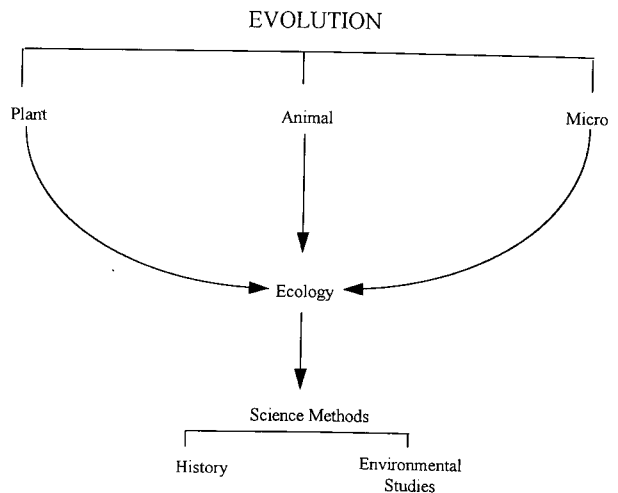


Fig. 2. Simple hierarchy format for subject matter structure (American Preservice Teacher)

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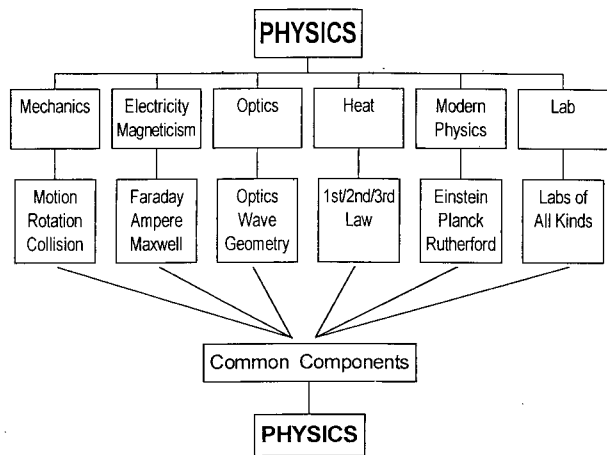


Fig. 3. Simple hierarchy format for subject matter structure (Taiwanese Preservice Teacher)

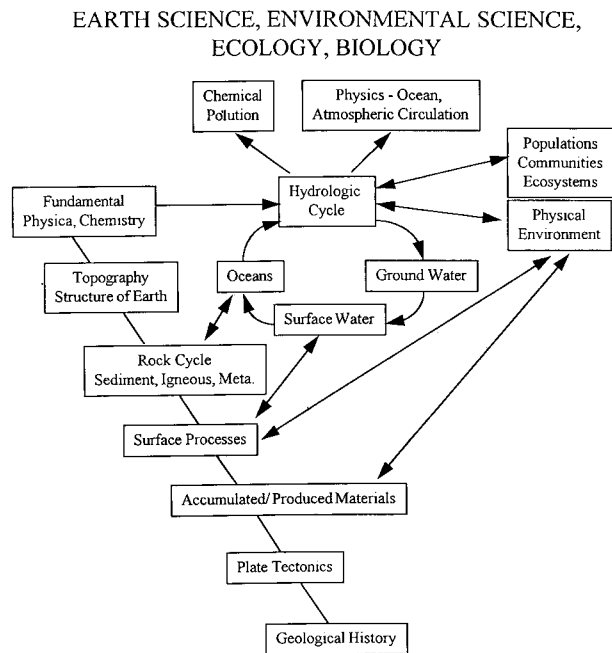


Fig. 4. Web-like/interrelated format for subject matter structure. (American Preservice Teacher)

describe the appearance of subject matter representations were a matter of convenience. As opposed to the descriptive labels, of more significance are the clear distinctions among the representations. It is important to again note that the preservice teachers were allowed to represent subject matter in any way that they felt best depicted their understanding. Although all of the teachers were familiar with concept mapping, none chose to follow the concept mapping approach of describing the meaning of connecting arrows and/or connecting lines. When asked for the meaning of these connections during

interviews, the preservice teachers (both Taiwanese and American) consistently described the meaning as a "connection or relationship" with no further elaboration. Rather, the responses tended to focus on the general organizational pattern of the representation, with the nature of the pattern having implications for the type of relationship depicted by connecting arrows and/or lines (e.g., in a hierarchical depiction, arrows or lines extending from a superordinate idea were intended to denote inclusion of those subordinate concepts/ideas listed below).

