Understanding Students' Explanations of Biological Phenomena: Conceptual Frameworks or P-Prims?

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ABSTRACT: This study explores two differing perspectives of the nature of students' biological knowledge structures, conceptual frameworks, and p-prims. Students from four grade levels and from three regions of the United States were asked to explain a variety of biological phenomena. Students' responses to the interview probes were analyzed to describe 1) patterns in the nature of students' explanations across grade levels and interview probes, and 2) the consistency of students' explanations across individual interview probes and across the range of probes. The results were interpreted from both perspectives of knowledge structures. While definitive assertions supporting either perspective could not be made, each hypothesis was explored. Although the more prevalent description of student conceptions within a broader conceptual framework could not be discounted, the p-prim of *need as a rationale for change* was also found to offer a useful description of knowledge frameworks for this content area. The difficulties endemic to the use of biology for the study of basic knowledge structures are also discussed. © 2001 John Wiley & Sons, Inc. *Sci Ed* **85:**328–348, 2001.

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INTRODUCTION

What does it mean to learn? In an intentionally broad and ambiguous sense, learning can be described as the action of applying and reorganizing knowledge in order to achieve a better understanding of the world. Notice that if the definition of learning is sufficiently broad, such as this, it can make no claims about how knowledge is structured within the individual, how an individual seeks to apply this knowledge to understand a specific situation, nor how this knowledge may be refined or restructured during instances of learning. Hence, it may be appealing to researchers from many theoretical orientations. However, in order to be useful, a description of learning must incorporate a description of the structure of a learner's knowledge.

One of the most fundamental elements of a useful description of learning lies in the description of the structure of knowledge. Linder (1993) described the most pervasive model of learning currently applied in science education research as a mental-model–based perspective. Within this model, a learner's conceptions are thought to exist inside the learner's head in conjunction with other related conceptions to form a large and complex *conceptual framework* for a topic (Smith, Blakeslee, & Anderson, 1993). Within this mental-model perspective, learners are thought to apply this relatively stable cognitive structure to understand some aspect of the physical world. Extending this notion, some researchers conceive of learners' knowledge as theory-like. Use of the term *theory* to describe students' conceptions reflects researchers' expectations of these structures to be fundamentally coherent, systematic, and consistent (Carey, 1985; Nersessian & Resnick, 1989). Using the mental-model based perspective, learning is often characterized as a series of cognitive restructurings in which a learner's conceptual framework undergoes structural modifications or revisions based upon new experiences, information, or concepts the learner encounters (Mintzes, Wandersee, & Novak, 1998; Strike & Posner, 1992).

An alternative to the mental-model or theory perspective of students' understanding is characterized by diSessa's (1993) description of "knowledge in pieces." Using this perspective, students' explanations of the physical world are not understood to be a reflection of coherent theories or systematic frameworks, but instead are seen as spontaneous constructions. These constructions result from the activation of fundamental knowledge elements that diSessa (1993) has described as phenomenological primitives (p-prims). diSessa's p-prims, much like Brown's (1995) core intuitions, are understood to be atomistic knowledge structures that are automatically and unconsciously activated by the learner in response to a particular situation. These p-prims are the basis on which a learner makes sense of a situation; the lens through which a learner's interpretation emerges. Thus, the learner may construct a number of explanations in response to a single phenomenon, based upon the p-prims invoked and the means through which they reason based on these p-prims. As Hammer (1996) and Smith, diSessa, and Roschelle (1993/1994) argue, the alternative conception/conceptual framework orientation confuses such instances of emergent knowledge constructions with a reflection of stable conceptual frameworks.

P-prims result from the learner's experience in the world (hence, "phenomenological" primitives). Once p-prims are established on the phenomenological level, they subsequently become established and internalized and become the vocabulary invoked to make sense of later experiences. This sensemaking process occurs at a very deep cognitive level, explaining why the learner is largely unaware of the basis of their understanding. P-prims play an important role in allowing the learner to interpret their experience, but they themselves are not explained within the learner's own knowledge structure. Instead, p-prims are fundamental pieces of knowledge that are understood by the learner to need no explanation, as they operate as implicit presuppositions of how the physical world works (Ueno, 1993). In diSessa's (1993) words, p-prims allow students to understand that "something happens because that's the way things are." (p. 112).

The vast majority of the past research focusing on student conceptions has focused on students' understanding of physical phenomena (Brown, 1995; Chi, 1992; diSessa, 1993; Hammer, 1996; Hewson & Hewson, 1992; Schwedes & Schmidt, 1992). Little work actually focusing on the nature of knowledge structures—that is, actually investigating the nature of students' knowledge instead of operating out of a conceptual framework orientation—has been undertaken in the discipline of biology. Abimbola (1988) suggests that this paucity of work may be due to the relative difficulty of grouping students' biological conceptions under a system of laws and overriding theories as is possible in the physical sciences. However, emerging recognition of the situated nature of student learning and the recognition of the possibility of a myriad of learning pathways requires that investigations of learning be conducted in a variety of conceptual areas. Thus, the present work focuses on understanding students' explanations of biological phenomena.

Research Questions

The goal of the research presented here was to explore the patterns that characterize students' explanations of biological phenomena, and through this exploration to examine the basis of students' biological knowledge structures. These broad foci were addressed through the following, more specific, research questions:

1. What are the various categories of reasoning employed in students' explanations of biological phenomena? Does the reasoning vary across grade levels of students?
2. Other than the categories of reasoning, what other patterns can be used to characterize students' explanations? Do these patterns vary across grade levels of students?
3. Given the findings to the previous questions, what theoretical lens allows for the most useful understanding of the basis and production of students' biological explanations, conceptual frameworks, or p-prim perspectives?

