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ABSTRACT

This longitudinal investigation assessed the development and changes in preservice science teachers' conceptions of subject matter and pedagogy as they proceeded through their secondary science methods course, practicum, microteaching, and student teaching. Twelve preservice science teachers were asked, on four occasions each several weeks apart, to specify what topics make up their primary teaching content area and what a diagram of the content area with these topics would look like. Interviews were conducted following student teaching to assess changes in preservice teachers' knowledge structures and to clarify any patterns. Results were analyzed in terms of the nature of preservice science teachers' subject matter and pedagogy knowledge structures; the source of these knowledge structures; stability of knowledge structures during teacher preparation; and the relationship between the knowledge structures and the act of teaching. Among the findings were: preservice science teachers do not have well-formed or stable subject matter or pedagogy knowledge structures; the responsibility of stimulating students to reflect on their subject matter seems to be most appropriately placed within the domain of the science educator; and preservice teachers reported that subject matter structures were translated into classroom practice with ease. Twelve handwritten charts and diagrams of the process are included. (Contains 17 references.) (JDD)

Becoming a Teacher: Balancing Conceptions of Subject Matter and Pedagogy

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Interest in teachers' knowledge of subject matter has gained renewed emphasis as a consequence of current attempts to increase the quality of teacher education programs (Carnegie Forum, 1986; Holmes group, 1986; Kennedy, 1990). In many states, teacher education reforms have been manifest in increased entry requirements such as academic degrees for prospective teachers. Prior attempts at correlating quantitative measures of what teachers know (e.g., GPA's and the number of courses taken) with measures of effective teaching have rarely produced relationships of strong, practical significance (Brophy & Good, 1986).

Past paradigms of research on teachers' knowledge and effectiveness have provided us with correlational data on quantitative measures of teachers' knowledge. This research appears to be inadequate in providing the information necessary to answer current questions and concerns about the importance of one's subject matter knowledge. More in depth qualitative measures of teachers' conceptual frameworks of subject matter are necessary to enlighten the discussion of teachers' subject matter knowledge, its formation, and its potential impact on instructional practice.

Consequently, recent attempts at exploring teachers' subject matter knowledge have been characterized by card sort tasks in which subjects are asked to organize and/or categorize topics or themes provided by the researcher in order to unveil underlying subject matter structures (Baxter, Richert, & Saylor, 1985; Hashweh, 1986; Hauslein & Good, 1989; Wilson, 1989). Unfortunately, methodological flaws such as assuming that a coherent and stable subject matter structure already exists, limiting topics/themes to those suggested by the researcher, and the short duration of investigations call into question the results obtained thus far. To date, almost no studies have avoided the pitfalls of limiting subjects' representations of content knowledge to an a priori list of topics while assessing development over time. One exception is Morine-Dershimer's (1989) assessment of preservice teachers' conceptions of lesson planning and subject matter structures during a microteaching course. Over the duration of the course these teachers adjusted their subject matter structures to be more consistent with what and how they taught.

Although the development 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; Morine-Dershimer, 1989), has yet to be systematically analyzed. In addition, the interaction of these two domains of knowledge, as specified in Shulman's (1987) model of pedagogical content knowledge, also remains an enigma. The purpose of this longitudinal investigation was to assess the development and changes in preservice science teachers' conceptions (i.e., knowledge structures) of subject matter and pedagogy as they proceeded through their professional teacher education program and student teaching experience. In particular, this investigation attempted to answer the following questions: 1. What is the appearance/nature of preservice science teachers' subject matter and pedagogy knowledge structures? 2. What is the source of these knowledge structures? 3. Are these knowledge structures stable during teacher preparation? 4. What is the relationship between these knowledge structures and how do they relate to the act of teaching?

Although there is general agreement that all individuals structure their knowledge in some manner, an exact definition of 'knowledge structure' remains elusive. For the purposes of this investigation, 'knowledge structure' refers to an individual's conceptions and/or organization of a specified domain of knowledge (e.g., science discipline, pedagogy).

Design

Sample

Twelve preservice science teachers, six female and six male, were selected for this investigation. These individuals consisted of all preservice science teachers enrolled in their first professional science education courses (i.e., field practicum with seminar and a methods course). Seven of the preservice teachers were pursuing initial certification in biology, three in general science, and two in chemistry. These individuals were studied as they proceeded (as a cohort group) through the field practicum and methods course (Fall Term), microteaching and science practicum (Winter Term), and student teaching experience (Spring Term). In short, these preservice teachers were followed throughout the totality of their subject-specific teacher education program.

Similar data, although not longitudinal, were collected for six student teachers (five biology and one general science; three males and three females) during the Fall Term and 14 student teachers (six biology, five general science, two physics, and one chemistry; eight males and six females) during the Winter Term. These non-cohort groups were used to corroborate, or call into question, any patterns or trends noted in the 12 member longitudinal cohort group.

Given the nature of this research, it is important to provide the context of the course work in which the preservice teachers were enrolled. The Secondary Science Methods course included instruction on the nature of science, the writing of lesson plans and objectives, classroom questioning, teaching methods and strategies, science curricula, science-technology-society interactions (STS), evaluation, and classroom management. The field-based practicum exposed the preservice teachers to secondary students in actual classroom settings. Responsibilities ranged from that of an instructional aid to full teaching responsibility for 1-2 lessons. The Microteaching practicum served as an opportunity for the application and refinement of the methods and strategies discussed in the methods course. Each student was required to plan and teach four 20-minute lessons using the following methods/strategies: lecture/recitation, general inductive model, general deductive model, and "laboratory." Lesson topics, chosen from those typically taught in the public schools, were randomly assigned for the lecture/recitation and deductive presentations. Due to the nature of the teaching strategies and time constraints, students were allowed to select their own topics for the inductive and "laboratory" presentations. Lessons were videotaped and verbally critiqued by instructors and peers. Written critiques were provided by the course instructors and a self-critique was completed by the presenter. Finally, the Science Practicum focused specifically on laboratory and demonstration techniques, and laboratory safety. In addition, students were involved in the development of a resource file, collection of teaching ideas, and were given practice in completing budgets and laboratory inventories. The microteaching practicum and methods course were taught by one or two of the researchers and the science practicum was the responsibility of another individual. These classes were required of all science education majors and the content was not focused on any particular science discipline. No special attempts were made to influence students' conceptions of science content or pedagogy beyond the normal scope of the courses as described.

Data Collection and Analysis

Given the exploratory nature of this study, the case study design, as specified by Bogdan and Biklen (1982), was considered to be most appropriate. Specific details of the case study methodology will follow. Data was collected and analyzed in two phases. Of initial interest was whether preservice science teachers possess coherent conceptions/structures of their subject matter specialty and pedagogy. This question was addressed primarily in **Phase I.** The additional questions proposed by this study were addressed in **Phase II.**

Phase I. Each subject was given approximately 15 minutes, on the first day of the field practicum seminar, 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 been asked to do so above?

