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Evolutionary theory is the central and unifying theme of the discipline of biology. Its broad explanatory power allows for the investigation of a wide range of intriguing biological questions and serves as an underlying framework of the discipline. Because of its explanatory and unifying powers, scientific and educational organizations have called for instruction in evolution to be commensurate with its station in biology (American Association for the Advancement of Science, 1989; National Association of Biology Teachers, 1997; National Academy of Sciences, 1998; National Research Council, 1985; National Science Teachers Association, 1997). Results from several studies, however, suggest that instruction in evolutionary biology at the high school level has been absent, cursory, or fraught with misinformation (Eglin 1983; Johnson 1986; Roelfs 1987; Shankar & Skoog 1993).

The factors contributing to the current state of instruction in evolutionary biology have proven to be manifold. Historically, restrictive board of education policies; opposition from religious groups, school administrators, and community members; and inadequate textbook coverage have contributed to the de-emphasis of evolution in the high school biology curriculum (Eglin 1983; Roelfs 1987; Shankar 1990; Skoog 1970; Tatina 1989; Troost 1967; Zimmerman 1987). Yet there may be additional, perhaps more fundamental, factors that impact the teaching and learning of this important concept–factors concerning the biology teachers themselves.

Research has revealed that teachers' attitudes and views about subject matter can impact their curricular and instructional decisions (Carlesen 1991; Grossman 1989; Hashweh 1987; Shulman 1986; Wilson, Shulman & Richert 1987). Thus, a biology teacher's acceptance or rejection of evolutionary theory as a scientifically valid explanation is potentially important to the place that evolution takes in the biology curriculum. Additionally, student knowledge structures have been found to approximate those of their teachers (Bates 1976; Diekhoff 1983). Thus, a teacher's conception and knowledge structure of evolution may impact student understanding of this powerful and unifying idea.

While several studies have documented teacher opinions and attitudes concerning the evolution-creation controversy (Affanato 1986; Eglin 1983; Ellis 1983; Osif 1997; Van Koevering & Stiehl 1989), little research has been conducted to determine what teachers' conceptions of evolutionary theory actually are. The present study was designed to explore the conceptions and knowledge structures of evolution held by teachers with varying levels of acceptance of evolutionary theory. Associations between teacher acceptance of evolution and teacher academic background in evolution were also explored.

To determine teachers' conceptions of evolutionary theory, the technique of concept mapping was utilized. Developed by Novak (1984), concept mapping

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is a graphic technique of depicting relationships among concepts in a given domain. A concept map is a graph consisting of nodes and labeled lines. The nodes correspond to important concepts in the domain. Such concepts are typically represented inside a circle or ellipse. The lines between the nodes denote relationships between a pair of concepts. Descriptive words placed on the line indicate how the two concepts are related.

As individuals graphically represent and describe the relationships among concepts, they construct a visual representation of their cognitive structure of a domain. Research on the use of concept mapping as an evaluation tool in science education suggests that it is an effective, reliable and valid research tool for elucidating cognitive structures (Arnaudin & Mintzes 1985; Beyerbach 1986; Pendley, Bertz & Novak 1994; Shymansky et al. 1993; Wallace & Mintzes 1990).

Methods

To answer the questions posed in this study, a supplied response survey and a concept mapping activity were mailed to 989 Indiana public high school biology teachers at the school where they taught. The survey included items about their teaching of evolution and academic background (Appendix A). The concept mapping activity included a brief description of concept mapping as a technique and an example of a concept map. A total of 552 (56%) teachers completed the survey items and 235 (24%) teachers also completed the concept mapping activity.

The teachers' responses to the survey items were tabulated and their concept maps were evaluated. Concept mapping techniques vary widely. Perhaps the most significant variation is whether or not individual concept terms are supplied, or if they must be generated by the respondent. For this study, a mapping activity in which the teachers generated the concepts to be mapped was utilized. It was reasoned that this particular form of concept mapping would be less subject to researcher influence of data produced by the a-priori selection of concepts. Thus, it was expected that the maps generated would more accurately represent the teachers' knowledge structure than if the concepts were supplied by the researchers.

The maps were not numerically scored. Rather, they were analyzed for trends and used to gain an overall impression of the teachers' conceptual framework of evolution. The maps were grouped into the categories of 'NonAcceptance,' 'Undecided' and 'Acceptance' based on teacher response to item 6 of the survey which queries, "Do you accept evolutionary theory to be a scientifically valid explanation of the state of living organisms of the present and past?" Comparison of concept maps between groups provided a means for determining differences in knowledge structures of evolutionary theory between teachers who did not accept, were undecided about, or accepted the scientific validity of evolutionary theory.

