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ABSTRACT

The knowledge construction and scientific reasoning of two classes of seventh grade students (22 to 24 students in each class) were examined during a 3-week inquiry unit in genetics, in which anomalies were used as a catalyst for conceptual change. During the unit, students used genetics simulation software to mate fruit flies that varied on a single trait (e.g., eye color) to produce offspring. Inherent in the data that students were investigating were two anomalous inheritance patterns. Based on pretest/posttest analyses, students significantly improved overall in their ability to explain the anomalous inheritance patterns. However, the improvement was not symmetric. Approximately 80% of students were able to explain the more frequently occurring anomalous pattern relative to only 53% who were able to explain the less frequently occurring pattern. Examination of student hypotheses and testing patterns indicated that students were sensitive to the relative difference in anomalous outcomes during their investigations. They were more likely to propose hypotheses for the more frequently occurring anomaly and also more likely to run the test that could produce that outcome. In contrast, they were least likely to run the test that produced no anomalous outcomes, and slightly more likely to conduct the test for the less frequently occurring anomaly. It was concluded that the percentage of anomalous outcomes influenced the extent to which students proposed hypotheses, ran tests, and constructed explanations for these outcomes. (Contains 6 tables and 18 references.) (Author/SLD)

Running head: INFLUENCE OF ANOMALIES

The Influence of Anomalies on Knowledge Construction and Scientific Reasoning During Inquiry

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Abstract

Knowledge construction and scientific reasoning of seventh-grade students were examined during a three-week inquiry unit in genetics, in which anomalies were used as a catalyst for conceptual change. During the unit, students used genetics simulation software to mate fruit flies that varied on a single trait (e.g., eye color) to produce offspring. Inherent in the data that students were investigating were two anomalous inheritance patterns. Based on pretest/posttest analyses, students significantly improved overall in their ability to explain the anomalous inheritance patterns. However, the improvement was not symmetric. Approximately 80% of students were able to explain the more frequently occurring anomalous pattern relative to only 53% who were able to explain the less frequently occurring pattern. Examination of student hypotheses and testing patterns indicated that students were sensitive to the relative difference in anomalous outcomes during their investigations. They were more likely to propose hypotheses for the more frequently occurring anomaly and also more likely to run the test that could produce that outcome. In contrast, they were least likely to run the test that produced no anomalous outcomes, and slightly more likely to conduct the test for the less frequently occurring anomaly. It was concluded that percentage of anomalous outcomes influenced the extent to which students proposed hypotheses, ran tests, and constructed explanations for those outcomes.

The Influence of Anomalies on Knowledge Construction
and Scientific Reasoning During Inquiry

Anomalous events encountered by the learner are widely considered to be a catalyst for conceptual change learning (Posner, Strike, Hewson, & Gertzog, 1982). As such, exposure to anomalous events has often been used in the teaching and learning of science to stimulate construction of science ideas. This exposure has ranged from presenting texts to students in which anomalous claims are examined in relation to existing theories (Limon & Carretero, 1997) to having participants design and conduct experiments to investigate anomalies encountered in the data (Hafner & Stewart, 1995).

Findings from these studies have yielded various portraits of how learners react to anomalous information. By and large, conceptual change is likely to occur when anomalous events are encountered. However, there are exceptions as well as various degrees of change. Specifically, it has been found that conceptual change quite often occurs in fits and starts. Tao and Gunstone (1999) found that student conceptions in physics vacillated between canonical and intuitive notions throughout an inquiry unit in physics. Demastes, Good, and Peebles (1996) identified several non-linear ways in which conceptual change occurred during a unit on evolution in science. Burbules and Linn (1988) report that repeated instances of anomalous information caused students to gradually change from a weight-based rule to a volume-based rule regarding buoyancy of objects in water; however, students varied considerably in their tolerance for anomalous instances of data, with some student immediately changing their theory while others persisted.