One day later, during the first meeting of the methods course, 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 at the end of the field practicum, at the end of the microteaching practicum, and five weeks into student teaching. For the second, third, and fourth questionnaire administrations, Question #2 was replaced with: "Have your views changed? If so, how and why?" A total of four subject matter questionnaires and four pedagogy questionnaires were completed. These assessments spanned the entirety of subject-specific teacher preparation with the posttest diagram for a particular term serving as a pretest for the subsequent term. The preservice teachers were assured that there were no right or wrong answers to these questions and that their responses would in no way affect their grade in the course. It should also be noted that no specific methods of formatting the diagram were suggested or taught to the students. For instance, the students were not asked to diagram their topics in the form of a concept map, hierarchical structure, etc.

It was felt that this methodology was superior to past attempts to assess subject matter and pedagogy knowledge structures because it gave respondents the freedom to select their own topics (as opposed to card sorts) and organize the topics in any manner which felt comfortable (as opposed to artificially forcing topics into categories or formats). It was hoped that this approach would provide a clearer portrait of the preservice teachers' conceptions of subject matter and pedagogy.

Qualitative analysis of the data collected during this phase attempted to derive any evident patterns among, and within, the preservice teachers' stated subject matter and pedagogy structures. This initial analysis (conducted by one of the researchers) served as a guide for additional data collection during a follow-up interview which occurred one week after the completion of student teaching.

Phase II. Immediately following student teaching, an attempt was made to assess changes in the preservice teachers' knowledge structures and to clarify any patterns elucidated in **Phase I.** Each subject was asked to participate in a 45 minute videotaped interview conducted by the same researcher who analyzed **Phase I** data. The interviews were guided by questions which asked the subjects to describe their current knowledge structures, discuss changes which had occurred during the year 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 throughout the year. During the interview, the previously completed knowledge structure diagrams (four for subject matter and four for pedagogy) were displayed and discussed individually and as a group. Finally, all subjects were given an opportunity to revise their final questionnaire to conform to any changes which might have occurred since its completion. All interviews were transcribed 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 one of the researchers and later corroborated by independent and "blind" analyses performed on both written and videotaped data by the two other researchers.

Results and Discussion

The results reported represent the culmination of several rounds of data analysis and will be organized in terms of the initial questions guiding this investigation.

What is the appearance/nature of preservice science teachers' subject matter and pedagogy knowledge structures?

Interview responses indicated that the preservice teachers felt inadequate while completing the first two subject matter questionnaires. Many felt confused or uncertain about what to write. They were not confused about the task at hand, but rather were hesitant about the content of their responses as indicated by the following representative comments:

> "I knew what you wanted, but I didn't want to come off stupid."
>
> "Coming up with topics wasn't hard, but how to put them together in an intelligent way is hard."

In short, they were concerned that the questionnaire was a test of their content understanding. Interestingly, no hesitancy or confusion was expressed with respect to any administration of the pedagogy questionnaire. For example, one preservice teacher noted:

> "The teaching question was easy. I know what's important in teaching."
>
> "I felt comfortable with the questions about teaching. I know how all that stuff fits."

In general, if any response is accepted as a knowledge structure, the subject matter structures were primarily listings of discrete topics/science courses taken at the university and the pedagogy structures were primarily listings of the teacher oriented components of instruction with student oriented components (such as motivation) given little or peripheral emphasis. The presence of integrative themes or connections between or within the components of either subject matter or pedagogy structures was not common.

Organizational patterns, if they existed at all, were quite traditional with respect to subject matter. In general, subject matter structures were presented in three general formats: discrete (Figure 1), simple hierarchy (Figure 2), web-like (Figure 3).

Insert Figures 1, 2, 3 Here

Pedagogy structures tended to be organized in a linear fashion coinciding with the temporal sequence of instruction (Figure 4), discrete "listings" of responsibilities (Figure 5), or web-like representations of activities performed (Figure 6).

Insert Figures 4, 5, 6 Here

<u>What is the source of these knowledge structures?</u>

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

> "Well like I said before, I hadn't really thought about this before. So, what I put down was what I had in college here. It made sense to me that what I had must be chemistry."

> "I couldn't think of anything except what I have had in classes. That's when I first realized that a lot of the topics were included over and over again in more than one course."

These findings suggest that preservice science teachers are not being presented with an overt or covert structure of subject matter as part of their content preparation. This is not surprising considering the manner in which college science courses are taught and presented as disconnected from total programs. Unfortunately, this fragmented and discrete style of content presentation may be passed on, intact, as these preservice teachers attempt to teach courses at the secondary level.

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

> "I just put down the stuff we talked about in education courses."
>
> "Sitting in classes all your life as a student, it's not too difficult to figure out what to put down."

When students were asked if they had ever thought about their subject matter specialty or pedagogy in the manner requested by the questionnaire, only five of the 12 preservice teachers (and none of the non-cohort teachers) admitted having previously thought of their subject matter in this manner. Only two admitted having done so for their knowledge of pedagogy. Contrary to the findings of previous research (Baxter, et. al., 1985; Hashweh, 1986; Hauslein & Good, 1989), these preservice teachers, completing their final year of course work appeared to possess no coherent structure for subject matter. Thus far, no similar assessment of pedagogical knowledge has been documented. Perhaps, the more directed card sort tasks used in previous investigations of subject matter structures served to create the resulting structures as opposed to providing an objective assessment.

Are these knowledge structures stable during teacher preparation?

Changes were clearly noted in each of the knowledge structures by the third and fourth questionnaire administrations (i.e., during microteaching or student teaching). Subject matter structures generally became more consistent with how each respective content area would be presented to secondary school students, an organization which the subjects reportedly found difficult to include in initial conceptualizations. Clearly, the planning and implementation of science lessons directly influenced the preservice teachers' conceptualizations of subject matter:

> "It's changed a lot. Now I have the kids and their needs to think about."

> "I think my changing views about my content area have come about through the re-thinking of my topic area as I have student taught. I have become more aware of the interrelatedness of things."

> "In courses you just have to know your subject to pass the test. But how I view what I know has definitely changed because I have had to think about teaching it to someone else."

Insert Figures 7 & 8 Here

Overall, many individuals altered their representations into integrated and interrelated networks of topics (Figure 7). However, these representations were often made simpler in response to the needs of students:

> "I made things much simpler. You have to consider what the students really need in their every day lives."

This comment was made by the individual who created Figure 8. The same individual previously created Figure 2. Instructional themes such as the importance of making subject matter concrete and relevant to students were added to most representations. However, overriding curriculum themes such as science-technology-society interactions were not typically added, a finding in stark contrast with prior research (Gess-Newsome & Lederman, 1991) and the representations created by the non-cohort groups in this investigation. The significance of this discrepancy is explicitly addressed in the implications section of this paper.

Pedagogy representations became increasingly more complex during the duration of the investigation. A proliferation of student focused components (e.g., motivation, learning styles, relevancy, 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.

Insert Figures 9 & 10 Here

In general, as with subject matter structures, representations of pedagogy appeared to be influenced by the planning and implementation of actual lessons. A common explanation for the change in the preservice teachers' pedagogy_structures is represented by the following comment:

"You can't ignore the students. You quickly realize their needs are more important than anything you need to do."

What is the relationship between these knowledge structures and how do they relate to the act of teaching?

As noted, the preservice teachers' representations of pedagogy and subject matter became increasingly integrated, but not necessarily more complex throughout the investigation. In addition, instructional themes such as making subject matter more relevant and concrete eventually were included in subject matter structure representations. However, when asked during the interview to relate the two sets of questionnaires and if they could be combined into one diagram, the subjects uniformly responded negatively:

"Absolutely not. Teaching and knowledge of content are two different things. You need to have both, but they are different."