Results

Survey Items & Associations

Teacher response to the survey items generated data relating to teachers' academic background (credit hours in biology, coursework in evolution, coursework in the nature/philosophy of science), teaching of evolution (number of days, role in the curriculum), and their acceptance of evolution. The results of teacher responses are summarized in Table 1.

Chi-square analysis reveals significant associations between teacher acceptance of evolutionary theory and overall number of credit hours in biology (Table 2), completion of a course in evolution (Table 3), and completion of a course in the nature/philosophy of science (Table 4). The distribution of the data reveals a distinct pattern of increased teacher acceptance of evolutionary theory with increased subject matter preparation.

A third (33%) of teachers indicated that they spend fewer than three days on the topic of evolution. Forty-three percent of teachers characterized their teaching of the topic as "Avoidance" or "Briefly mentioned." A significant association between teacher acceptance of evolutionary theory and the amount of time devoted to evolution in the school year was observed (Table 5). Analysis of the data reveals a strong trend of increased time devoted to the topic of evolution with increased teacher acceptance of evolutionary theory.

Concept Maps

The purpose of the concept mapping activity was to provide an open-ended method for teachers to communicate their conceptions and knowledge structures of evolution. The concept maps were divided into the groups of 'NonAcceptance,' 'Undecided' and 'Acceptance' based on teacher response to Item 6 of the survey.

The percentage of teachers who completed the concept mapping activity was proportionately consistent with the overall percentage of teachers who participated in the study: Teachers who noted that they accepted evolution comprised 67% of the teachers participating

Table 1.
Teacher response to survey items about their academic background and the teaching of evolution.

Question	Percent Response
1. How many credit-hours do you have in the biological sciences (Graduate & Undergraduate)?	
A. 12 or less	1
B. 13-24	13
C. 25-40	36
D. over 40	49
2. Have you had a specific course in evolution?	
A. yes	31
B. no	69
3. Have you had a specific course in the nature/philosophy of science?	
A. yes	33
B. no	67
4. How much time in the school year do you devote to the topic of evolution?	
A. 0-3 days	34
B. 4-7 days	27
C. 8-14 days	23
D. 15 or more days	17
5. Which expression best characterizes your teaching of evolutionary theory?	
A. avoidance	7
B. briefly mentioned	36
C. studied in depth as a distinct content area	25
D. the unifying theme for the content of the course	33
6. Do you accept evolutionary theory to be a scientifically valid explanation of the state of living organisms of the present and past?	
A. yes	67
B. no	19
C. undecided	14

in the study and 59% of the teachers completing concept maps. Teachers who were undecided about evolution represented 27% of the teachers participating in the study and 19% of those completing concept maps. Teachers who did not accept evolution represented 19% of the teachers participating in the study and 14% who completed concept maps.

Table 2.
Teacher credit hours earned in biology versus teacher acceptance of evolutionary theory.

Credit hours in Biology	Acceptance		
	No	Undecided	Yes
Less than 24	52	21	10
25-40	45	67	86
Over 40	38	50	183

chi-square = 114.4 df = 4 Level of Significance < 0.001

Table 3.
Teacher completion of a course in evolution versus teacher acceptance of evolutionary theory.

Course in Evolution	Acceptance		
	No	Undecided	Yes
Yes	16	17	139
No	97	50	232

chi-square = 26.9 df = 2 Level of Significance < 0.001

Table 4.
Teacher completion of a course in the nature of science versus teacher acceptance of evolutionary theory.

Course in Nature of Science	Acceptance		
	No	Undecided	Yes
Yes	19	14	150
No	94	53	222

chi-square = 26.7 df = 2 Level of Significance < 0.001

Table 5.
Allocation of instructional time to evolution versus teacher acceptance of evolutionary theory.