Pedagogical structures tended to be organized as web-like/interrelated representations of concerns, knowledge, and/or activities performed (Fig. 5), with students conspicuously absent as a primary focus in the representations of the American group (but as a clear focal point in the representations of the Taiwanese group) or as discrete "listings" of teacher-focused responsibilities and activities (Fig. 6). Again, descriptive labels were for convenience and should not distract from the clear visual and substantive distinctions among representations. As with the subject matter representations, connecting lines and arrows were described as simply denoting relationships, with the overall organizational pattern of the representation providing further clarification of the nature of the

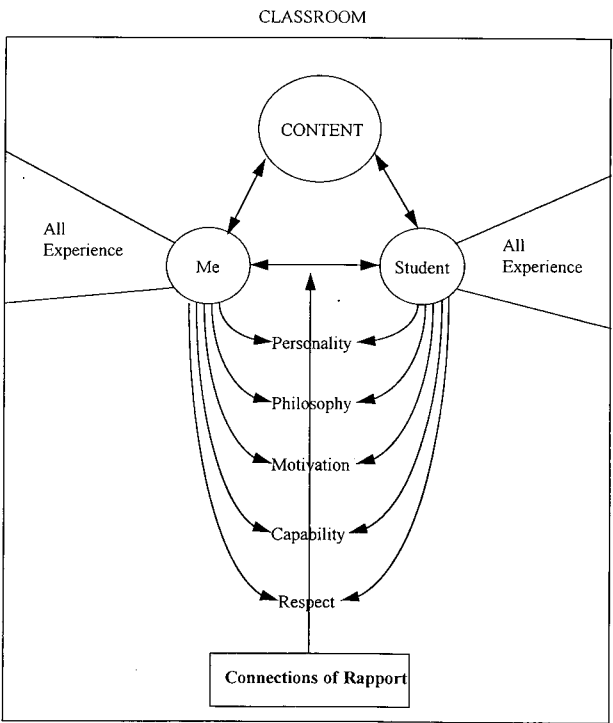


Fig. 5. Web-like/interrelated format for pedagogical structure. (Taiwanese Preservice Teacher)

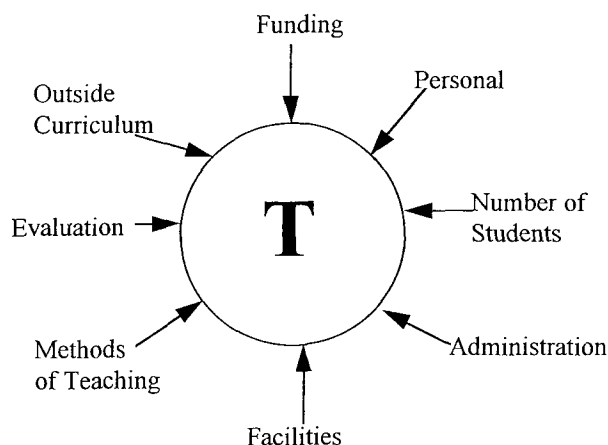


Fig. 6. Discrete responsibilities/activities format for pedagogical structure. (American Preservice Teacher)

relationship.

2. What is the Source(s) of these Knowledge Structures?

When asked about the source of their subject matter structures, many student teachers admitted, as might be expected, that the portrayed elements and organizational scheme came from college courses and that the representations were only tentatively delineated without any conscious rationale. For example, comments along the lines of the following were common:

I just put down the things we learned and did in my physics classes. Everything I know about physics comes from my teachers and books I have read. (Taiwanese Preservice Teacher)

How I view earth science is what I learned in school. Probably from all of my schooling, but mostly from what I had in college. (American Preservice Teacher)

These findings suggest that preservice science teachers (regardless of nationality) are not being presented with an overt or covert structure (or global conceptual framework) of subject matter (or at least one that is recognized) as part of their content preparation. The reader is also reminded that both groups of preservice teachers possessed subject matter knowledge backgrounds exceeding that included as part of an undergraduate degree in the U.S. Consequently, the lack of any recognizable subject matter structure does not appear to be unique to those with only undergraduate level preparation in subject matter. The reader is reminded that neither subject matter nor pedagogy

structures were stressed within the teacher preparation programs of the Taiwanese or American preservice teachers. Consequently, the representations given indicate the individual knowledge structures formulated by the preservice teachers as they proceeded through subject matter and pedagogy courses.