METHODS

Research Participants

Students were selected from three different geographical regions of the United States: Durham, New Hampshire; Baton Rouge, Louisiana; and Salt Lake City, Utah. A second-, fifth-, eighth-, and twelfth-grade classroom from each locality was observed at least 1 week prior to the beginning of the interviews in order to describe the classroom context and to allow the researcher to establish some degree of familiarity with the student participants. The eighth- and twelfth-grade students were selected from science classrooms. Because the second and fifth graders from each site experienced integrated instruction, a classroom in which science was taught during some period in the week was selected. The selection of second, fifth, eighth, and twelfth grades answered the American Association for the Advancement of Science's (1993) call for research to inform curricular decisions at specific ages. Three study sites from different geographical regions were employed in order to provide a more generalizable portrait of what learners know at various points in their academic careers. The interviews were conducted in the final weeks of the school year in each of the study sites.

In order to obtain a comparable spread of ability in each age group in each of the classrooms teachers were asked to categorize students into high, average, and low achievement groups based on their past science performance. (While this was possible for students in the eighth and twelfth grades, students from the lower grades often had to be categorized based on the teachers' assessment of their overall school achievement.) Drawing from the pool of potential voluntary participants, the authors selected students from each group for participation. These selections were made in order to reflect the diversity of possible student achievement in science. The final selection of eight students from each classroom also took into account students' degree of comfort with the researcher–research process and the gender and ethnic makeup of the entire class to adequately reflect the demographics of the students in the class.

A total of 96 student volunteers (8 students from each of 4 grades at 3 localities) were involved in the interview process. There was roughly equal participation by students of both genders. The majority (90%) of the students were of European ancestry, 6% were African American, 3% were American Indians, with one Asian-American student.

The first three authors were responsible for data collection and each were involved in the analysis of the data. The fourth author assisted in data analysis.

Interviews

Each student participant was interviewed individually. During this interview, the student was presented a series of graphics depicting natural phenomena. This series included: 1) a bean plant growing toward a sunny window, 2) a ptarmigan in summer brown pelage and winter white pelage, 3) a group of birds in a flying V formation, and 4) a cactus with very thick, dense, thorny leaves. After observing each graphic, the student was asked a series of questions:

1. What do you see in this picture?
2. How does this (i.e., migration, growth, and color change) happen?
3. Would this (i.e., migration, growth, and color change) be a good thing for the organism involved? How?
4. Did the organism involved in this phenomena (i.e., plant, bird, or cactus) think about this change?

Although this was the formal interview protocol, the actual form of the questions asked was dependent on student responses. Additional questions were posed to ascertain, as far as possible, the students' meaning for specific terms and phrases. Because the purpose of this study was to describe students' understanding, the interviewers made every attempt to avoid using terminology that would prompt the use of specific ideas. Scientific terminology was used only if initially introduced by the student. The interviews lasted approximately 15–20 min each.

Data Collection

All interviews were audiotaped and videotaped. The audiotapes formed the primary basis of transcription, with additional comments (e.g., students' actions or facial gestures) taken from the videotapes being made on the final transcripts. Researchers' field notes were used as an additional data source.

Data Analysis

For the purposes of the research reported here, only students' explanations offered in response to the question of *how* something occurred were coded. (The discussion of the other data can be found in Abrams, Southerland, & Cummins (in press). Students' explanations of questions concerning *how* something occurred were assigned to one of seven reasoning categories based on a coding scheme developed by the researchers after initial interview analysis and also based on the prior work of Tamir and Zohar (1991). The reasoning categories included:

1. **Anthropomorphic.** An explanation based on the use of human attributes as the causal agent for changes seen in nonhuman organisms. ("The ducks know it's turning cold so they decide to fly down south.")
2. **Teleological.** An explanation in which the ends are considered as the agent in determining the nature of the phenomena (Clough & Wood-Robinson, 1985). ("The plant needs the sunlight, so it grows that way.")
3. **Mechanistic proximate.** An explanation in which a specific physical/biological agent is identified. Typically, such an explanation described the actions of just the individual and did not consider the entire group or population of organisms. ("The bird flips his feathers over and the white part shows.")
4. **Mechanistic ultimate.** An explanation in which a long-term (generally genetically based) agent is identified. Typically, such an explanation described the entire population of organisms and not just the actions of an individual. ("They [the ducks] fly south because of an instinct they inherited . . . from their parents.")
5. **Predetermined.** An explanation in which the agent is identified as a god, nature, or the agent is not clearly identified. ("The cactus has thorns 'cause it's made that way.")
6. **Don't know.**
7. **Blended.** An explanation that fulfilled the requirements of more than one category within the span of an individual response. ("They know once it starts to get cold [that] they need to go to warmer climate, and it's gone on from generation to generation.") In such instances, not only was this explanation categorized as blended, but the composite categories (anthropomorphic, teleological, and mechanistic ultimate) were also included in the final tallies.

Students' explanations in response to each *how* question were coded. For each interview prompt offered, several *how* questions may have been posed until the researcher was satisfied that she adequately understood the basis of each student's explanation. Therefore, each participant may have several explanations coded for any one interview prompt.

After three of the authors refined the categorization scheme, the reliability of their employment of this system was checked using a randomly selected series of 12 interview questions and responses. The reasoning categories to which each of three coders assigned these explanations were compared. A level of agreement between the three coders of over 95% was obtained for the question series.

After initial categorization, the analysis then proceeded to the second stage. Each of the three coders reported students' responses to each *how* question for each interview prompt. Then, instances in which the reasoning categories of students' explanations shifted in response to a number of questions about the prompt were tallied. The shifting tally differs from a blended category of response in that the explanation offered in the blended category considers causality indicated by the student within an individual response. An explanation was tallied as shifting if the category of reasoning changed through subsequent responses. Additionally, the explanations offered by a single individual were examined across each of the four prompts. Instances in which students' reasoning changed over the span of the four prompts were then tallied. A shift either within or across interview prompts was documented if the later explanations failed to contain aspects of the reasons initially offered or contained additional aspects to those initially offered.