"I could put them on the same piece of paper, but in my mind they are more easily thought of as different and separate."

The preservice teachers clearly expressed the belief, that pedagogy and subject matter knowledge were separate entities which were applied in an integrated manner during teaching. For example, when provided with a hypothetical situation in which students are unable to understand a particular aspect of subject matter, the preservice teachers typically described their decision making process as essentially involving two types of knowledge:

> "I use my knowledge of teaching to see that 'hey this isn't working.' The subject matter knowledge comes in because it allows me to present another example or another way of looking at something."

Pedagogical knowledge was considered to be at work during the assessment of students' understanding and the decision to try a different approach, while subject matter knowledge was considered to be involved by providing the flexibility to present content in a different manner. Additionally, the preservice teachers clearly expressed the belief that pedagogical knowledge was the more important for making instructional decisions:

> "My knowledge of teaching has been the most important during student teaching. You have to know how to keep the students interested and on task."

> "Subject matter knowledge is important, but you already know so much more than your students. How to explain what you know is the part that's hard. Knowing how to teach is much more important at this level."

As mentioned, the preservice teachers began to structure their subject matter knowledge in terms of how it should be taught by the third and fourth administrations of the questionnaire (just at the time they were in the microteaching practicum or student teaching). This finding supports suggestions made by Hauslein and Good (1989) 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 had a significant influence on the way that subject matter was conceptualized. Pedagogy structures were also seen to shift toward a focus on student concerns at the same time the preservice teachers were actively involved in the planning and implementation of lessons. This finding is consistent with assertions made by Lederman and Gess-Newsome (1991) relating to the shift in concerns of preservice science teachers.

When specifically asked if their stated subject matter and pedagogy knowledge structures were evidenced in their teaching, either microteaching lessons at the university or while student teaching, the preservice teachers were confident that each of the knowledge structures was reflected in how and what they taught:

> "For sure. If you watched any of my lessons I always try to make things concrete and relevant. I also try to show students how all the content is related. This would be harder for you to see in one lesson because it (the lesson) usually focuses on one topic, but overall I try to interrelate things."

"How I view teaching and how I view biology both come out in my teaching. It's kind of a chicken and egg situation. Teaching has affected both and both affect my teaching."

These results contradict previous research on subject matter structures (Gess-Newsome & Lederman, 1991) which indicated that preservice teachers are too overwhelmed by day-to-day instructional responsibilities to adequately and consciously incorporate integrated subject matter structures into daily instruction.

Implications for Science Education

It does not appear that preservice science teachers have well formed or stable subject matter or pedagogy knowledge structures. The structures which do exist are largely the result of college course work and are often vague and ephemeral with little evidence of coherent themes. With respect to subject matter structures, the perennially popular policy of requiring increased subject matter backgrounds for preservice teachers may not be an effective approach for the improvement of K-12 science instruction. Consider the nature of the subject matter representations which the group of preservice teachers in this investigation derived from their science course work. Since any significant reform in the instructional approach which typifies college science teaching seems unlikely, the responsibility of stimulating students to reflect on their subject matter seems to be most appropriately placed within the domain of the science educator. It is possible that repeated opportunities to reflect on one's subject matter structure 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. Since one of the results of this investigation elucidated the significant influence of how one uses his/her subject matter upon its structure, science education courses again appear to be the logical arena for the development of preservice science teachers' subject matter structures.

The inability of the preservice teachers to present a coherent conceptualization of pedagogy during the initial administrations of the questionnaires is not surprising. As prior research has indicated (Lederman & Gess-Newsome, 1991), a well formed 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 self-reported influence of preservice teachers' subject matter structures on classroom practice is consistent with much of the research on pedagogical content knowledge (Gudmunsdottiir & Shulman, 1987; Shulman, 1987). However, the resolve of these preservice teachers concerning the separate application of subject matter knowledge and pedagogical knowledge to instructional decisions is at odds with the current view of pedagogical content knowledge as a separate domain of knowledge. The elevated status given to pedagogical knowledge in making instructional decisions, however, is consistent with much of the research on problem solving (Chi, Feltovich, & Glaser, 1981). It is quite possible that classroom decisions are primarily pedagogical problems which naturally require access to pedagogical knowledge as opposed to subject matter knowledge. Clearly, research which compares the pedagogy structures of experts and novices, as well as the relationship of these structures to classroom practice and instructional decisions needs to be pursued.

Finally, the apparent ease with which subject matter structures were translated into classroom practice, as reported by this group of preservice teachers, contradicts the findings of Gess-Newsome and Lederman (1991). The subjects in their research (as well as the non-cohort groups in this investigation) included global, integrative (and arguably abstract) curriculum themes such as the nature of science and science-technology-society interactions in their subject matter structures (Figures 11 & 12).

Insert Figures 11 & 12 Here

Such themes were largely absent from the representations of the preservice teachers in this investigation, rendering the knowledge structures to be relatively simple by comparison. 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 related to curriculum constraints, administrative policies, etc. The complexity of one's knowledge structure is especially critical since many of the new reforms in science education depend on the incorporation of highly integrative themes such as the nature of science and science-technology-society interactions. It may be that reforms in science education depend on the development of subject matter structures which are exceedingly difficult for anyone other than an expert teacher to translate into classroom practice.

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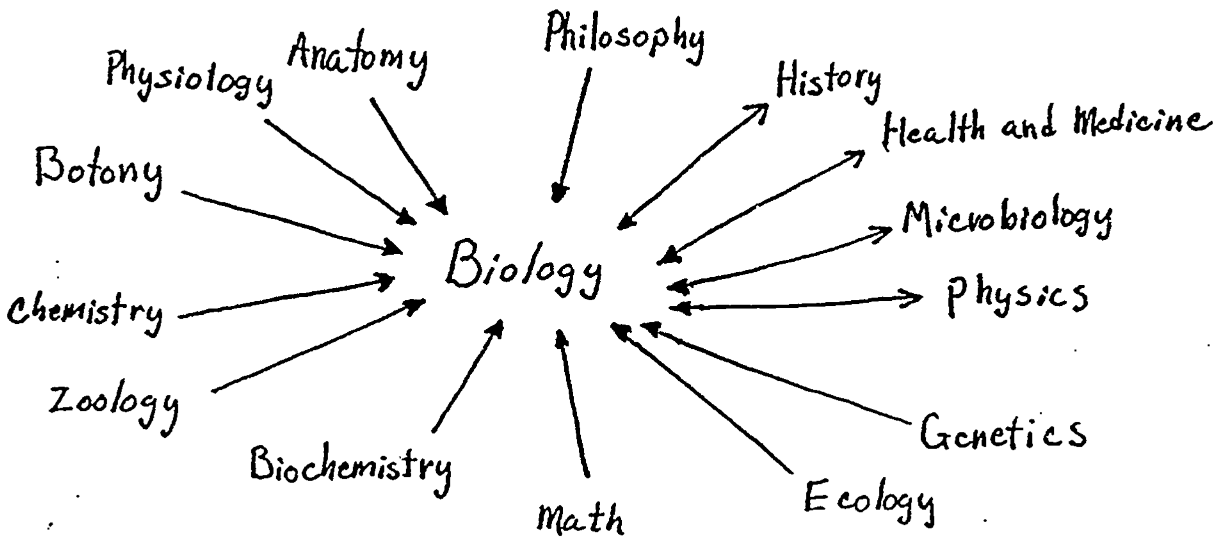

Figure 1. Discrete topics/course format for subject matter structure.

