6.5 The Subject Matter Knowledge of Preservice Science Teachers

KATHRYN F. COCHRAN AND LORETTA L. JONES
University of Northern Colorado, Greeley CO, USA

Until recently, little notice has been paid to the development of science subject matter knowledge in preservice teachers. The implicit assumption is that an undergraduate degree in a subject area or a related area (and relevant pedagogical preparation) provides an adequate basis for teaching. However, as concerns increase regarding children's subject matter knowledge (as exemplified by voluminous research on misconceptions in science and by recent movements toward standards-based education), corresponding concerns are being raised about teachers' subject matter knowledge.

Researchers in science teacher education are just beginning to deal with the complex issues involved in the development of subject matter knowledge (Tobin, Tippins & Gallard 1994). Studies are starting to provide evidence that subject matter knowledge, by itself, is not enough preparation for teaching (e.g., Carlsen 1991; Feiman-Nemser & Parker 1990; Grossman, Wilson & Shulman 1989), other studies suggest that subject matter knowledge is a matter of concern to new teachers themselves (Loughran 1993; Tamir 1992), and still other studies suggest that the characteristics and levels of teachers' subject matter knowledge are specifically related to teaching practices (Tobin et al. 1994).

The purpose of this chapter is to outline research on the nature and development of the subject matter knowledge of preservice teachers. Because the amount of research that directly addresses this issue is somewhat sparse, we also have included studies that focus on the subject matter knowledge of novice teachers as well as preservice teachers, and on comparisons between experienced teachers and preservice or novice teachers. The first main section describes current research on preservice teachers' subject matter knowledge and includes research on the quality and quantity of subject matter knowledge, teachers' misconceptions and the organisation of teacher subject matter knowledge. The second section focuses on aspects of teacher education programs relating to subject matter knowledge development and summarises three areas of research that inform the preparation of science teachers: the influence of teaching on

Chapter Consultant: Instead of using chapter consultants, chapter authors in the Teacher Education section provided editorial comments on each other's chapters.
subject matter knowledge; the relationships between subject matter knowledge and pedagogical knowledge; and evidence regarding the sequences of experiences in preservice programs.

CURRENT RESEARCH ON PRESERVICE TEACHERS’ SUBJECT MATTER KNOWLEDGE

Although several terms have been used to describe the content of the disciplines (Alexander, Schallert & Hare 1991), this chapter follows the lead of Tamir (1988) and uses the term subject matter knowledge. This term was originally coined by Schwab (1978), and was later developed by Ball and McDiarmid (1990) and Grossman, Wilson and Shulman (1989). In its use by many authors in science education, subject matter knowledge represents an umbrella conception, with four components nested within:

- content knowledge (the facts and concepts of the subject matter);
- substantive knowledge (the explanatory structures or paradigms of the field);
- syntactic knowledge (the methods and processes by which new knowledge in the field is generated);
- beliefs about the subject matter (learners’ and teachers’ feelings about various aspect of the subject matter).

The first two components of the subject matter knowledge framework are the focus of this chapter as the others are too extensive to be covered by this review (see Gabel 1994).

A principal finding of research on the first dimension of subject matter knowledge, content knowledge, focuses attention on general differences in quantity and quality of subject matter knowledge. Concerns about the subject matter preparation of teachers, especially primary teachers, are no doubt partly the impetus for some of these studies, as pointed out by Wandersee, Mintzes and Novak (1994). These issues are often raised on the basis of perceptions that the science requirements in primary preservice preparation programs are limited or haphazard.