In order to describe the tentative nature of students' responses, replies to each *how* question were tallied as being tentative if the students' explanations included phrases such as, "I don't know," "Maybe," and "I guess," only if the student went on to offer an explanation in addition to these comments. Note that instances in which students offered only an "I don't know" response but failed to continue in their explanation were not understood to represent a tentative responses and were not included in this tally.

RESULTS

Reasoning Categories

Overall, the proportion of students using a specific category of reasoning in their explanation was similar across study sites (see Table 1). (One exception to this pattern of similarity can be found in the twelfth graders' use of mechanistic ultimate responses, in which the group from New Hampshire was found to use this form of reasoning more frequently than similar students from the other two sites. This pattern will be discussed in

TABLE 1
Frequency Distribution of Students' Explanations of Biological Phenomena, Sorted by Site

	Reasoning Category	Totals By Site			Means Across Sites
		Louisiana	New Hampshire	Utah	
Second	Teleological	20	18	17	18.3
	Anthropomorphic	9	8	10	9.0
	MP	14	9	11	11.3
	MU	0	0	1	0.3
	Predetermined	7	8	10	8.3
	Blended	8	10	5	7.7
	Don't know	3	4	4	3.7
Fifth	Teleological	22	18	22	20.7
	Anthropomorphic	7	10	8	8.3
	MP	15	12	15	14.0
	MU	3	0	3	2.0
	Predetermined	8	13	9	10.0
	Blended	7	5	7	6.3
	Don't Know	4	6	2	4.0
Eighth	Teleological	25	20	22	22.3
	Anthropomorphic	7	10	13	10.0
	MP	7	9	8	8.0
	MU	4	3	6	4.3
	Predetermined	8	13	12	11.0
	Blended	10	6	6	7.3
	Don't Know	9	6	5	6.7
Twelfth	Teleological	18	23	22	21.0
	Anthropomorphic	8	13	8	9.7
	MP	14	11	14	13.0
	MU	14	25	10	16.3
	Predetermined	7	11	12	13.0
	Blended	9	11	15	11.7
	Don't Know	2	2	1	1.7

a subsequent section.) Due to the overall similarity in responses, the data from the three sites were lumped together for subsequent analyses.

Likewise, the proportion of students using a specific category of reasoning in their explanation was similar across grade levels. As Figure 1 shows, the most prevalent category in each of the four grade levels was the teleological response in which the ends of the situation are used as a causal agent in determining the means:

> **R** (Researcher): What's happening in this picture (of the bean plant)?
>
> **St** (Student): It's growing toward the mountains, where the sun is coming.
>
> **R:** Um, how would that happen?
>
> **St:** Because you (the plant) need(s) light to grow, so it grows that way. (Utah, fifth grade)
>
> **R:** This is a picture (birds flying in a V formation). What do you think that is?
>
> **St:** Let's see. Birds. Are they?
>
> **R:** They're supposed to be geese (. . .) flying South for the wintertime.
>
> **St:** Okay. That's helpful. (Laughter by both)
>
> **R:** How does that happen?
>
> **St:** It's also, well they go down there to protect themselves. They can't stay here, because they can't stay warm. They won't be warm. (Louisiana, twelfth grade)

In the excerpts shown previously, a plant is understood to grow toward the sun because it needs the light for food. In the second example, the need to stay warm is the cause of birds flying south for the winter.

Other, less frequent, reasoning categories were roughly equivalent to one another in

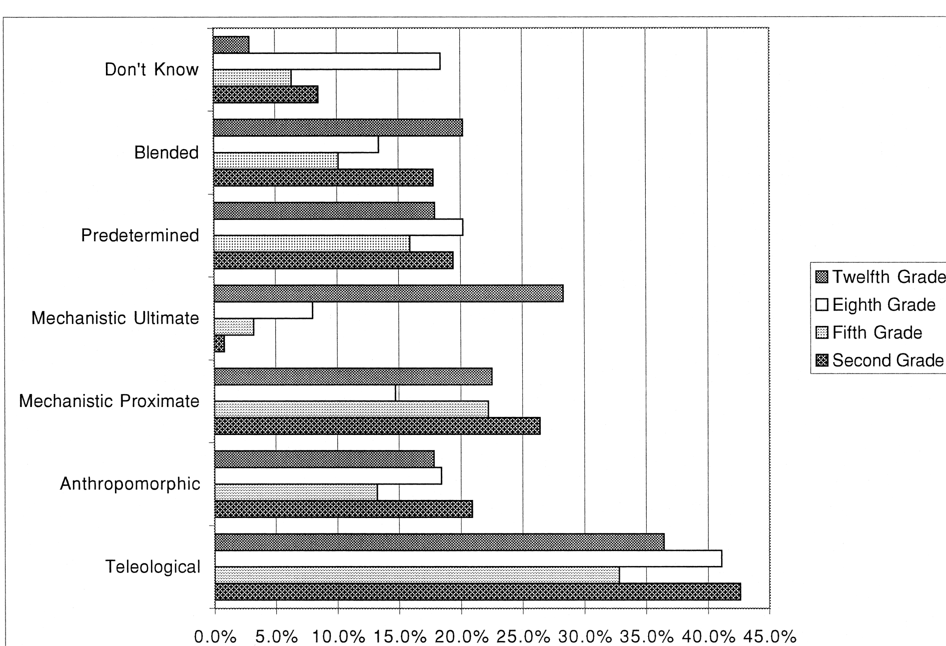

Figure 1. Comparison of percentages of total responses in each category of explanation used by students across grade levels.

prominence (i.e., anthropomorphic, mechanistic proximal, and predetermined) across the grade levels. In many instances, these categories were blended with a teleological reasoning pattern. Following is an example of a blended explanation that exhibits mechanistic proximal and teleological reasoning:

[A student is shown the ptarmigan interview prompt.]

R: How do they [ptarmigans] change the color of their feathers?

St: Um, I think one by one it [the ptarmigan] pulls 'em out (the feathers), because in the winter it needs to be camouflaged, so it turns white.