Days Devoted to Evolution	Acceptance		
	No	Undecided	Yes
0-3	78	32	75
4-7	29	19	103
8-14	3	13	108
15 or more	3	3	85

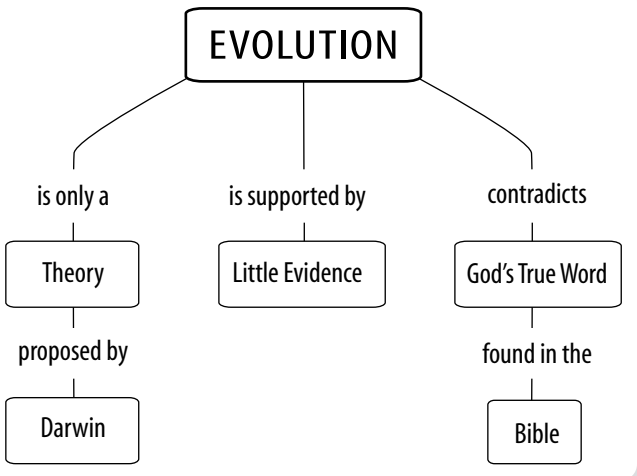
chi-square = 121.6 df = 6 Level of Significance < 0.001

NonAcceptance Group

Teachers of the NonAcceptance Group generated concept maps that averaged 5.7 concepts (nodes) and 4.8 relationships (linkages) per map. In general, maps of this group are characterized by the inclusion of concepts concerning the scientific status of evolutionary theory, available evidence supporting evolution, the historical aspects of the development of evolutionary theory, and creationism.

Specifically, teachers of this group tended to depict evolution as an explanation of low scientific status, as a vast majority of these teachers characterized evolution as "only a theory" or "only a hypothesis," suggesting that they hold misconceptions about the status of scientific explanations. Further, the characterization of evolution as being supported by "little evidence" was common among teachers of this group, suggesting that these teachers differ markedly with the scientific community with respect to the weight and significance of evidence supporting evolutionary theory. Historical aspects of the development of evolutionary theory was a common theme in the maps of this group with "Darwin" and "Lamarck" frequently cited as contributors to the theory. Also characteristic of this group's maps was the inclusion of religious concepts, as a number of teachers included the concept of "creationism" in their maps. Commonly, creationism was credited as the definitive explanation of life and its characteristics, as opposed to evolutionary theory. An example of a typical concept map of this group is found in Figure 1.

Figure 1.
Representative concept map of NonAcceptance Group.



Maps of this group of teachers tended to be dismissive of evolutionary theory and lacking in detail about the mechanisms of evolution. Detail included about evolutionary theory was limited to the historical aspects of its development. Further, the relationships formed between concepts suggest that these teachers have a poor understanding of the status of scientific theories. The inclusion of distinctly nonscientific, religious concepts in the maps suggests an interference in the understanding and acceptance of evolutionary theory due to personal religious beliefs. Overall, the concept maps revealed this group of teachers to have a knowledge structure of evolution that is spartan and superficial with respect to the process of evolution and potentially confounded by religious views.

Undecided Group

Teachers of the Undecided Group generated maps that averaged 10 concepts and 12 relationships per map. Maps of this group tended to include both scientific and religious concepts. "Creationism" and "evolution" were commonly represented as ideas of equivalent validity and support. Similar to the NonAcceptance Group, the characterization of evolution as "only a theory" that it is "weakly supported" was prevalent among this group. However, teachers did tend to note some detail about the evolutionary process. The concept of "natural selection" as a mechanism was common, as was the concept of "speciation."

A number of teachers in this group included the idea of theistic evolution in their maps. The term "theistic evolution" was utilized by some teachers, while others formed relationships between the concepts of "evolution" and "God," linking them with phrases "guided by" or "directed by." An example of a typical map from this group is found in Figure 2.

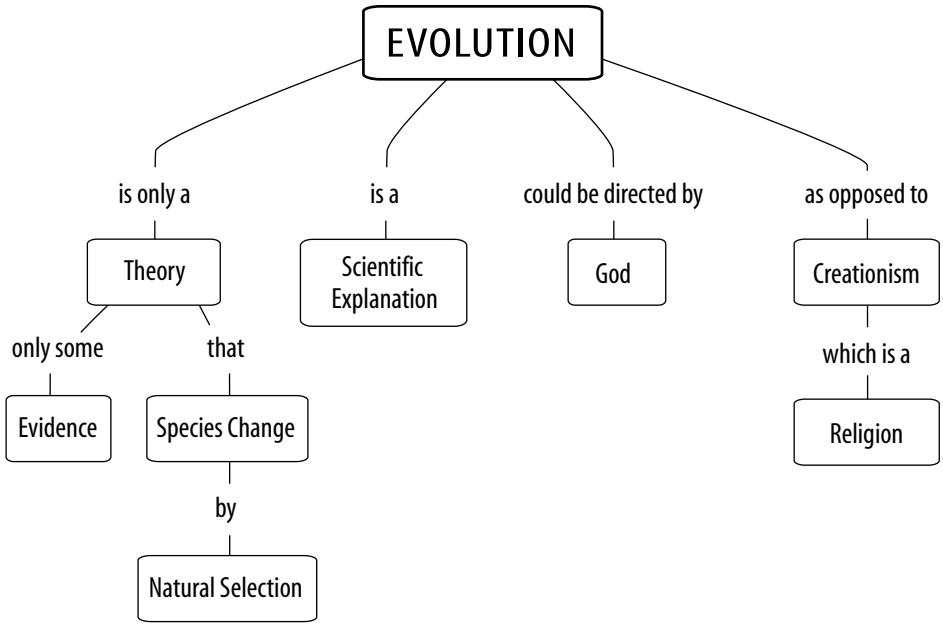
Teachers of this group appear to have a knowledge structure dominated by aspects of the creation-evolution controversy. Explanations of life produced by two distinctly different ways of knowing—science and religion—appear to them to be of equal validity. They seem uncertain as to which explanation to subscribe to, or if the two explanations are mutually exclusive to one another.