Ball and McDiarmid (1990) suggest that much of primary teachers’ subject matter knowledge is grounded in everyday experiences and in their educational experiences occurring prior to postsecondary education, rather than in professional science knowledge developed during a teacher preparation program. Anderson and Mitchener (1994) depicted the science knowledge of preservice primary teachers as limited in amount, narrow in perspective and characterised by a lack of understanding of the nature of science; this view has been corroborated by Harty, Samuel and Andersen (1991) and Scharmann (1988a, 1988b). Wenner (1993) found that preservice primary teachers have low levels of science knowledge overall and less confidence in their ability to teach science than other subjects; however, these teachers also showed high levels of motivation to improve their knowledge for teaching science.
A few studies have attempted to relate teachers' subject matter knowledge to teaching strategies. Carlsen (1987, 1991) has shown that high levels of teacher content knowledge are related to fewer teacher questions, more student questions and higher levels of student participation. Low levels of teacher subject matter knowledge, on the other hand, seem to relate to low student participation levels and to low-level teacher questions designed for classroom management purposes. Carlsen also showed that teachers are more likely to use whole-group instruction for topic areas in which they have better subject matter knowledge. Lee (1995) provides similar evidence from a case-study approach, and shows that the limitations in subject matter knowledge of one middle school teacher (along with a strict approach to classroom discipline) resulted in a heavy reliance on the textbook and on seatwork, and on avoidance of whole-class methods such as discussion. These results are certainly preliminary, but they indicate the need to explore relationships between the dynamics of classroom interaction and the subject matter knowledge of teachers.

An intriguing finding of research on content knowledge has been on the area of teachers' misconceptions. In general, teachers are found to hold the same types of misconceptions as do students, but they are fewer in number (Wandersee et al. 1994). Ameh and Gunstone (1988) found misconceptions in nine general science concepts among both preservice and experienced secondary teachers in Africa. (The concepts were animal, plant, living, force, friction, gravity, electric current, light and chemical reaction.) The teachers' misconceptions were similar in nature and pattern to those found for students, but were couched in more sophisticated scientific language. Ameh and Gunstone suggest that such misconceptions are often a result of postsecondary science instruction, and they reject the notion that these results are specific to the Nigerian population, citing similar evidence from data collected in New Zealand and Australia. Bodner's (1991) study of misconceptions in beginning chemistry graduate students supports these data. A variety of misconceptions were found in this population and were thought to be the result of undergraduate instruction. Bodner suggested that, because knowledge is not the same as understanding, such misconceptions might be construed as knowledge without understanding.

It has also been shown that the extent of teachers' subject matter knowledge becomes important when experienced teachers are asked to focus outside their major subject matter area. Hashweh (1987) found teachers to have less accurate conceptions in areas with which they were less familiar. In this study, experienced biology teachers had difficulty with the physics concepts of work and force, and physics teachers had difficulty with the notion of cell respiration. Moreover, when asked to develop lessons for these topics, the teachers embedded the misconceptions into their plans for teaching and would have directly passed on these ideas to students. This is a matter of concern for science teacher educators, because science teachers who have a good background in only one science often teach classes in other science areas for which they are less well prepared.

In the light of research on the development of expertise (Chi, Feltovich & Glaser 1981), these results have been interpreted as showing that experts exhibit
higher-level domain knowledge and better-organised conceptual structures than novices. For example, when Barba and Rubba (1992) compared secondary preservice and inservice teachers on their general ability levels, content knowledge and problem-solving skills in earth science, they found that inservice teachers were better overall in each area. In addition, there is evidence of small correlations between the extent of teacher preparation (both in subject matter and pedagogy) and student achievement (Anderson & Mitchener 1994). Perhaps these relationships are not linear or we need better measures of knowledge in general (Grossman et al. 1989).