R: Uh, huh. (Yes)

St: . . . and then in the summer, it does it again, so, um, it can blend in with the trees and grass. (Louisiana, fifth grade)

As shown in Figure 1 and Table 2, students' tendency to use teleological reasoning was relatively stable across grade levels. However, the twelfth graders in our study demonstrated a less frequent use of this reasoning pattern than the younger grades and, as mentioned previously, the twelfth graders also employed the use of mechanistic ultimate reasoning patterns more frequently than the other groups. An example of a shifting explanation that includes mechanistic ultimate reasoning (along with a teleological pattern) follows:

R: What do you think that plant is doing in that picture?

St: Ah, it's leaning toward the light because it absorbs light to grow. It needs light to help it grow. And so, wherever there's light, it'll grow. (. . .)

R: Do you think that plants strive or try to get to the light?

St: They strive to get to the light. Yes, definitely. Like if you have a plant half in the shade and half not in the shade like this one, it will start to lean towards the light. So, yeah.

R: Okay, do you think that it knows it's doing it?

St: Um, I don't know. It doesn't have a brain. But I think it knows that it has to do that because all plants do it. It's not just certain plants. All plants do it to live. So yeah, I guess it knows it has to do it.

R: How do you think they know to do it?

St: I don't know. Ever since plants have been around. So, I guess just like over the years developed that and part of the like their genes would know to do that. (New Hampshire, twelfth grade)

In the prior interview excerpt, the student relied upon an ultimate mechanism expressed by an explanation in which a long-term (generally genetically based) agent is identified (Cummins & Remsen, 1992). Other instances of mechanistic ultimate reasoning used by the students included discussion of instinct, natural selection, inheritance, and evolution. Typically, such descriptions were directed toward the population of organisms and not the actions of a discrete individual.

Other Patterns in Students' Explanations

Tentativeness. In addition to the categories of students' responses, another salient aspect of the students' responses revolves around the tentative nature with which they were

TABLE 2
Frequency Distribution of Students' Explanations of Biological Phenomena, Sorted by Prompt

	Interview Prompt	Categories of Explanations						
		Teleological	Anthropomorphic	Mechanistic Proximate	Mechanistic Ultimate	Predetermined	Blended	Don't Know
Second Grade	Plant	13	8	4	0	5	6	4
(n = 129)*	Ptarmigan	23	6	15	0	3	5	3
	Duck migration	16	13	10	1	2	10	3
	Cactus	3	0	5	0	15	2	1
	Totals	55	27	34	1	25	23	11
	%	42.6%	20.9%	26.4%	0.8%	19.4%	17.8%	8.5%
Fifth Grade	Plant	12	7	9	1	4	2	6
(n = 189)*	Ptarmigan	19	8	22	0	7	10	1
	Duck migration	22	10	3	4	3	6	2
	Cactus	9	0	8	1	16	1	3
	Totals	62	25	42	6	30	19	12
	%	32.8%	13.2%	22.2%	3.2%	15.9%	10.1%	6.3%
Eighth Grade	Plant	21	7	3	2	6	3	6
(n = 163)*	Ptarmigan	22	4	11	6	9	7	11
	Duck migration	18	18	4	4	4	10	9
	Cactus	6	1	6	1	14	2	4
	Totals	67	30	24	13	33	22	30
	%	41.1%	18.4%	14.7%	8.0%	20.2%	13.4%	18.4%
Twelfth Grade	Plant	16	5	8	4	7	8	3
(n = 173)*	Ptarmigan	20	9	17	16	9	13	1
	Duck migration	8	13	10	12	4	9	1
	Cactus	19	2	4	17	11	5	0
	Totals	63	29	39	49	31	35	5
	%	36.4%	17.8%	22.5%	28.3%	17.9%	20.2%	2.9%

* *Note.* n = number of instances in which students responded to the question, "How did this [biological phenomenon] occur?"

offered. Just as was demonstrated in many of the data clips reported previously in this section, the following excerpt reveals the tentative manner that characterized many of the students' responses:

> **R:** So how do you think it happens that the bird turns white in the winter and brown in the summer? How does that happen?
>
> **St:** I guess it's 'cause it just needs to blend in with its environment. I guess, I don't know. Like it gets colder so, it turns white (Utah, eighth grade).

As shown in Table 3, a noteworthy number of the explanations documented were characterized as being tentatively offered, meaning students used phrases such as "I guess," "I don't know, but maybe it's . . ." before they went on to offer an explanation. It is important to note that these figures do not include those students who did not offer an explanation, answering "I don't know." Instead, this table only included data from those students who provided an explanation of the biological phenomena in a tentative manner. As shown in Table 3, this tentativeness characterized many of the explanations offered from students from all but the second grade.

Instability of Causal Mechanisms Employed—Shifting Explanations. A shift in an explanation either within or across interview prompts was documented if the latter explanations failed to contain aspects of the explanation initially offered or if the latter explanations contained additional aspects to those initially offered. The following interview excerpt demonstrates a fifth-grade student's shifting explanation for how a ptarmigan changes feather color:

> **R:** This is ptarmigan in the summer time [showing the two prompts]. *This* is the same bird in the wintertime.
>
> **St:** Um.
>
> **R:** What's going on there?
>
> **St:** I don't know. Looks like that one right there . . . he has white feathers under those brown ones.
>
> **R:** How does that happen?
>
> **St:** I think he just came out of winter or something like that. . . . When the winter comes, that bird, I think that the coat turns white and when it gets summer it [the bird's coat] gets some color.

TABLE 3
Tentativeness of Explanations for One Interview Prompt

Grade Level ($n = 96$)*	Number of Tentative Explanations	%
Second	18	18.8%
Fifth	42	43.8%
Eighth	42	43.8%
Twelfth	45	46.8%

* *Note.* Total number of individual interview prompts offered within each grade level.

R: Yeah.

St: Oh, I know what it's for then.