When asked about the source of their pedagogy knowledge structures, the preservice teachers uniformly referred to introductory education courses and personal experiences as a student:

I have been a student and a student in education courses. Where else could I better learn about teaching? (American Preservice Teacher)

My science education courses at the university have taught me what I need to know to be a good teacher. (Taiwanese Preservice Teacher)

When asked if they had ever thought about their subject matter specialty or pedagogy in the manner requested by the questionnaire, only one of the American preservice teachers, and none of the Taiwanese, admitted having previously thought about his subject matter in this manner. No individuals of either group admitted having done so for their knowledge of pedagogy. This finding is quite consistent with the lack of explicit attention to knowledge structures in both the Taiwanese and American teacher preparation programs. Contrary to the findings of previous research which has relied on card sorting tasks and other possibly restrictive assessment procedures (Baxter *et al.*, 1985; Hashweh, 1986; Hauslein *et al.*, 1992; Hoz *et al.*, 1990; Wilson, 1989), but consistent with research using more open-ended assessments (Lederman *et al.*, 1994), the preservice teachers appeared to possess no coherent, as typically defined by curriculum reform movements (Kennedy, 1990), or carefully considered structure for their subject matter. Furthermore, the topics, themes, and processes, etc. used in the representations of this group of preservice teachers exhibited little resemblance to the *a priori* elements/topics used in previous investigations. Perhaps the more directed approaches (e.g., concept maps, card sorting tasks, semantic maps) used in previous investigations of subject matter structures served to create the resulting structures (with respect to both content and organization) and did not necessarily provide an objective assessment. With respect to pedagogy, the results of this investigation were consistent with those obtained in previous investigations (Lederman *et al.*, 1994; Morine-Dershimer, 1989).

3. Are these Knowledge Structures Stable During Student Teaching?

Overall, virtually no changes were noted in the subject matter representations of either group. Although changes were clearly noted in the pedagogical knowledge structures of the American group, the representations of the Taiwanese group remained quite stable. The lack of change in subject matter conceptions of either group, despite the planning and implementation of lessons during student teaching, is a finding that contradicts an emerging and consistent body of literature (e.g., Hauslein *et al.*, 1992; Gess-Newsome & Lederman, 1993; Lederman *et al.*, 1994). When asked to discuss their conceptions of subject matter during the interview, typical responses clearly reinforced the impressions provided by the written representations.

How I view biology really hasn't changed much. I pretty much think of things the same as I said before. (American Preservice Teacher)

I am probably a bit more frustrated than before I taught. But I still view the teaching of physics the same. (Taiwanese Preservice Teacher)

The interviews definitively indicated that these preservice teachers had not altered their views toward the subject matter in response to the use of the subject matter in the context of teaching. Of particular interest here is the Taiwanese preservice teacher's reference to "the teaching of physics." The representation and related discussion was intended to be limited to the subject matter. However, as mentioned before, the Taiwanese preservice teachers consistently exhibited a subconscious (and often conscious) difficulty or unwillingness to consider subject matter as separate from the teaching of the subject matter. The significance of this clear difference from the American preservice teachers will be addressed in the *Implications* section of this paper.

Pedagogical representations became increasingly more complex for the American preservice teachers. A proliferation of student-focused components (e.g., motivation, learning styles, relevance, etc.) as well as additional teacher roles (e.g., friend, counselor) and responsibilities were clearly evident. Of most significance was a general shift away from linear representations of pedagogical knowledge to more web-like frameworks which placed the students and their concerns at the center (Figs. 7 and 8). For example, the individual who created Fig. 7 had initially created