While findings from these studies indicate that presentation of anomalous information can promote conceptual change, there is no guarantee that such change will occur. In fact, Chinn and Brewer (1993) cite seven ways in which a learner may respond to an anomalous outcome, only one of which involves making a change to an existing theory. Chinn and Brewer refer to the remaining six alternative responses to changing a theory as "theory-preserving" responses because they permit the learner to leave his/her theory intact. Of these seven options, conceptual change is the most effortful and radical. In order to accommodate anomalous information, the learner must actively choose to do so over other less radical options.

While extensive research has documented the conceptual change process in response to anomalies, what has been examined to a much lesser extent is how the learner may further choose to investigate an anomalous event, and what impact that investigation may have on the knowledge that is subsequently constructed. Specifically, with respect to knowledge construction, prior research has focused heavily on presentation of anomalous information to learners with little investigation as to how learners may subsequently attempt to gather additional information to resolve the discrepancy. It is unclear from these studies then, how learners might reason scientifically when presented with anomalous information. For example, will learners choose to pursue tests that produce anomalous outcomes? Or will they ignore those tests in favor of tests that produce outcomes consistent with their theories?

Prior research that has examined student scientific reasoning has infrequently examined specific response to anomalies. Rather, research on scientific reasoning has largely focused on rigor of experimentation with respect to systematicity of testing and validity of inferences (Kuhn, Schauble, Garcia-Mila, 1992; Schauble, Klopfer, & Raghavan, 1991). A common framework is to provide participants with a system to explore in which they must determine the causality or noncausality of several variables in relation to an outcome. For example, Schauble (1990) investigated the extent to which children were able to determine the relation between various design features of a race car and the speed of that race car. Using such a framework, strategies of experimentation are examined, most often with respect to whether or not participants will control for other variables and only vary one thing at a time when drawing inferences of causality or noncausality (Friedler, Nachmias, & Linn, 1990; Vollmeyer, Burns, and Holyoak, 1996).

While these studies provide valuable insights into approaches to scientific reasoning, they do not provide information about subsequent conceptual change beyond that of establishing which variables a learner believes to be causal or noncausal due to patterns of covariation or noncovariation, respectively. In particular, they do not also examine ideas related to the mechanism by which a learner believes a variable to be causally related to an observed outcome. Thus, there exists an apparent dichotomy in the research literature in which studies tend to primarily focus on student ideas and explanations in response to anomalous information or on processes and systematicity of scientific reasoning. This dichotomy holds for studies conducted in laboratory settings (Kuhn, Garcia-Mila, Zohar, & Andersen, 1995) as well as those conducted in the classroom (Roth & Roychoudhury, 1993; Shepardson & Moje, 1999). Infrequently are knowledge construction and scientific reasoning studied together to determine how processes of scientific reasoning in response to anomalies contribute to the ideas and explanations constructed by the learner to account for anomalous phenomena. This is an important focus to provide a more holistic and naturalistic look at how learners respond to and deal with anomalies. This was the focus of the present study, in which the knowledge construction and scientific reasoning of middle school students were examined as they encountered anomalous data during an inquiry unit on trait transmission in fruit flies. The particular questions of interest were, 1) How will students' knowledge change in response to anomalous data? 2) How will students reason scientifically in response to anomalies? and 3) What is the nature of the relationship between knowledge construction and scientific reasoning?

Anomalies in genetics

In the present study, exposure to anomalies was examined in relation to knowledge construction and scientific reasoning. Knowledge construction was defined as the change in student ability to provide explanations for anomalous data patterns. Scientific reasoning was examined with respect to generation of hypotheses and design of tests when investigating the data. The context of the study was a three-week seventh-grade unit on Mendelian genetics, in which students studied the transmission of a single trait in fruit flies. During the unit, students used genetics simulation software to mate fruit flies that varied on a single trait (e.g., eye color) and observed the type of offspring produced. Students worked in pairs on the unit, and were free to develop their own hypotheses, tests, and conclusions to construct an understanding of how a trait was transmitted from one generation to the next.