R: Okay. Go ahead.

St: In the winter, ah, there's a lot of hunting going on.

R: Oh, yeah?

St: And, I think they change that color because they don't. (Pause) It's easier for people not to be hunting for them, so they change color for them not to be hunted. (. . .)

R: How does the bird turn that color?

St: Ah, the, I think he's white all over. And there's feathers that grow in the summer.

R: Uh, huh. (Yes)

St: Or, the snow falls on him and he keeps the snow on him now.

R: Uh, huh. (Yes). Do you think it's something the bird's working to do? You know, is the bird thinking about doing that? Or does it just happen?

St: I think it just happens.

R: It just happens?

St: Yeah. (. . .) I think it's just nature taking over.

R: Oh, nature taking over. Give me an example. (. . .) What does that mean?

St: Um, I guess it means that, um, nature can—I don't know. Nature can change things. Nature can be—nature can be—nature's the whole role, practically. (. . .) They, I, um, it just controls some things.

R: Nature can control some things?

St: It isn't a he or a person or she ain't a person.

R: No?

St: It's just—it's just a spirit or something like that, that ah, thinks and does stuff.

R: Makes things happen? Okay. So, when things happen, it's because nature does it?

St: I guess. Something in the world that the world has to do at sometime or another. (Utah, fifth grade)

This interview excerpt can be used to illustrate two points: the difficulties in identifying anthropomorphism and the consistent alteration of the causal mechanisms employed. The phrase "I think they change color because they don't. (Pause) It's easier for people not to be hunting for them, so they change color for them not to be hunted" could be understood in anthropomorphic terms. However, later questioning of the student suggests that this was not the form of reasoning the student had intended to employ. Past researchers have demonstrated that teleological and anthropomorphic explanations are commonly used by biology teachers, texts, and popular educational programming because of the value of such explanations as a heuristic device and not as a true reflection of the causal mechanism (Dagher & Cossman, 1992; Halldèn, 1988; Jungwirth, 1975). Thus, there is a potential discrepancy between an individual's understanding of causal mechanism and their written or oral explanations. Because of the very real possibility of error, the findings of the previous studies completed in the area of students' biological explanations are called into question as many of the earlier studies relied solely on students' written responses (Jungwirth, 1977; Lawson & Weser, 1990).

For the second point, the excerpt demonstrates how a student consistently alters the

TABLE 4
Shifting Explanations across One Interview Prompt

Grade Level (n = 96)*	Number of Shifting Explanations	%
Second	37	38.5%
Fifth	42	43.8%
Eighth	41	42.7%
Twelfth	52	55.2%

* *Note.* Total number of individual interview prompts offered within each grade level.

causal mechanisms employed in their explanation within the confines of a single interview prompt. In this instance, the student's explanation shifted from:

1. Teleological—"I think they change that color because they don't. (Pause) It's easier for people not to be hunting for them, so they change color for them not to be hunted."
2. Mechanistic proximal—"Feathers that grow in the summer."
3. Mechanistic proximal—"[the bird] keeps the snow on him."
4. Predetermined—"It's just nature taking over."

Notice there was not an overt rejection of the initial causal mechanism (teleology), instead, additional mechanisms were employed as the question of how the change occurred continued to be asked. It could be argued that the student recognized that the causal mechanisms she or he employed were unable to answer the question. In the phrasing of conceptual change theorists, the student determined that their theory could not account for the data. However, if this recognition occurred, it was not explicit in this segment. Instead, this excerpt demonstrates a continual shift in the explanation offered by the student as they react to the interview prompt and questions.

Table 4 shows the relative number of instances in which the explanation offered by a student to a single interview prompt shifted during the course of the interview. It is interesting to note that the tendency to change the nature of one's explanation is greater for the twelfth graders than the younger students. But, even for the second graders, 38.5% of the students shifted their explanation of single biological phenomena during the interview. This tendency becomes more noteworthy when one considers the short time span (typically $<$2–3 min) spent discussing any single interview prompt.

Table 5 shows the relative number of instances in which students changed the nature of their explanation biological phenomena during the span of the interview series. The range of such changes is narrow, with a low of 62.5% of the eighth graders to a high of 75% of the fifth graders shifting the causal mechanism of their biological explanations over the course of the four interview prompts. Thus, the data demonstrate that regardless of grade level, students were very likely to change the causal mechanism used in their explanations across a series of similar interview prompts.

It could be argued that change in the use of a particular category of mechanisms is to be expected given the use of different interview prompts. However, the coding scheme employed served to categorize *general* types of causal mechanisms, not specific causes, thereby factoring out possible variations in the category of explanations students might employ data due to the specific nature of the interview prompt. (For instance, explanations

TABLE 5
Shifting Explanations across Interview Series

Grade Level (n = 24)*	Number of Shifting Explanations	%
Second	17	70.8%
Fifth	18	75.0%
Eighth	15	62.5%
Twelfth	16	66.7%

* *Note.* Total number of interview series offered within each grade level.

in which a ptarmigan was said to turn its feathers over to change coloration and one in which the bird was said to collect snow on its back were both documented as mechanistic proximal reasoning patterns, although on the surface these are different explanations.) However, specific prompts may trigger the employment of a general type of reasoning, such as teleological or anthropomorphic explanations (Tamir & Zohar, 1991). Additionally, some of the probes may have been more familiar to some of the students, also triggering specific responses. The data contained in Table 5 cannot address this issue. However, the data contained in Table 4 were taken from students' comments to an individual prompt. Even here, between 38.5 and 55.2% of the students changed the nature of their explanations. Such data adequately demonstrate the variability of the causality ascribed in students' biological explanations.

Basis of Shifting Explanations. Tables 4 and 5 demonstrate that it was common for students to change the causal mechanisms employed in their explanation (either within or between interview prompts), as Figure 1 and Table 2 show the relative use of various causal mechanisms across grades and prompts. But was there a pattern to the change documented in students' explanations? As shown in Table 6, a significant percentage of students' original explanations relied on teleology for the causal mechanism. While teleological explanations were those most commonly seen in *any* explanation, Table 6 illustrates that this reasoning pattern is also the first one that most students employed to explain biological phenomena.