Acceptance Group

Teachers of the Acceptance Group generated the most elaborate maps, averaging 14 concepts and 16 relationships per map. Maps of this group are characterized by the recognition of evolutionary mechanisms with considerable detail of the process of natural selection being supplied.

The concepts of "genetic variation," "over-reproduction" and "competition for limited resources" were commonly included in the maps of this group. The

Figure 2.
Representative concept map of Undecided Group.



potential for evolution to lead to the origin of new species was also a commonly recognized idea by teachers of this group, as the concept of "speciation" was included in many of the maps.

That evolution is a well-supported scientific explanation was a frequently included idea in the maps of this group. Further, teachers of this group tended to cite the distinct lines of evidence that support evolutionary theory. The recognition of evolutionary mechanisms in addition to natural selection was another distinguishing feature of the maps of this group of teachers.

Maps of the Acceptance Group were the most expansive and detailed of the three groups. The concept maps revealed this group of teachers to have knowledge structures that are distinguished from the knowledge structures of the other groups by being mechanistic and evidential in nature and generally devoid of religious concepts. An example of a typical concept map from this group is found in Figure 3.

Discussion & Conclusions

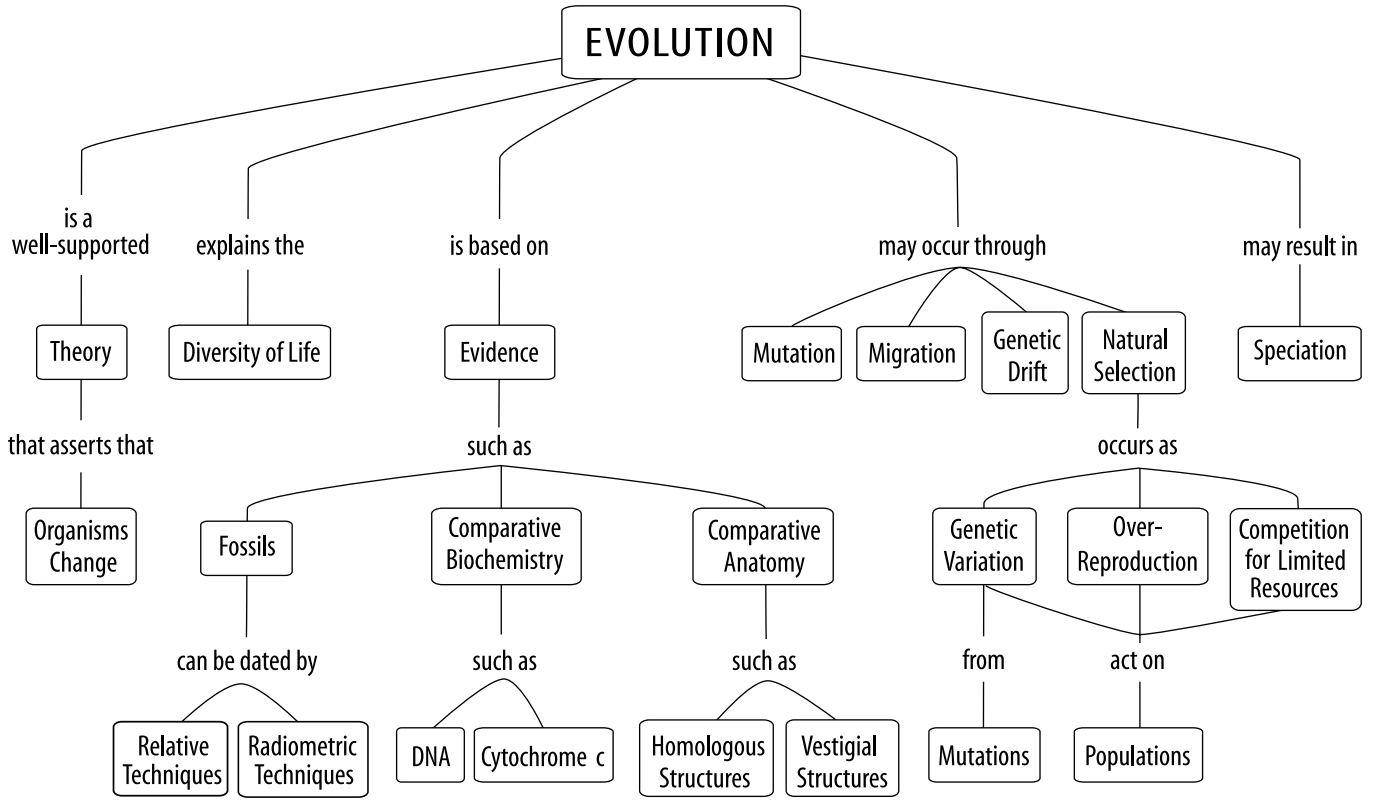
As teachers are critical determiners of the quality of classroom instruction, it is vital that they be capable of making professionally responsible instructional and curricular decisions. For biology teachers to make such decisions about evolution, they must possess a thorough knowledge of evolutionary theory and its powerful role in the discipline of biology. Additionally, they must be cognizant of how, in the sciences, knowledge is generated, and the nature of science as a way of knowing.