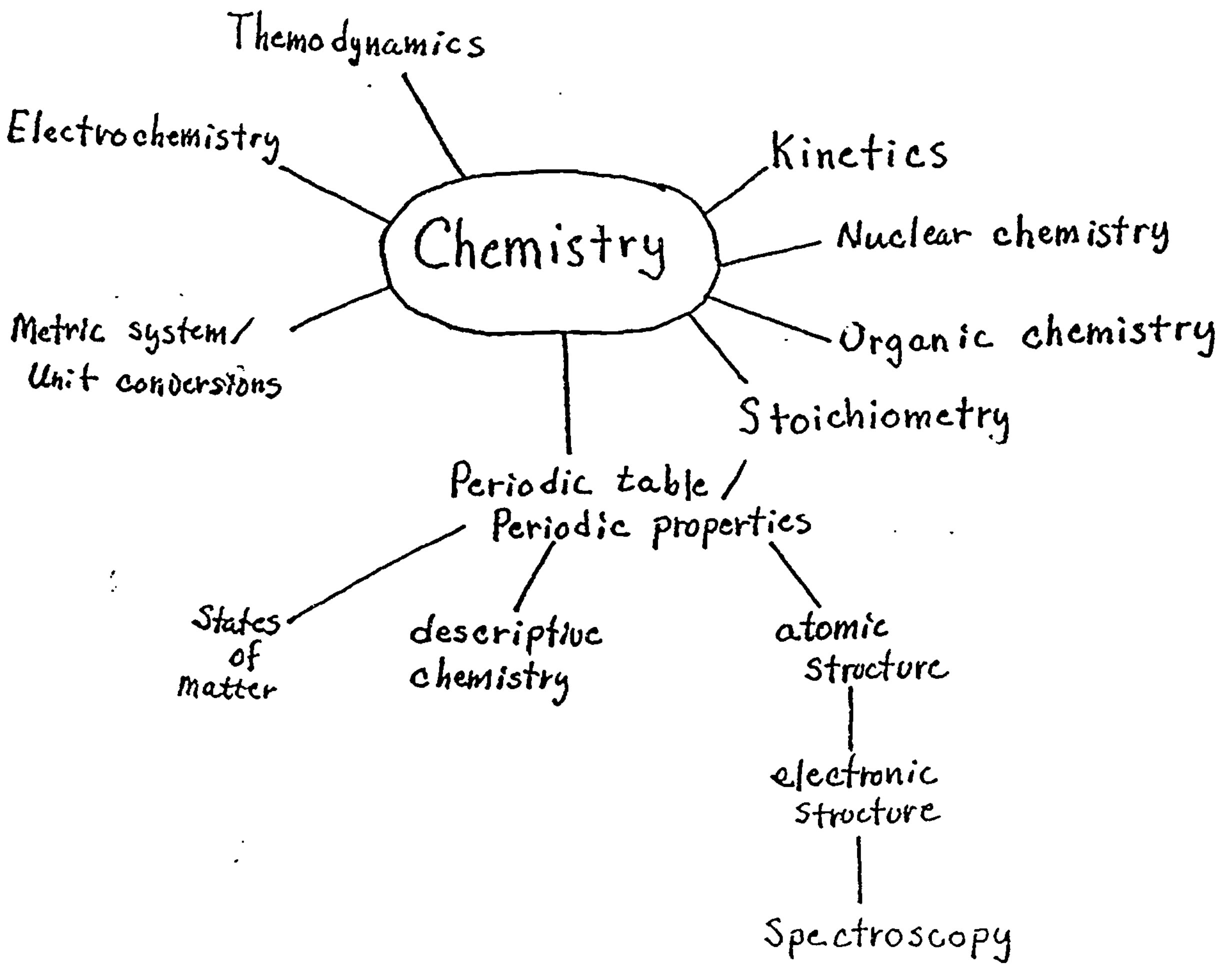

Figure 2. Simple hierarchy format for subject matter strucure.

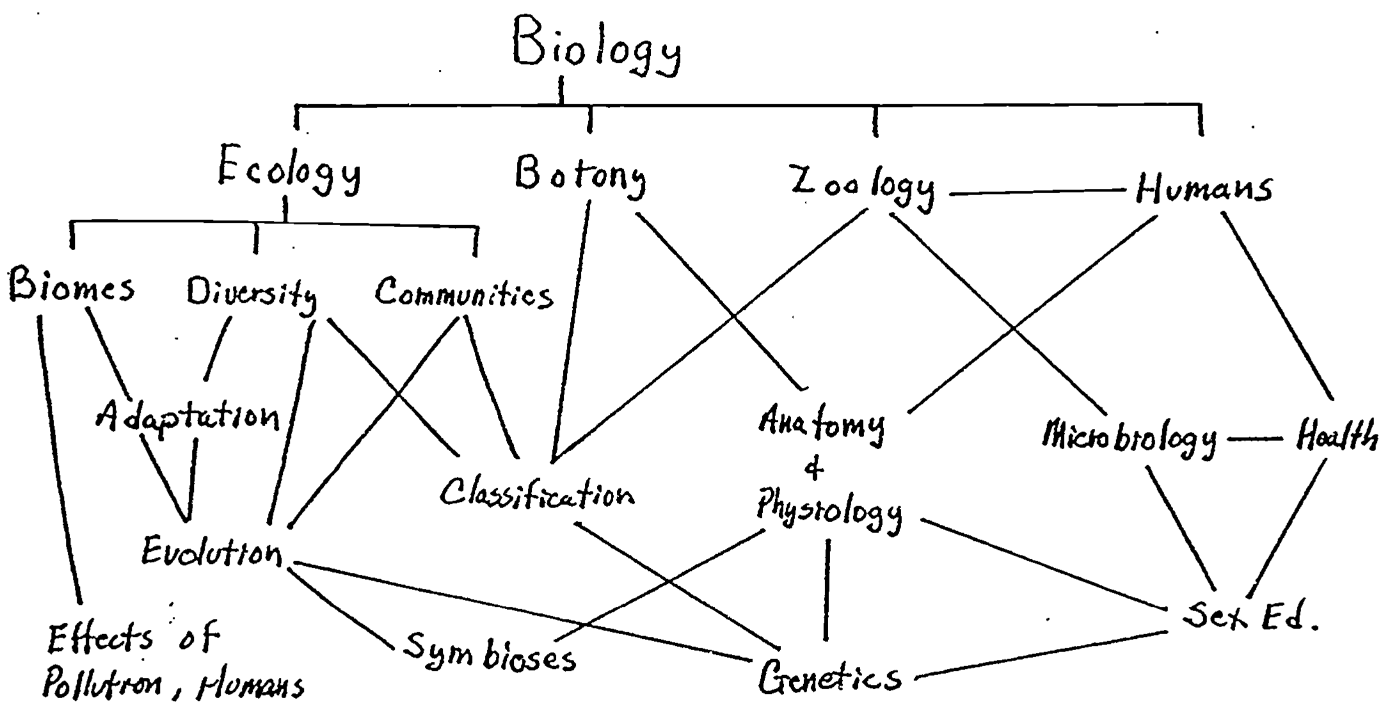

Figure 3. Web-like format for subject matter structure.