Inherent in the fruit fly data were two anomalous inheritance patterns. Anomalies were defined as those outcomes that were not readily explainable based on the observable characteristics of the parents. The first anomalous pattern consisted of a situation in which parents with the same variation of the trait produced offspring with two different variations. For example, for the trait of eye color, two red-eyed parents might produce both red- and white-eyed offspring. The second anomalous pattern was one in which parents with two different variations produced offspring with only one variation. For example, a red- and white-eyed fruit fly might only produce red-eyed offspring. Patterns in which the parents produced offspring with the same appearance were considered "standard" patterns because they were predictable based on appearance. These patterns consisted of parents of the same type producing only that type of offspring (e.g., red-eyed parents producing only red-eyed offspring) or parents of two different types producing two different types of offspring (e.g., red- and white-eyed parents producing red- and white-eyed offspring).

The mechanism by which these various outcomes occurred was dictated by a pattern of simple dominance Mendelian genetics, in which one genetic variation of a trait is dominant to the other. Each fruit fly carries two genetic variations (i.e., alleles) that make up one gene. The two variations together determine the appearance of the trait. One variation of the gene is dominant, and the other is recessive. If the dominant variation is paired with the recessive variation, then the organism will have the appearance of the dominant variation. The organism will only have the appearance of the recessive variation if it is paired with itself. Therefore, if red is the dominant variation for eye color, a fruit fly with a red-white or a red-red genetic combination would appear as a red-eyed fruit fly. A white-eyed fruit fly would only be apparent if it had a white-white genetic combination. Table 1 indicates the various genetic combinations that would lead to anomalous and standard outcomes.

Table 1

Standard and anomalous inheritance patterns for the mating of red-eyed and white-eyed fruit flies

Parent genetic make-up	Parent appearance	Offspring appearance	Outcome
(w-w) x (w-w)	W x W	All W	Standard
(r-r) x (r-r) or (r-r) x (r-w)	R x R	All R	Standard
(r-w) x (w-w)	R x W	R, W	Standard
(r-r) x (w-w)	R x W	All R	Anomalous
(r-w) x (r-w)	R x R	R, W	Anomalous

The implementation of the genetics unit was based on a social constructivist theoretical framework in which construction of meaning was theorized to occur reflexively between the level of individual and the whole class (Cobb & Yackel, 1995). During the unit, students could construct meaning individually and in pairs as they worked with the genetics simulation software. In addition, knowledge construction occurred through whole class discussion during which the specific focus was on constructing explanations for anomalous data patterns. During whole class discussion, students reported on specific data patterns they had encountered and then theorized about potential explanations. Thus, exposure to anomalies occurred through individual encounters with the data, as well as through whole class discussion. Students were not provided with any formal instruction on Mendelian genetics. Therefore, their explanations were their own constructions.

Methods

Study context

This study took place in two seventh grade science classrooms in a large suburban middle school in upstate New York. Each class consisted of approximately 22 to 24 students, ranging in age from 11 to 13 years. The student population of the middle school was predominantly White and middle class. This particular school was selected because the science director is an advocate of constructivist-oriented approaches to teaching science. Given the constructivist-oriented nature of the genetics unit, this was considered an appropriate match.

The science teacher who participated in the study was recommended by the science director as an excellent candidate given the nature of this study. She had taught science at the middle school level for eleven years. She also taught mathematics at the seventh grade level. This teacher had conducted short inquiry tasks with her students and thus was familiar with allowing students to come up with their own answers to investigations. Both of her science classes were involved in the study.

In addition to the science teacher, I was a participant/observer in the classroom to facilitate implementation of the unit as well as to record data about how the unit was progressing. I have an undergraduate degree in electrical engineering, which included study in several science courses. As an educator, my particular area of study and interest is in constructivist-oriented approaches to teaching. As a co-teacher in the classroom, I was involved with the students on a daily basis and interacted with them one-on-one during their investigations. I also facilitated whole-class discussions on students' evolving conceptions of how traits were transmitted in the fruit flies and the plants. As an observer in the classroom, I set up audio- and video-taping equipment, recorded observational notes, conducted pre- and post-interviews with select dyads and administered pre- and post-assessments to the whole class.