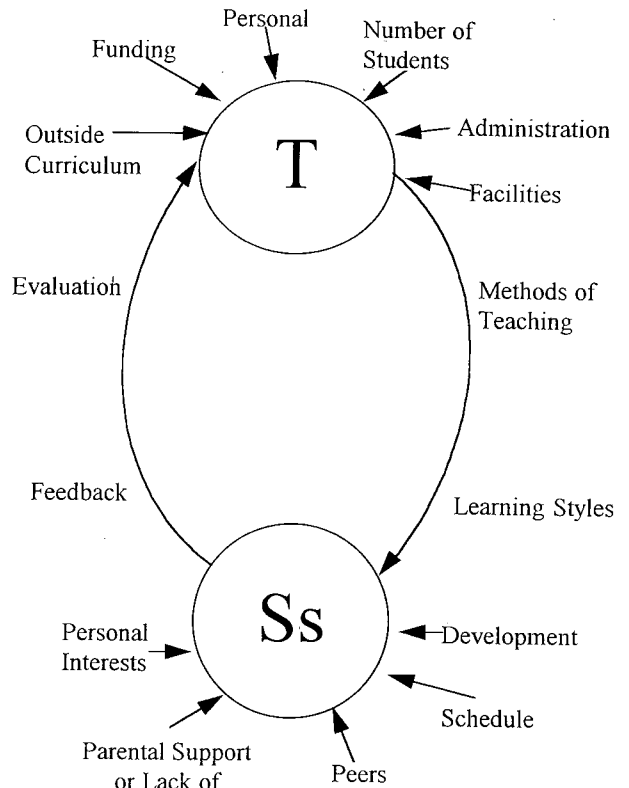


Fig. 7. Web-like/interrelated format for pedagogical structure (American Preservice Teacher)

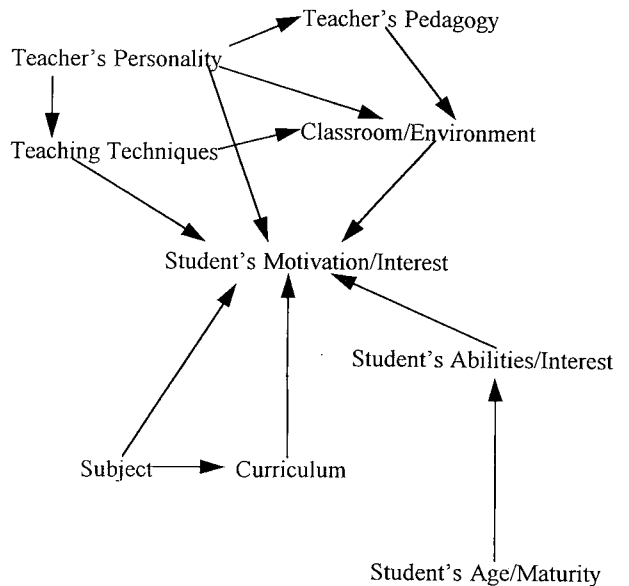


Fig. 8. Web-like/interrelated format for pedagogical structure. (American Preservice Teacher)

Fig. 6.

In general, the pedagogical representations of the Taiwanese preservice teachers remained the same as

before student teaching. The representations of the American preservice teachers became more similar to the initial and stable representations of their Taiwanese counterparts. The changes in representations of pedagogy by the American group appeared to be influenced by the planning and implementation of actual lessons. A common explanation for the change in the American preservice teachers' pedagogical structures is illustrated by the following comments:

The students demand your attention. You couldn't ignore them if you wanted to. (American Preservice Teacher)

You can talk about the importance of the students all you want. You may even believe you have a focus on students' needs. But it's all abstract until you're actually face to face with 30 of them. (American Preservice Teacher)

In short, the American preservice teachers reinforced one of the commonly voiced shortcomings of campus-based teacher preparation courses. It is interesting to note, however, that the Taiwanese preservice teachers initially placed students as a focal point in their pedagogical structures and continued to do so throughout the duration of the investigation.