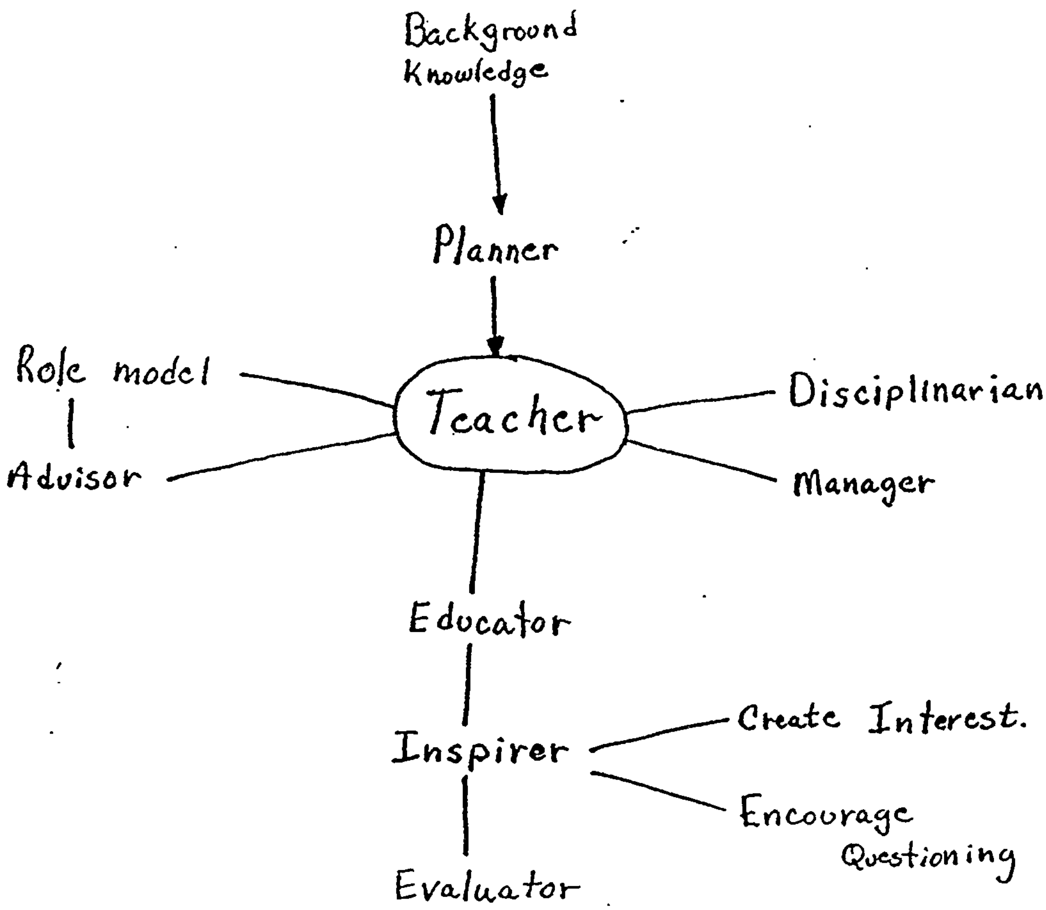

Figure 4. Temporal sequence format for pedagogy structure.

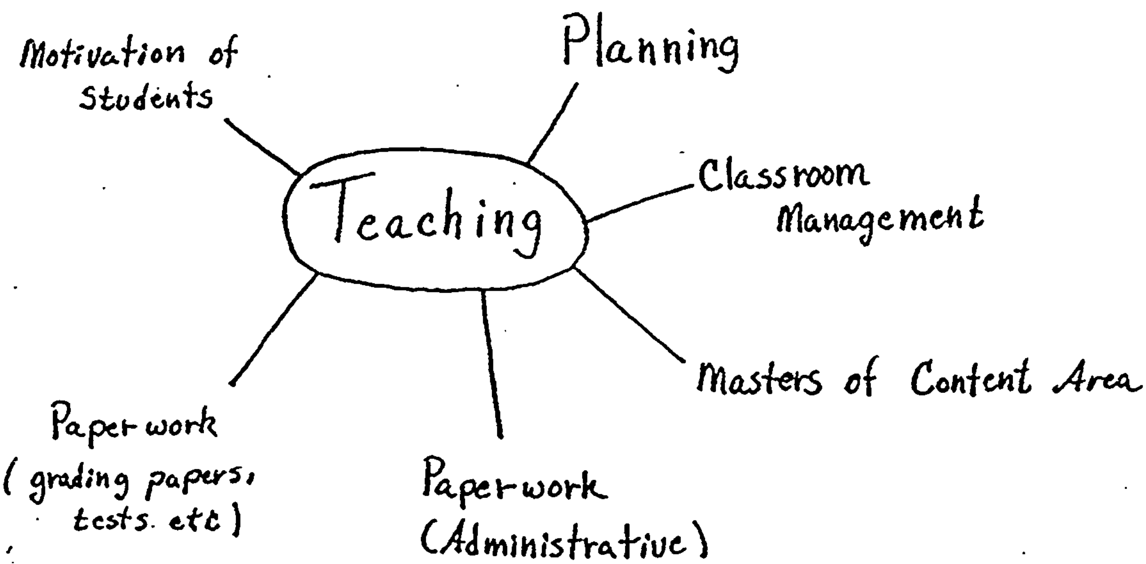

Figure 5. Discrete responsibilities format for pedagogy structure.

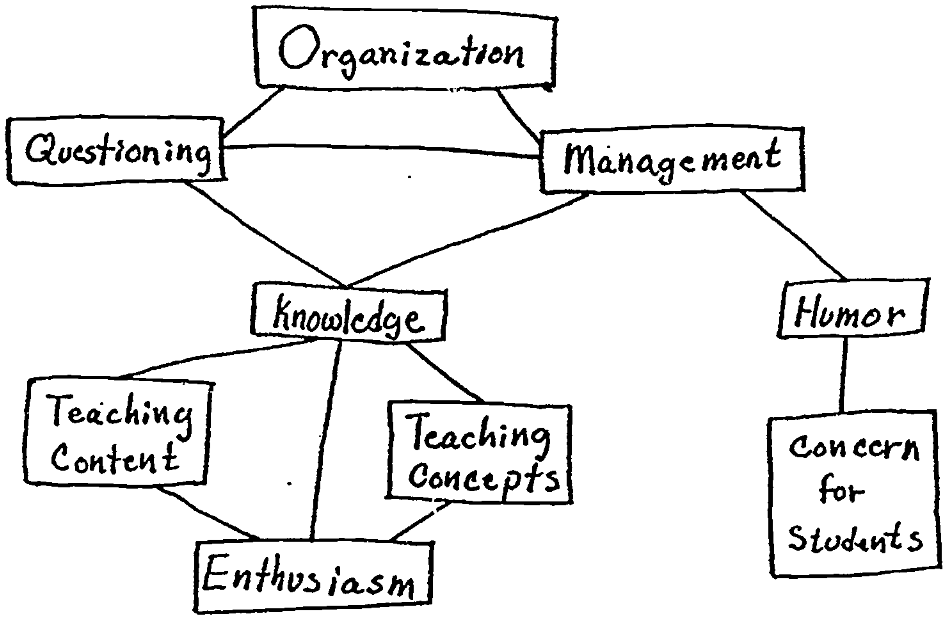

Figure 6. Web-like format for pedagogy structure.