The genetics unit was a new unit and was developed collaboratively between the teacher and myself. We initially met for four one-hour sessions after school to discuss lesson plans for the study and to look over the materials to be used. During the course of the unit we discussed plans each day for the following day's lessons, adjusting plans where we deemed necessary based on students' understanding of the unit. The core of the inquiry unit was designed around a conceptual change framework in which anomalies were used as a catalyst to provoke cognitive disequilibrium in students, and subsequent conceptual change.

Materials

To investigate trait transmission in genetics, students used a genetics simulation software (Genetics Construction Kit) and observed the growth of Wisconsin Fast Plants. In both the software and the plants, students investigated or observed the transmission of one trait (e.g., eye color in fruit flies; stem color in plants). The trait could vary with the fruit flies (e.g., wing shape, antennae shape, eye shape), but was fixed with the plants

Genetics Construction Kit (GCK)

The GCK is a genetics simulation software that students could use to breed fruit flies to observe how traits were transmitted to the offspring. The GCK simulates work done in a genetics laboratory by providing students with an initial "vial" of fruit flies, from which they can produce subsequent vials of offspring by cross-breeding two fruit flies. For the purposes of this study, the software was set up so that students could examine simple dominance inheritance patterns for fruit flies that varied on only one trait (e.g., eye color). Figure 1 shows an initial fruit fly vial that students could have seen when they first entered the program.

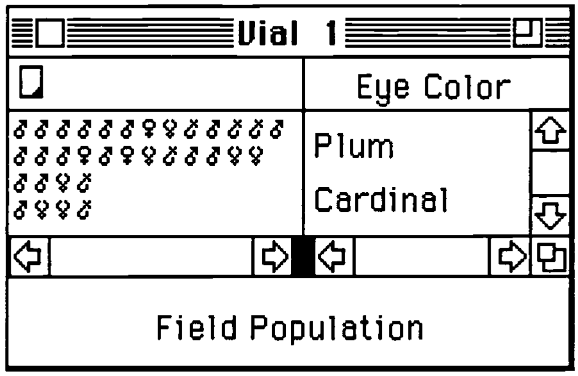


Figure 1. Initial vial containing field population of plum-eyed and cardinal-eyed fruit flies.

The vial in Figure 1 represents a vial full of fruit flies (symbolized as male and female) that differ on eye color. The first two rows of fruit flies have plum-colored eyes. The second two rows of fruit flies have cardinal-colored eyes. This vial represents an initial field population of fruit flies. This field population is analogous to a scientist gathering a sample of fruit flies, about which nothing is known regarding which parents produced which offspring. To obtain information about the exact number of fruit flies contained in the vial, students could access a summary chart of each vial. In this case, the summary chart would indicate that vial 1 contained 25 plum-eyed fruit flies and 8 cardinal-eyed fruit flies.

To "breed" the fruit flies, students could select a male and a female from vial 1 and "mate" them to produce offspring in a second vial. The second vial shown in Figure 2 shows the offspring of two plum-eyed parents from vial 1. In this case, both plum-eyed and cardinal-eyed offspring were produced, although once again a majority of the offspring have plum-colored eyes. The information at the bottom of the window indicates which parents were crossed to produce the offspring in vial 2. In this case, the number one followed by a gender symbol and eye color indicates that both parents came from vial 1 and had plum-colored eyes. If students clicked on the gender symbol of one of the parents they could use the identical fruit fly in a subsequent cross.

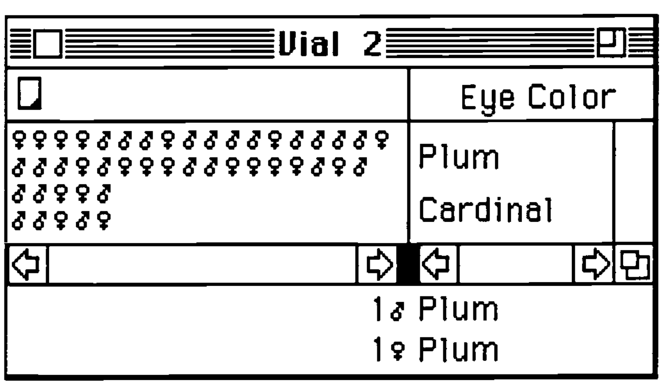


Figure 2. Second vial containing cardinal- and plum-eyed offspring from two plum-eyed parents.