TABLE 6
Use of Teleology as Basis of Original Explanations

Grade Level (n = 96)*	Number of Original Explanations Using Teleology	%
Second	41	42.7%
Fifth	48	50.0%
Eighth	60	62.5%
Twelfth	45	46.9%

* *Note.* Total number of individual interview prompts offered within each grade.

DISCUSSION

The discussion will be organized around the research questions that guided this study: *What are the various categories of reasoning employed in students' explanations of biological phenomena? Do these reasoning patterns vary across grade levels of students?*

The most prominent category of response in each of the four grade levels was the teleological reasoning pattern in which the ends of the situation are used as a causal agent in determining the means. The relative prominence of teleological responses in our study is not surprising considering past work accomplished in this area (Bishop & Anderson, 1990; Demastes-Southerland, Good, & Peebles, 1996; Tamir, 1985). Tamir and Zohar (1991) report that 71% of the tenth graders and 56% of the twelfth graders in their study used teleological reasoning when giving explanations of evolutionary change.

Many of the students' explanations in this study were found to consist of a blend of possible categories, but with teleology prominently featured. This finding echoes that of Tamir and Zohar (1991) who describe the tendency that learners use teleological reasoning combined with anthropomorphism to explain biological phenomena. They suggest that such reasoning is based upon "the assumption that biological systems are structured functionally, so that they are adapted to the needs of individual organisms" (p. 65). Our data support this earlier work, with teleological reasoning patterns being the most common pattern employed by students to explain the four types of biological phenomena presented in the interviews.

It is noteworthy that while the twelfth graders in the study employed the mechanistic ultimate explanation more than any other grade level of students, they were less likely to employ teleological reasoning and were less likely to respond "I don't know" in the interviews. Thus, there is some improvement in students' ability to reason scientifically within biological domains as grade levels increased. This increase was particularly true for students from the New Hampshire sample—perhaps indicating that use of this conception can be increased as a result of instruction. However, the use of mechanistic ultimate explanations was still minimal for even this group, and alternative conceptions were still prominent for all twelfth graders, suggesting that the majority of students fail to develop scientific conceptions for the biological situations in the prompts throughout their grade school years.

Despite this increase in the use of mechanistic ultimate reasoning patterns in the twelfth graders, the continued use of alternative, scientifically inappropriate reasoning throughout the grade levels was surprising. While the prominence of these alternative explanations is to be expected based on the past research in this area, the idea that explanations generated by the twelfth graders in this study were very similar in nature to those of the second graders remains disconcerting. The sampling employed in this study was designed to focus on the development of biological explanations across grade levels, minimizing the effects of any particular teacher or means of instruction, hence the use of a number of students at multiple grade levels at multiple study sites. Despite this wide sampling, little change could be discerned in the explanations offered across grade levels. Using the conceptual framework approach to understanding explanations, it would be expected that as students experience more biology instruction that they would develop a richer, more coherent conceptual framework for the basic patterns of biological explanations, a framework that would result in a change in reasoning patterns. Our results fail to support this assertion.

What other patterns can be used to characterize students' explanations? Do these patterns vary across grade levels of students?

It was only during the analysis of the data that the fluid nature of students' responses was recognized. The shifting, tentative patterns were not expected as we began our work using the conceptual framework approach to understanding students' explanations. What we expected as we began this study was a gradual shift in the category of reasoning patterns employed as students from different grade levels were interviewed. Instead, we documented relatively similar patterns of the categories employed by students from each grade level, a tendency to shift reasoning patterns even within the confines of one interview prompt, and an extreme tentativeness that characterized all explanations but those offered by students in the earliest grade levels. What can account for the tentative, shifting patterns of explanation documented in this study? There are at least three possible hypotheses: 1) a misinterpretation of the goals of the interviews, 2) the multiple levels of causality found in biological domains, and 3) student employment of p-prims. In this section, the first two of these three alternatives will be explored.

The first possible explanation for the patterns documented in this study revolves around the research methods employed. It is possible that the students viewed the interviews as a conversation with a relatively unfamiliar authority figure, and so employed the habits of conversation typical to such situations; that is, students were attempting to offer a "correct" answer to the authority and reacted to interview cues to provide that answer. As a result, students changed the nature of their explanation when they understood their answer to be insufficient or unacceptable for the interviewer.

Alternatively, in an effort to more fully ascertain the basis of students' explanations, the interviewers in this study followed each interview question with a series of additional queries (e.g., "talk about that," "help me understand that," and "why do you say that?"). When the interviewer probed the student to more fully describe, explain, or reason about a phenomenon, students may have believed that additional prompting was designed not to elicit further clarification, but as an indication that they were on the "wrong track" in terms of describing the phenomena. Despite our assurances that we were seeking to describe what students knew with little interest in a single correct answer, students may have fallen into traditional patterns of student–adult academic conversations, and thus began searching for an acceptable answer.

As Erickson (1986) has described, explaining is a highly audience-sensitive activity in which the actions of the speaker are largely determined by their appraisal of the understanding of the listener. Our need to determine underlying meaning of statements could have been interpreted by the student as a disagreement or lack of understanding—such miscommunication may account for the shifting patterns of explanation documented in this study.

A second possible interpretation for the shifts and blends in student responses is found in the multiple levels of causality that can be used to understand biological phenomena. As described by Cummins and Remsen (1992), for every biological phenomenon, there are two causal explanations: a proximate one (which answers "how" a change occurs), and an ultimate one (which answers "why" a change occurs). In essence, this is the difference between the actual mechanisms of a physiological change undergone by an organism as opposed to the adaptive or evolutionary reasons for the change. Because of the multiple levels of causality in biology, there are inherent problems in determining one correct answer to any question. In this study, when faced with the unexpected task of providing an explanation of proximal causality, students may have interpreted our prompts in a manner more familiar to them that would allow them to offer a reasonable explanation. When asked to explain *how* a change occurred, students may have been responding to the more ultimate question; that is, *why* did the change occur. In other words, if they were unsure *how* something occurred, they offered what they did know, which in many cases was a teleological response.