4. What Is the Relationship between these Knowledge Structures and How Do They Relate to the Act of Teaching?

During the interview the preservice teachers were asked to discuss and relate to each other the set of four questionnaires (two subject matter and two pedagogy questionnaires). Whenever overlaps or similarities between the two types of structures were noted, the subjects were asked if they could be combined into one diagram or whether a combined depiction would be more accurate. The American preservice teachers uniformly responded negatively:

It makes more sense to me to keep the two separate. After all, knowledge of subject matter and how you teach subject matter are two different things. (American Preservice Teacher)

They're different things. When I teach I need to know my subject matter, but my knowledge of teaching tells me how to present what I know. (American Preservice Teacher)

On the other hand, the Taiwanese students were clearly less willing to distinguish between subject matter and pedagogy. As noted previously, they continued to integrate pedagogy into their conceptions of subject matter:

There is much overlap, of course. I have learned science because I wanted to become a science teacher. I learned science always with a view of teaching it. (Taiwanese Preservice Teacher)

The American preservice teachers clearly perceived pedagogy and subject matter knowledge as separate entities which were applied in an integrated manner during teaching, while the Taiwanese preservice teachers perceived the two in a much more integrated manner. During the interview, individuals were provided with a hypothetical teaching situation in which students are unable to understand a particular aspect of subject matter. When asked about what their response would be, the two groups of preservice teachers described their decision making process quite differently:

If students do not understand, I must find where the confusion is. To do this involves my knowledge of physics teaching. It is not a problem of subject matter or pedagogy. (Taiwanese Preservice Teacher)

High school students do not really know much biology. If they do not understand something, I must rely primarily on my knowledge of teaching. My knowledge of subject matter is important, because it gives me alternative examples to use, but it is my knowledge of teaching that lets me choose the correct solution to the problem. (American Preservice Teacher)

In short, even when presented with a hypothetical classroom situation/problem, the American group tended to conceptualize the influence of subject matter knowledge and pedagogy separately, while their Taiwanese counterparts exhibited a more integrated approach to the two knowledge domains.

As previously mentioned, neither group of preservice teachers altered their conceptualizations of subject matter knowledge in response to their exposure to public school students and the planning and implementation of science lessons. This finding does not support prior suggestions (Hauslein & Good, 1989; Hauslein *et al.*, 1992) that it may be impossible to view subject matter as separate from the manner in which it is, or will be, used. The act of teaching and/or thinking about how one will teach subject matter did not appear to have a significant influence on the way subject matter was conceptualized among these two groups of preservice teachers.

The pedagogical structures of the American group were seen to shift toward a focus on student concerns following the student teaching experience. This finding is consistent with assertions made by Lederman

& Gess-Newsome (1991) concerning the shift in concerns of preservice science teachers toward students as soon as they begin to teach lessons in actual field settings.

When specifically asked if their stated subject matter and pedagogical knowledge structures were evidenced in their teaching, both groups of preservice teachers were confident that each type of knowledge (i.e., subject matter and pedagogy) was reflected in how and what they taught:

Of course, at least I hope, my teaching is based on what I know and think. (Taiwanese Preservice Teacher)

I teach chemistry the way I view chemistry and I teach in a way that reflects my philosophy of teaching. I believe modeling to be very important in chemistry and it is continually stressed. I believe students learn best if they are actively involved and so I organize my class in that way. (American Preservice Teacher)

These results are consistent with a large body of literature on the relation of subject matter structures and teaching (e.g., Baxter *et al.*, 1985; Hashweh, 1986) and contradicts recent research (Gess-Newsome & Lederman, 1993; Hollingsworth, 1989) which indicates that preservice teachers are too overwhelmed by day-to-day instructional responsibilities to adequately and consciously incorporate integrated subject matter structures into daily instruction. The present results concerning the translation of subject matter and pedagogy knowledge structures into classroom practice must, however, be interpreted with extreme caution. The discrepancies between teachers' self-reports and actual classroom practices have been well documented. Additional research of this nature that includes actual classroom observations should be pursued.

IV. Implications for Science Education

Prior to any elaboration of the implications of this investigation, the reader is reminded that only one teacher preparation program from the U.S. and Taiwan were investigated. Consequently, it would be inappropriate to generalize differences between the two samples to obtain definitive differences between Taiwanese and American teacher education. Nevertheless, the two teacher preparation programs investigated were significantly different in approach and several of the noted differences in findings are seemingly related to programmatic differences.