Using the GCK students could choose any fruit flies to cross, and then could analyze the results to see if any particular patterns arose. Thus they could construct hypotheses and design their own tests to investigate how a particular trait was transmitted.

Wisconsin Fast Plants

Concurrent with their investigation of the fruit flies with the GCK, students made observations of the transmission of traits with Wisconsin Fast Plants (Carolina Biological Supply Company, 1989). The plants paralleled the data that the students were gathering from the GCK in that they also illustrated simple dominance inheritance patterns. The Wisconsin Fast Plants varied on one trait, stem color. The stem color could be either purple, which was the dominant variation of the trait, or green, which was the recessive variation. Students observed the growth of three generations of plants. The first generation consisted of purple- and green-stemmed plants. The offspring of those plants consisted of only purple-stemmed plants. The third generation of plants consisted again of both purple- and green-stemmed plants. Students collected data on various characteristics of the plants, determining how they were similar and different, and observing how those similarities and differences were transmitted to the next generation.

Procedure

The duration of the genetics unit was three weeks. Preliminary introductory activities for the unit took two days and involved a fingerprinting activity and a mental model building activity. The fingerprinting activity consisted of analyzing fingerprints on a worksheet and solving a mystery using fingerprints. For the mental model building activity, a box was given to each dyad with unknown objects inside. Students had to generate hypotheses for what the objects were, indicate how they were testing and gathering information on the objects, and write down the conclusions they were drawing.

The next segment of the unit involved students investigating the transmission of traits in fruit flies using the Genetics Construction Kit (Jungck & Calley, 1993). As an introduction to the Genetics Construction Kit, a video of scientists collecting data on genetics of fruit flies was shown to the students so that they could see what actual fruit flies looked like and could see the vials that scientists used and how they examined the fruit flies (e.g., looking at eyes or wing shape). After the video, the students worked in dyads on the computer to familiarize themselves with the GCK software. Data cards were also handed out so that students could practice recording their crosses, including their hypotheses, tests, and conclusions. The video presentation and initial work with the GCK took approximately two days.

After working for a short time with the GCK, students were provided with handouts of the parts of the fruit flies, a list of fruit fly traits, and further examples of how to fill in the data cards. Students were also given some introductory information and a short presentation on the Wisconsin Fast Plants, and given some ideas for the types of characteristics to observe with the plants. For the next few days, students alternated working on the plants and the GCK. Students observed and recorded characteristics such as height, number of leaves, buds, and similarities and differences between generations with the plants, and recorded their hypotheses, tests, and conclusion for the GCK data.

On two separate days, I initiated whole class discussion to discuss current student findings. The intention during these discussions was to a) have students describe the results they were getting, and b) generate ideas to explain why those results were occurring. To facilitate these discussions, I prompted and extended student ideas by re-stating, pointing out anomalous instances of data, and probing ideas for inconsistencies between explanations from one scenario to another. These discussions generally lasted for half a period. During the other half of the period, students either made bee sticks to use when pollinating the plants, or listened to a presentation on the parts of the flower and the parts of the bee. Towards the end of the unit, the students' regular classroom teacher gave a presentation on the phases of meiosis. Students then completed a sticker activity in which they simulated the phases of meiosis. For the last day, students continued gathering data on the plants and the GCK.

Data collection

This study incorporated a mixed method participant/observer design, in which qualitative and quantitative data were gathered on both processes and outcomes during the unit. As such, data were collected in a pre/post fashion as well as through artifacts during the unit.

Content knowledge measures

Students were administered a pre-unit assessment one week prior to the beginning of the unit and a post-unit explanation assessment on the Monday after the conclusion of the unit. The purpose of these measures was to determine the level of students' content knowledge to explain the two anomalous inheritance patterns before and after the unit. Both measures were paper-and-pencil assessments. Students took approximately five to ten minutes to complete the pre-unit assessment and approximately ten to fifteen minutes to complete the post-unit assessment.