Support for the dual levels of causality argument can be found in the number of twelfth graders (28.3%) that offered mechanistic ultimate explanations in response to our questions about *how* the changes occurred. In light of this argument, for every response, the factor of how the question was heard or interpreted by the student becomes a critical one. For a further discussion of this issue, see Abrams, Southerland, & Cummins.

What theoretical lens allows for the most useful understanding of the basis and production of students' biological explanations, conceptual frameworks, or p-prim perspectives?

Both of these first two interpretations of the fluid nature of students' explanations do not argue against the traditional model of students' science knowledge: the students' explanations are a reflection of their conceptual frameworks for these topics. Applying this model to these data, we see that although students have an underlying conceptual framework for the topics, the tentative, shifting pattern documented in the study could be caused by an artifact of the interview protocol or as a reflection of the dualistic nature of explanations of biological phenomena. The alternative and shifting conceptions that were documented, combined with the extreme tentativeness of responses (as was particularly true for all but the youngest students in the study) certainly suggest that students' conceptual frameworks in this area are not only unscientific, but that they are also poorly constructed. Even if one considers that students may have been perplexed by their roles in the interview, it is important to note that a majority of these students were not so assured of the strengths of their understandings to defend or argue their positions. If the model of conceptual frameworks is used to understand these findings, we must conclude that students have weak, poorly constructed frameworks for biological phenomena and that these weak conceptions do not change substantially throughout years of schooling.

One could argue that the students in our study may not have had direct experience or studied the specific phenomena in question, and this lack of familiarity would make the poor structure of their frameworks understandable. However, that argument is difficult to accept for all of the prompts (e.g., the plant growing toward the light or birds migrating). Even given the small chance that all the prompts were unfamiliar, it is surprising that the data provide little evidence of the recognition of valid (mechanistic proximate or ultimate) and invalid (i.e., teleological, anthropomorphic, or predetermined) patterns of scientific explanations. Thus, if we are to use the conceptual framework model of knowledge structure to interpret our findings, we must conclude that at present science education does not help students develop or refine the conceptual frameworks they are to use to explain biological phenomena.

There is an alternative framework through which we could view these findings, one that contradicts the more traditional conceptual framework interpretation, as it makes use of diSessa's (1993) "knowledge in pieces." Using this hypothesis, students' explanations are understood to be fluid because they are constructed on the spot, in direct response to the very particular cues of the biological phenomenon and the interview questions. Thus, students' explanations might not be an exclusive reflection of ill-formed-but-existing conceptions; rather, they are spontaneous constructions. Using this theory, students are not thought to hold preformed, static conceptual frameworks for all topics. Instead, they construct understandings and generate explanations based upon the p-prims activated by the specific characteristics of the phenomena and situation in question. Using this theoretical lens, it is not that students hold poorly constructed, incoherent conceptual frameworks, but that they have no formal, pre-existing framework for this topic. Instead, students are understood to spontaneously reason from core intuitions.

What might diSessa's "theories in pieces" gain us that the traditional interpretations of conceptual frameworks and alternative conceptions do not? If we understand students to be reasoning from core intuitions based upon the characteristics of the particular situation, a great deal of variability in the causal mechanisms employed in their explanations is to be expected. The tentativeness that characterized the explanations offered by all but the youngest students and the shifting explanations documented throughout the grade levels are not signs of students' static but ill-constructed, haphazard conceptual frameworks. Instead, we understand students to be reacting to specific aspects of the phenomena, specific data, to activate p-prims in order to construct explanations on the spot. The spontaneous nature of explanations based on p-prims would account for the tentative patterns, the shifting patterns, as well as the lack of development documented in students' explanations across grade levels.

The Biological P-Prim of *Need as a Rationale for Change*

diSessa (1993) argues that students gradually acquire a sense of mechanism for the physical world—"a sense of how things work, what sorts of events are necessary, likely, possible or impossible" (p. 106). He proposes that this sense of mechanism is based on the activation of small, deeply rooted p-prims that are then used to construct an explanation. We argue that students also gradually acquire a view of mechanism for many aspects of the biological world that rely on the activation of biological p-prims. We suggest that the biological p-prim identified in the data presented here is *need as a rationale for change.*

P-prims are understood to be atomistic knowledge structures that originate in the learner's superficial interpretations of experience. These knowledge structures become the building blocks through which the learner then interprets, explains, and remembers experience. Because these elements exist at such a primitive level, they are often understood to be self-explanatory and the learner often does not recognize these elements as requiring further justification. The prominence of teleological explanations in both the overall percentage of use and as the basis of shifting explanations can be understood as a reflection of the p-prim of *need as a rationale for change.* As Tamir and Zohar (1991) have explained, teleological formulations describe that an organism's structure is based upon its needs. Using diSessa's formulation, teleologically based explanations are the consciously accessible notions based upon the p-prim of *need;* that is, biological phenomena happen because the organism needs this adaptation/occurrence.

The role of *need as a rationale for change* as a p-prim identifies it as a deeply rooted aspect of knowledge, an organizing core intuition. This role as p-prim explains why teleological formulations are so prevalent in the explanations provided by students in each of the grade levels sampled here and in other related studies (Bishop & Anderson, 1992; Demastes-Southerland et al., 1996; Tamir & Zohar, 1991) in addition to explaining why the use of teleological reasoning is so embedded in students' reasoning despite years of formal schooling. It also helps understand the heuristic value of such explanations (Dagher & Cossman, 1992; Halldèn, 1988; Jungwirth, 1975); teleological explanations are useful means to explain biological relationships because they make sense on a deep, intuitive level.