The subject matter knowledge of preservice teachers also has been measured by more direct methods used in cognitive structure research (Gess-Newsome & Lederman 1993; Hauslein, Good & Cummins 1992; Lederman, Gess-Newsome & Latz 1993; Lederman & Latz 1993). This evidence seems to be related more to the substantive knowledge component of subject matter knowledge. Hauslein et al. compared the understandings of 37 biology concepts across five groups: preservice teachers; relatively novice teachers (1–3 years of experience); experienced teachers (5 years or more of experience); seniors majoring in biology; and PhD research biologists. The concepts were sorted into categories by each individual using a Free-Sort procedure and the data were subjected to factor analysis and multidimensional scaling of the cognitive distance between groups. The findings reported by Hauslein et al. included few differences between preservice teachers and majors, which is not surprising because the authors state that the coursework for the two groups was highly similar. The subject matter knowledge of these groups was characterised by a loose organisation that reflected their program coursework. However, when these two groups were compared to the others (i.e., novice teachers, experienced teachers and scientists), the latter three groups showed a deeper and more complex organisation of their cognitive structures. The cognitive structure of teachers (both novice and experienced) was more fixed or rigid but, for the scientists, it was more fluid or flexible. For scientists, this flexibility is likely to be related to the nature of their work and is critical for dealing with the testing of new hypotheses and continual reports of new findings that must be integrated into ones’ understanding of the field. The fixed nature of teachers’ cognitive structures was attributed to pedagogical constraints imposed via the curriculum and the school environment. It also could be related to the rigid and limited organisation of subject matter fields typically presented in textbooks. There seems to be little variation in organisation within the introductory texts of any field, and most subject area experts can easily outline the most likely sequence of chapters in these texts. These findings suggest that, as science teachers gain expertise, their content understandings do not develop in the same manner as that for scientists.

This superficial level of organisation of subject matter knowledge for preservice teachers also has been supported by the work of Gess-Newsome and Lederman (Gess-Newsome & Lederman 1993; Lederman, Gess-Newsome & Latz 1993; Lederman & Latz 1993). In these studies, concern for the restrictiveness of common measures of cognitive structure (such as card sort tasks) and limited time
frameworks for data collection led over time to a series of measures in which pre-service biology teachers were asked to draw diagrams for and explain the concepts which they would be teaching. Preservice teachers showed little integration or stability in their subject matter knowledge. What organisation was present seemed to arise from subject matter coursework, but in general the students seemed to be unable to present their subject matter knowledge in a coherent manner. There was some evidence of restructuring of both subject matter knowledge and pedagogical knowledge over time as a result of methods coursework and student teaching, but overall the preservice teachers seemed to have had few opportunities to reflect on their subject matter. Moreover, the preservice teachers were reluctant and nearly unable to show any relationships between content and pedagogy in their diagrams.

This lack of coherence in preservice teachers' subject matter knowledge has been discussed by Kennedy (1990), Morine-Dershimer (1989) and Tamir (1992), and Ball and McDiarmid (1990) have described the problem as a lack of deep understanding. Yager and Penick (1990) assert that even students with science majors know little science, especially with respect to connecting real-world examples with scientific phenomena. Tamir (1992) investigated teachers' ratings of their knowledge and interest levels of eight thematic areas within biology (e.g., evolution, structure and function) and for seven levels of organisation (from biome to molecular). He collected several types of data from both student teachers and experienced teachers and found that most tended to think about their subject matter in terms of only one or two of the thematic areas and only one or two levels of organisation. Overall, student teachers rated themselves lower than experienced teachers on both knowledge and interest levels. Both groups rated the importance of these areas for pre-college students as higher than their own knowledge levels. According to Tamir, these results implied that the teachers felt they did not have sufficient levels of subject matter knowledge.

The results described so far imply that students completing baccalaureate degrees show, at least to some extent, unorganised, superficial and inaccurate knowledge of subject matter areas. The studies depict teachers' subject matter knowledge quite negatively, although this is neither the intention of this chapter or the researchers working in this area. The research and the results can be viewed as reflecting the implicit expectation that novice teachers will leave undergraduate programs with a sophisticated understanding of the subject matter; this view could be unrealistic. Yager and Penick (1990) also point out that college and university science majors' programs have remained substantially unchanged for decades, and that we actually know little about how and how well our traditional programs prepare students for graduate work in science fields or for professional schools, such as medicine.

An important point here is that, although these studies seem to raise concerns about teachers' subject matter knowledge, they tell us very little about what teachers really do know (even primary teachers), and about the positive influences that this knowledge has on teaching and on the subsequent learning of their students. In fact, the concepts and relationships in subject matter areas that teachers actually teach are not identical with the concepts and relationships that they are asked to learn in coursework sequences which constitute their programs of specialised
International Handbook of Science Education
Fraser, B.; Tobin, K. (Eds.)
1998, xxx, 1271 p. 11 illus. In 2 volumes, not available separately., Hardcover