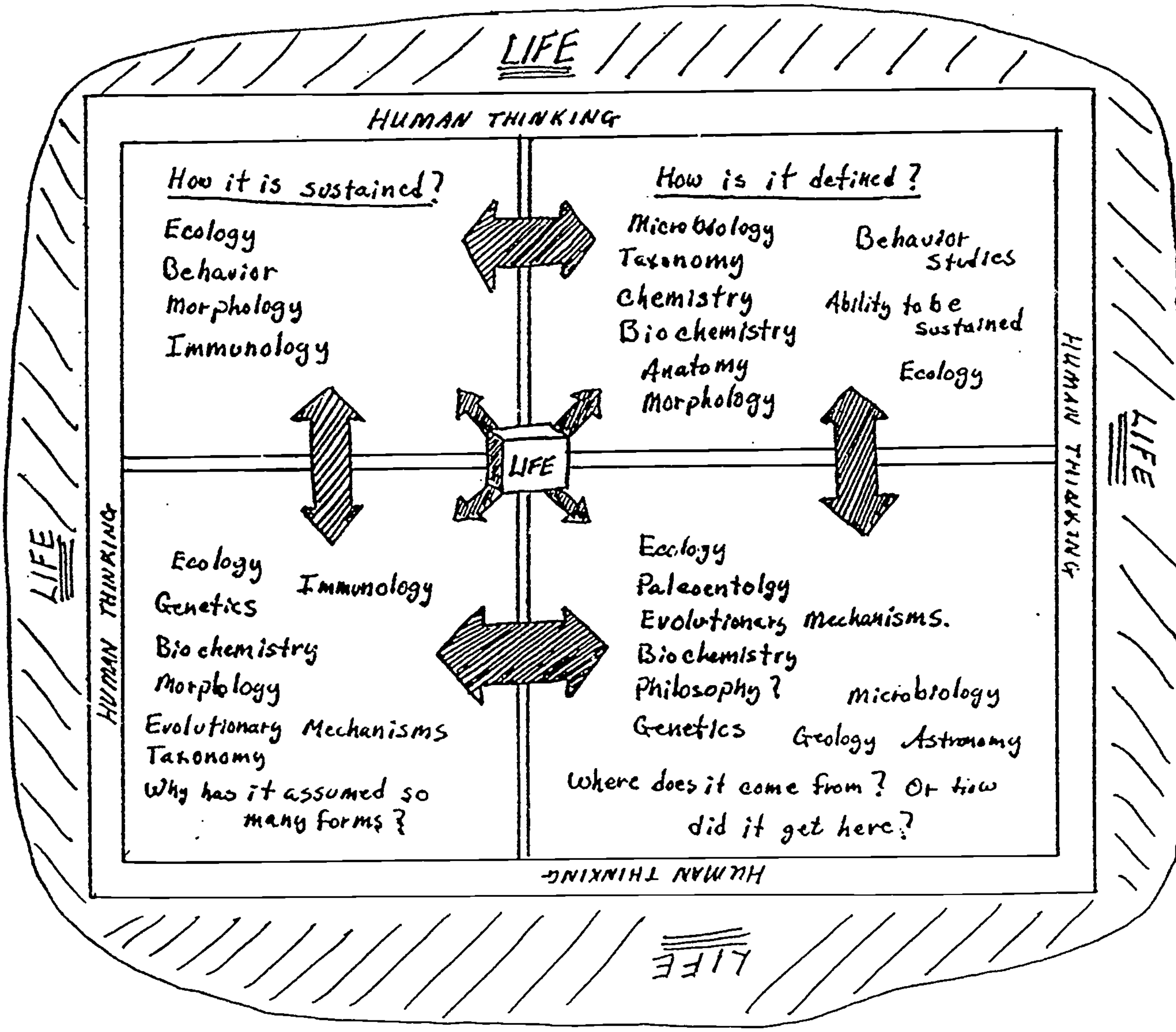

Figure 7. Integrated conception of subject matter upon completion of student teaching.

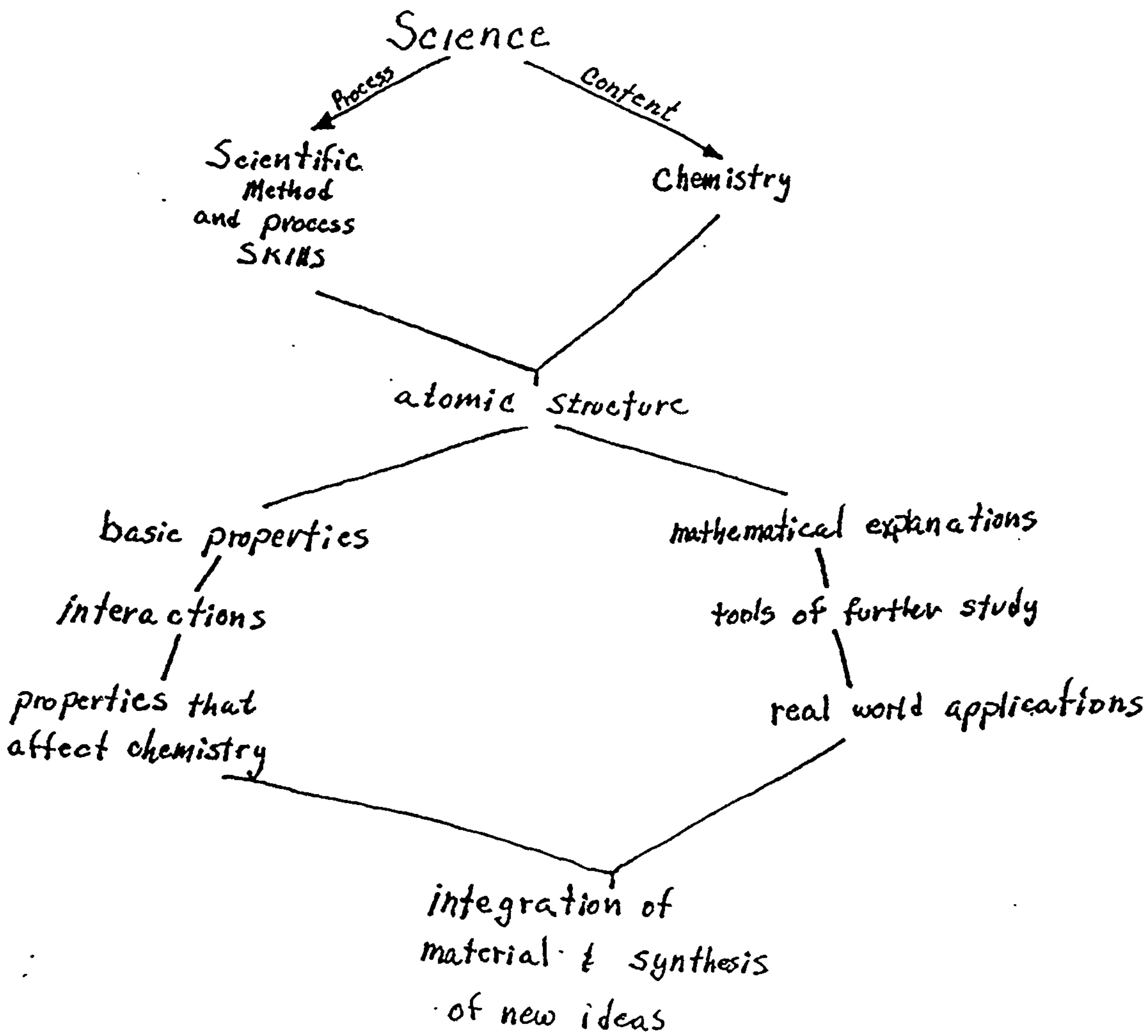

Figure 8. Simplification of subject matter structure, after student teaching, by individual who created Figure 2.