The data from this study suggest that the topic of evolution does not receive appropriate emphasis in the high school biology curriculum. Despite the fact that Indiana has developed state standards for the teaching of evolution that are recognized as being excellent (Lerner 2000), 43% of the teachers surveyed avoid or only briefly mention evolution in their biology classroom. Clearly, the status of evolutionary theory as the central and unifying theme of biology is not reflected in the teaching of a disturbing number of Indiana public high school biology teachers. Given the ability of evolutionary theory to bring meaning to the vast array of traits, behaviors and characteristics of life and to promote understanding of biology as a discipline, the overall quality of instruction in a significant number of Indiana public high school biology classes is problematic.

Teacher academic background and personal religious beliefs may be a contributing factor to teacher acceptance of evolution as well as the teaching of evolution. Teachers who lack an understanding of evolution and the nature of science may be incapable of making informed decisions of acceptance or rejection of evolutionary theory, as well as professionally responsible curricular and instructional decisions regarding the teaching of evolution. Further, teachers who don't have a thorough understanding of the nature of science may not be able to differentiate between the scientific validity of evolution and strongly held religious views—a condition that may confound their teaching of evolution.

What can be done to improve the teaching of evolution? Given the profound role of biology teachers in determining the quality of instruction, the strong associations between teachers' academic background and their teaching of evolution may inform efforts to improve evolutionary biology education. The results of this study and others suggest that a critical evaluation and modification of the preparatory programs for biology teachers could serve to improve the teaching of evolution in high schools.

Figure 3.
Representative concept map of Acceptance Group.



It may be that teachers aren't comfortable teaching evolution because it is controversial and they don't feel they have a sufficient understanding of evolutionary principles and the compelling nature and scientific validity of the supporting evidence. The fostering of prospective biology teachers' understanding of evolution and the nature of science should be a priority of biology departments. Specific courses in evolution and the nature of science should be a requirement of the subject matter preparations of biology teachers, yet many biology departments do not offer or require such courses.

Science methods courses must promote prospective biology teachers' appreciation of their professional responsibility to make curricular and instructional decisions that result in the classes they teach being reflective of the disciple of biology. They must also place special emphasis on promoting effective practices for teaching evolution, the most fundamental idea of the discipline. Professional development opportunities that promote an understanding of evolution and the nature of science, as well as effective teaching practices, must additionally be made available for biology teachers already in the classroom.

While many factors have been identified as negatively impacting the teaching of evolution in high schools, many aspects of the teaching of evolution are still unknown. Elucidating how evolution is taught (explicit vs. evasive), the methods that are utilized in teaching evolution (teacher centered vs. student centered) and the focus of instruction (historical aspects vs. biological significance) could further contribute to the improvement of the preparation of biology teachers and the teaching of evolution.

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