It does not appear that these preservice science

teachers, regardless of nationality, possess "well-formed" or highly integrated subject matter or pedagogical knowledge structures. Consistent with previous research (Gess-Newsome & Lederman, 1993; Hauslein *et al.*, 1992; Lederman *et al.*, 1994), the subject matter knowledge structures that do exist are largely the result of college course work and are often fragmented and disjointed with little evidence of coherent themes. Consequently, the currently popular policy of requiring stronger subject matter backgrounds for preservice and inservice teachers, as a means of resolving the myriad of concerns about the quality of science instruction, may not be an effective approach. Such an approach, as seen with this group of preservice teachers, would most likely not lead to the development of the highly prized integrated subject matter conceptions advocated by prominent science education reform movements (A.A.A.S., 1989; NRC, 1996; NSTA, 1993). Furthermore, the preservice teachers investigated in similar studies (Gess-Newsome & Lederman, 1993; Lederman *et al.*, 1994) possessed far less extensive backgrounds in science but developed more integrated subject matter structures in response to the planning and implementation of instruction. In addition, it is important to note that the American preservice teachers studied in the present investigation completed the same professional teacher education coursework (e.g., methods, microteaching, practicum, etc.) as those in the studies by Gess-Newsome & Lederman (1993) and Lederman *et al.* (1994), with the only difference being the extent of subject matter background (i.e., degrees attained and course credit hours).

It is possible that the more extensive academic backgrounds of both the Taiwanese and American preservice teachers (which is consistent with current teacher preparation reforms) may result in the development of more firmly entrenched and inflexible conceptions of the subject matter. Consequently, although few would argue with the desirability of science teachers with extensive academic backgrounds, it might be that present approaches to college-level science instruction promote the development of relatively inflexible cognitive structures which are at odds with the integrated framework required for the implementation of currently advocated curriculum reforms. Although acquiring a relatively static view of one's subject matter as a consequence of a more extensive academic background is a problem in need of solution, the situation is further exacerbated if the nature of the structure is less than desirable. Since any significant reform in the instructional approach that currently typifies college science teaching seems unlikely, re-

sponsibility for stimulating students for reflecting on their subject matter (in an effort to promote the development of more integrated and flexible knowledge structures) seems to be most appropriately placed within the domain of the science educator. It is possible that repeated opportunities for reflecting on one's subject matter, as it is being learned, may be sufficient to provide preservice teachers with a coherent schema for their subject matter and allow them to integrate more of the information presented in their science courses. Certainly, the possible benefits to be derived from increased reflection upon subject matter within science education courses is an area needing further research.

The inability of the American preservice teachers to present a coherent conceptualization of pedagogy prior to student teaching is not surprising. As prior research has indicated (Lederman & Gess-Newsome, 1991), a well formed pedagogical knowledge structure should not be expected without actual experience with "real" secondary students. Other than simply increasing the length of field experiences (as many teacher education programs are already doing), it may be necessary to provide increased opportunities for preservice teachers to conduct systematic classroom observations (Good & Brophy, 1991) and reflect upon instructional sequences.

The American and Taiwanese preservice teachers clearly conceptualized pedagogy, and the relationship of pedagogy and subject matter, differently. Initially, the American group gave students only peripheral attention, while the Taiwanese group took students as a focal point (a view the American group adopted following student teaching). Furthermore, the Taiwanese group consistently exhibited difficulty in conceptualizing subject matter as separate from the teaching of the subject matter, while the American group clearly preferred to keep subject matter knowledge and knowledge of pedagogy distinct. It appears that distinct differences between the professional teacher education programs undergone by the two groups of preservice teachers may be responsible for the noted differences in conceptions of pedagogy and subject matter. In particular, the American group was completing a MAT program. This program requires a B.S. degree (or beyond) in one's subject matter specialty for admission. The program does include an additional nine graduate hours in the subject matter, but is primarily focused on science pedagogy with subject matter knowledge assumed to have been acquired prior to entrance. Virtually all of the American preservice teachers had decided to become secondary school science teachers during their senior year in

college or following graduation. The Taiwanese group, on the other hand, had been educated in a system much like the historic American Normal School. These students had decided to become teachers when they were completing their high school education, and spent much effort preparing for entrance examinations that would enable them to attend a college dedicated to the preservice education of teachers. Consequently, the Taiwanese preservice teachers received their subject matter background concurrently with their teacher preparation, and the subject matter was typically presented from the perspective of eventually having to teach it to others. Although this was not an experimental investigation, it does not take much to see why the Taiwanese students initially focused on students when conceptualizing pedagogy (while the American group did not) and experienced much difficulty in representing subject matter apart from its teaching (while the American group did not). Perhaps the U.S. may want to reconsider its current trend toward graduate level teacher preparation, with subject matter knowledge "front loaded," and focus specific attention on the conceptions of pedagogy and subject matter which are apparently needed to implement the currently popular reforms.