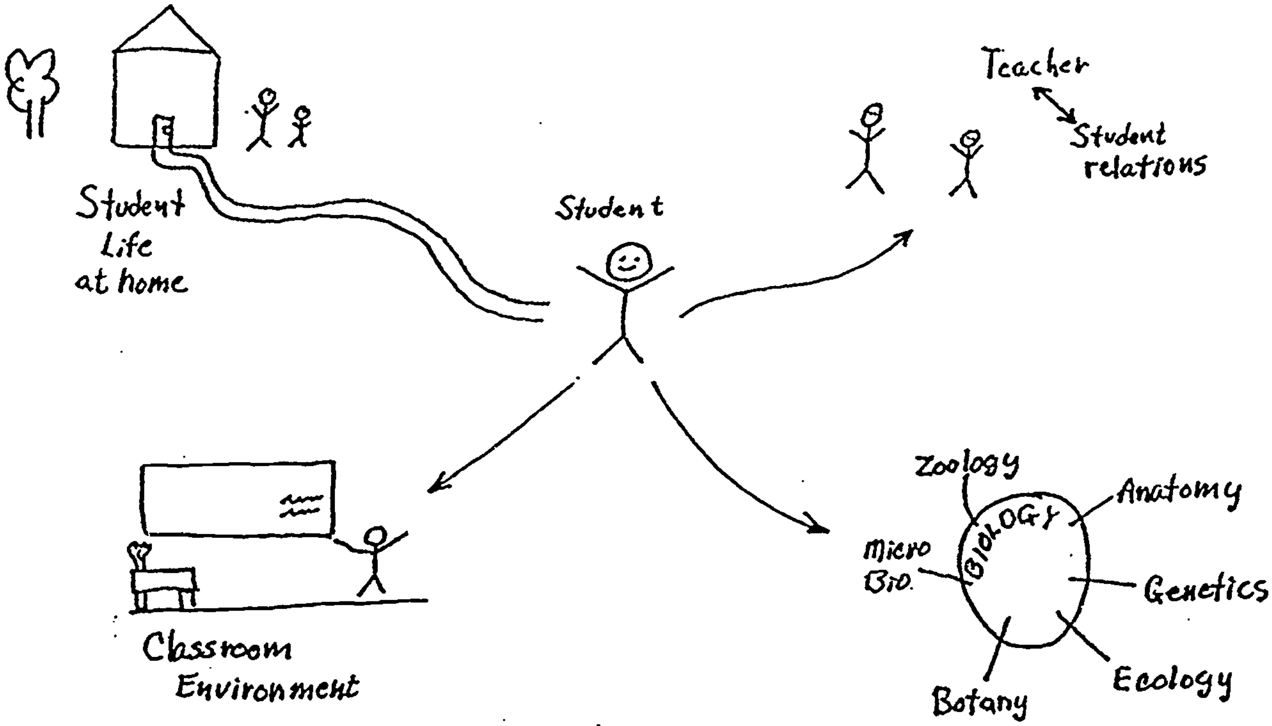

Figure 9. Representative diagram of student-centered pedagogy structure upon completion of student teaching.

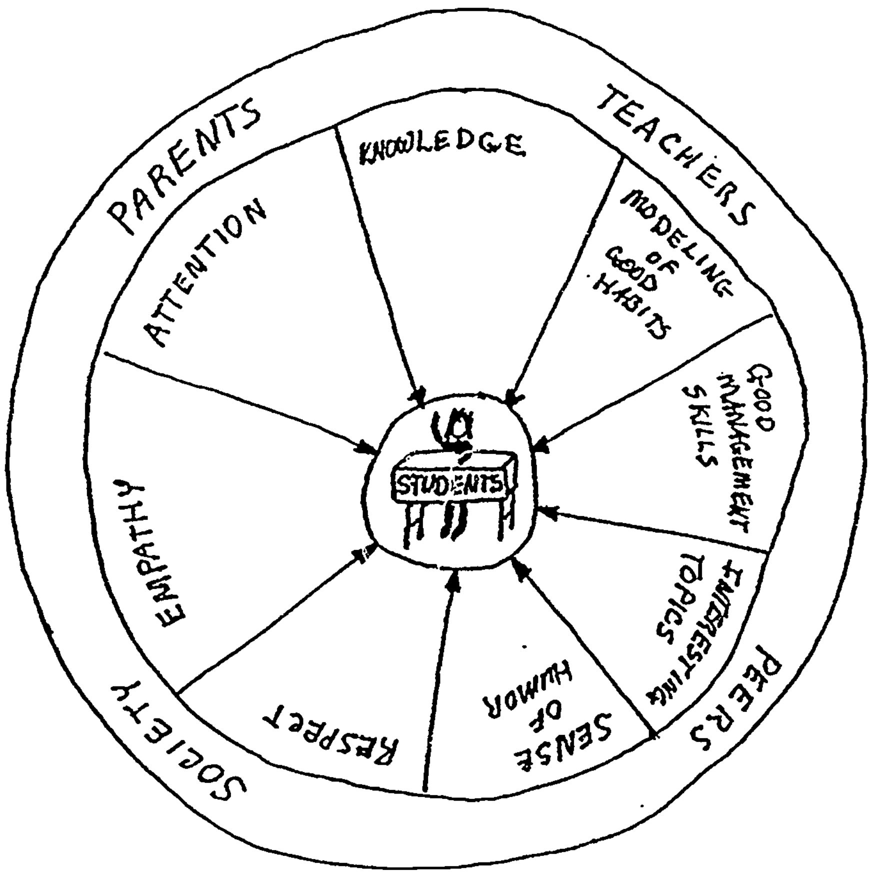

Figure 10. Representative diagram of student-centered pedagogy structure upon completion of student teaching.