The recognition of the p-prim of need *as a rationale for change* also explains how so many explanations can be generated in response to similar situations. Operating from this perspective, the explanations documented in this study (i.e., teleological, anthropomorphic, mechanistic proximal, etc.) can be viewed as the more conscious explanations spontaneously constructed in response to the activation of the *need* p-prim, the cues of the particular biological phenomena in questions, and the nature of the interview questions themselves. Thus, shifting explanations are not a reflection of pre-existing but incompatible conceptions, but are understood to be spontaneous variations on the unconscious theme of *need.* While the conscious, spontaneous explanations may change, the intuitive basis of these constructions, the underlying p-prim, remains intact. The shifting pattern of explanations documented in this study are supported by Jungwirth (1977) who demonstrated that even in-service science teachers often fail to differentiate between teleological, anthropomorphic, and mechanistic explanations of causality.

IMPLICATIONS

When students offer an explanation for a physical or biological phenomenon, what is the basis of this construction? Is it a reflection of an underlying preformed conceptual framework? Or, is it a spontaneous construction assembled in response to the peculiarities of the situation at hand, based on a deep-seated core intuition? The research presented here was an empirical effort exploring the use of the "theories in pieces" argument to understand the basis of the tentative, fluid nature of students' explanations. While we have argued for the use of p-prims as a way of understanding the patterns in students' explanations, there are two barriers to the support of this model, one methodological and one domain specific. Implications of each of these three interpretations will be discussed.

Given the discrepancies of past research in the area of students' biological explanations, in this research, we sought a method that would allow an exploration of these discrepancies, would provide a more accurate portrait of the manner in which the students understood biological changes, and one that could be used with a large sample of students. However, while we hoped to capture a deeper understanding of students' explanations through this probing, students may have misinterpreted our continued questioning. Future researchers in this area need to be mindful of this limitation and should seek greater *mode validity* for findings through the use of multiple data collection techniques (White & Gunstone, 1990). While the optimization of mode validity may require the use of smaller samples, in light of our findings this seems to be an appropriate tradeoff.

Much of the descriptions of the learning process and conceptual structures have been generated through research in the physical sciences (diSessa, 1993; Hewson & Hewson, 1992; Nersessian & Resnick, 1989; Schwedes & Schmidt, 1992; Vosniadou & Brewer, 1992). We had hoped to extend our understanding of science learning to the biological sciences through this research. However, the dual nature of explanations of biological phenomena introduces yet another variable in an already complex task. One may argue that descriptions of learning and conceptual structures may need to be accomplished in less complex domains. However, White's (1994) concern that learning has a domain specific character is a very real one. Instead, we would urge that further descriptive work into students' understanding of biological phenomena must be accomplished, but it should be designed to include recognition of problem of proximate and ultimate causality.

Although we have argued that the theoretical framework of p-prims and spontaneous constructions is a useful means in understanding the tentative, shifting nature of students' explanations of biological phenomena, we cannot conclusively argue against the conceptual framework theory. Indeed, neither diSessa (1993) nor Brown (1995) rules out the existence of conception at levels other than p-prims or core intuitions. Instead, students may be thought to work from both p-prims and conceptual frameworks. For the topics described in this study, we suggest that p-prims provide a more explanatory construct to understand both the tentative and shifting nature of students' constructions of these biological phenomena than that provided through conceptual frameworks. However, as indicated by the increased use of mechanistic-ultimate explanations in the twelfth graders, we suggest that students can form a scientific conception alongside their p-prims, supporting the multifaceted description of diSessa (1993) and Brown (1995).

We would argue for more empirical studies in order to more fully investigate the manner in which students make sense of physical and biological phenomena. What situations require/elicit spontaneous constructions? What situations call for more tightly formed conceptual frameworks? What is the relationship between p-prims and the conceptual ecology of Posner et al. (1982) and Strike and Posner (1992)? Can conceptions and core intuitions both play a role in this ecology? What are the specific characteristics of a situation that invokes use of a particular p-prim? Clearly, a reorientation that allows for broadening of interpretations, including but going beyond that of alternative conceptions and conceptual frameworks, could prove to be very illuminating.

What are the implications of this research in the science classroom? As Brown has described (1995), a student who seems to approach a situation with a firmly constructed framework or theory may benefit from the structured conceptual change approach. In this instructional sequence, the student is guided through a sequence of events, analyzing and comparing rival theories, leading to the eventual replacement of their present conceptions with more scientifically appropriate alternatives.

In contrast, if students are thought to be reasoning from p-prims, instruction has a different goal, as reasoning from p-prims is understood to be an essential aspect of understanding the world. If students are using p-prims, instruction should focus on developing regularities in their use. Learning becomes a process of developing and refining how and where p-prims are applied; teachers seek approaches that will activate more appropriate p-prims, instead of attempting to change or replace a learner's organizing conceptions. In this instructional mode, as suggested by Hammer (1996), teachers should seek to shape students' reasoning patterns, building on what students know, instead of seeking to dismantle pre-existing structures. In this case, teachers should help students recognize their use of the *need* p-prim in their explanations of biological changes and allow them to see how this p-prim stops short of actually providing a mechanism for the change. Such a recognition would provide a sound starting point for subsequent instruction regarding scientifically appropriate explanations of change.

The conceptual framework perspective understands alternative conceptions to be barriers to the construction of a scientific understanding of phenomena. The p-prim perspective views reasoning from core intuitions to be essential to the construction of an understanding of the world, although students need to be guided in scientifically appropriate patterns of reasoning. Both approaches require that students explore and address their existing ideas, but one approach suggests the elimination of alternative conceptions while the goal of the second is to shape the ways in which students reason. But, as Hammer (1996) has pointed out, neither perspective enjoys such widespread acceptance in the science education community to prescribe educational practice. Instead, the debate should broaden our continuing description of learning, a description that should inform and shape our reflective educational practice.

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