Keeping in mind the caution necessitated by the fact that classroom observations of these preservice teachers were not performed, the self-reported influence of preservice teachers' subject matter structures on classroom practice is consistent with much of the research on pedagogical content knowledge (Gudmundsdottir & Shulman, 1987; Hashweh, 1986; Shulman, 1987). However, the conclusions of American preservice teachers concerning the separate application of subject matter knowledge and pedagogical knowledge to instructional decisions are at odds with current thinking related to pedagogical content knowledge. Again, the Taiwanese preservice teachers were more integrated in their application of pedagogy and subject matter to classroom decisions. It may be that teacher preparation in a manner similar to the Normal University is more consistent with promoting pedagogical content knowledge than current approaches to achieving this end. Again, however, it must be noted that the Normal University approach to teacher education experienced by the Taiwanese group did not appear to alleviate the problem of discrete and fragmented conceptions of subject matter. This finding serves as a clear reminder that significant reform in science teacher education will necessarily involve full cooperation between subject matter specialists and science teacher educators.

The apparent contradiction with those of Gess-

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Newsome & Lederman (1993) of the findings related to subject matter structures is particularly intriguing. The subjects in that study included global, integrative (and arguably abstract) curriculum themes such as the nature of science and science-technology-society interactions in their subject matter structures. Such themes were virtually absent from the representations of both the American and Taiwanese preservice teachers, making their knowledge structures relatively simple in comparison. Consequently, it is quite possible that the ease with which a subject matter structure affects classroom practice (if at all) is as much a function of the relative complexity of the knowledge structure as it is of curriculum constraints, administrative policies, management concerns, etc. Indeed, the findings of this investigation concerning the complexity of a teacher's subject matter structure are supported by the recently reported investigation of Lederman *et al.* (1994). However, given that the data concerning translation of subject matter conceptions/structures into classroom practice was self-reported in nature, additional research that includes direct classroom observations should be performed in order to focus on the relationship between knowledge structure complexity and classroom practice. The possible importance of the complexity of one's knowledge structure is especially problematic since many of the new reforms in science education seem to depend on the incorporation of highly integrative themes such as the nature of science and science-technology-society interactions. If such highly complex and integrated subject matter structures are so difficult to translate into classroom practice, our expectations with respect to the ability of beginning and novice teachers to implement curriculum reform may have to be drastically reconsidered.

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職前科學教師教學與學科知識結構的國際研究

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摘 要

職前科學教師的學科知識和教學知識結構之本質與發展，是針對二十六位我國、美國兩地的職前教師，在進行實習教學之中評鑑而得。有十二位美國的職前教師和十四位我國的職前教師參與本項研究，研究的重點主要在教學實習前後，將他們的學科知識和教學知識以適當的圖形加以繪製出來。此外，也針對這些實習教師的教學表現進行晤談，並將晤談加以錄影。然後，將所收集的知識結構之表徵與晤談內容轉錄資料，在職前教師之間和每一位職前教師本身，運用質的研究法加以比較分析。研究結果顯示，這些職前教師起始的知識結構，基本上，呈現了線性，也缺乏同調。在實習教學之後，美國職前教師之學科知識表徵呈現穩定狀態，然而，教學知識結構發生改變。而且，美國職前教師認為教學與學科知識是屬於不同領域的知識，而且對課室教學的影響也是各自獨立的。對於要把學科知識和教學知識加以區別，我國的職前教師則一致地認為有相當程度的困難。對於我國和美國兩地的職前教師之教學知識和學科知識結構的本質與發展之差異，應係關聯到兩國文化的基本差異，及師資培育的方式之差異使然。若考慮將以前研究的情境因素考慮在內，本研究的結果仍然支持如下的主張：教師知識結構之複雜性與其轉化為課室教學的表現是存在著明確的關係。