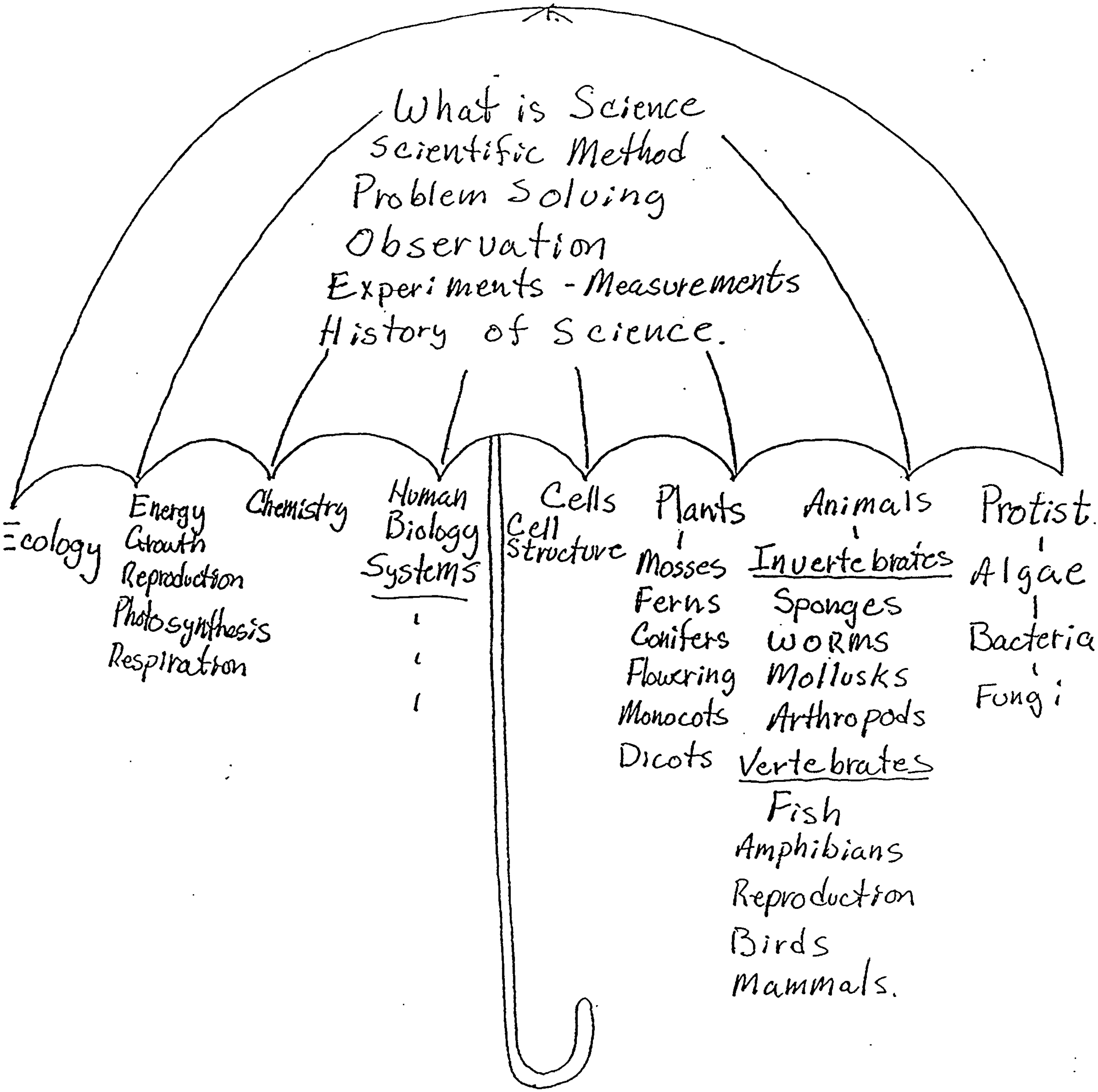

Figure 11. Subject matter structure with nature/history of science as an integrative curriculum theme.

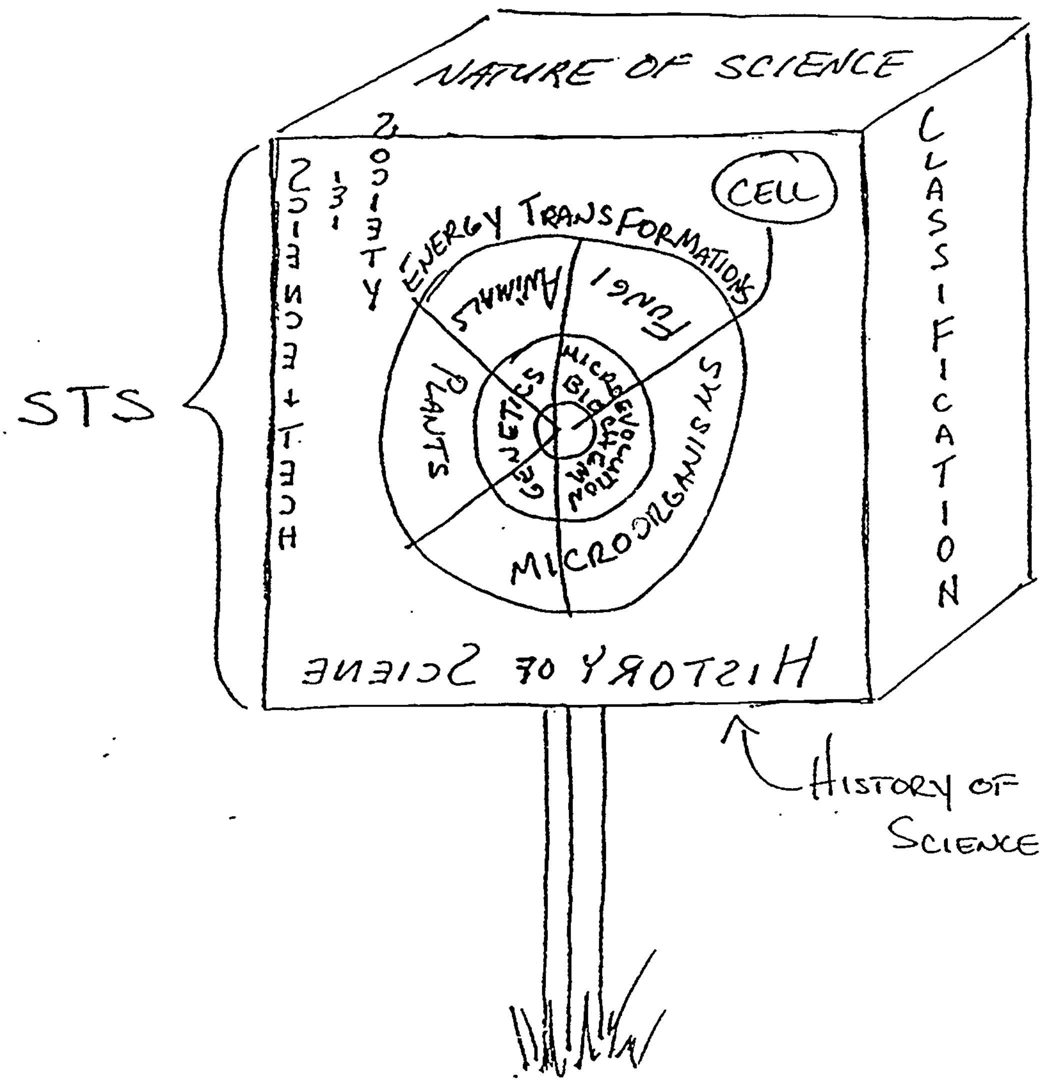

Figure 12. Subject matter structure with nature/history of science and science-technology-society as integrative curriculum themes.