For the pre-unit explanation assessment, students were shown an inheritance pattern in which the offspring of a tall and a dwarf plant were all tall plants. However, the next generation of offspring from the tall plants were both tall and dwarf plants. The inheritance pattern depicted in this assessment was a standard Mendelian inheritance pattern with "tall" as the dominant variation of the trait. Students were asked to explain why the plants had turned out that way.

The post-unit explanation assessment consisted of two questions in which students were asked to explain several contrasting inheritance patterns for fruit flies. For both questions, the trait involved was shape of the fruit fly abdomen. The two variations of abdomen were bobbed and cut.

The first question depicted two bobbed abdomen fruit flies that were crossed to produce bobbed children. The contrasting inheritance depicted two different bobbed parents that were crossed and produced only bobbed children. For the second question, bobbed and cut abdomen parents were crossed and produced only bobbed children. In contrast, a different set of bobbed and cut parents were crossed and produced both bobbed and cut offspring. Students were asked to explain the difference in outcomes. Incorporated into the first two diagrams on each page was the same Mendelian inheritance pattern tested at the beginning of the unit.

Whole class discussion

During the unit, there were two episodes of whole class discussion that were either videotaped or audiotaped. These discussions primarily involved discourse between myself and the students, with the classroom teacher occasionally interjecting comments as well. The purpose of our discussions was to describe and explain the data the students were collecting, and also to discuss how to analyze it. Excerpts from class discussion are used to illustrate student construction of ideas.

Student scientific reasoning

To gain an understanding of how students were reasoning during the inquiry unit, student data cards and computer logs on diskette were collected. The data cards provided an indication of student hypotheses and the tests they ran. The computer logs, in addition to the data cards, provided a log of the different types of tests students had run. While the overall sample of students consisted of 22 dyads, data cards were obtained for only 10 dyads, while diskettes were obtained for 20 dyads. The discrepancy in data collection arose because students had taken data cards home to use when writing up their reports for the unit and had not brought them back in. While the remaining subset of data cards represented slightly less than half of the overall sample, it did provide examples of a wide range of student work. Student hypotheses on the data cards varied from no hypotheses to somewhat complex hypotheses. The number of tests produced per dyad, based on the data cards alone, also varied tremendously from nine to fifty-one, with an average number produced of 22.1. This number was slightly higher than the average number of tests produced for the overall sample of twenty-two dyads, which was 21.0; this number was compiled from saved computer logs in addition to the data cards. Given these parameters, it was concluded that this subset appeared to be representative of the larger sample. Thus, these data cards were considered a valid subset from which to draw conclusions regarding typical student behavior.

Analyses

Content knowledge

To analyze students' content knowledge, responses for the pre- and post-unit explanation assessments were examined to determine whether students had made gains in their ability to explain the anomalous inheritance patterns. Only those students who had completed both assessments were included for this analysis (N=41). To make a parallel comparison, student responses for the first explanation assessment were compared to the responses for the corresponding anomalous inheritance patterns on the second explanation assessment. Thus, a student's response explaining why a tall and a dwarf plant produced only tall offspring was compared to the same student's response explaining why a bobbed and a cut fruit fly produced only bobbed offspring. Likewise, the response to why two tall plants produced both tall and dwarf plants was compared to the response to why two bobbed fruit flies produced both bobbed and cut offspring.

To analyze both assessments, student responses were first coded and categorized and one rubric was developed to encompass responses from both assessments. Two independent raters then analyzed a stratified sample of 10-15% each of the pre-unit and post-unit assessments. The sample was selected such that each coding category was represented at least once. Raters were blind as to whether the responses were pre-unit or post-unit. Interrater reliability on the codes assigned to student responses was .88 and .93 for pre-unit and post-unit responses, respectively. After coding by the independent rater, discrepancies were discussed and then resolved to achieve 100% agreement on the ratings. These discussions either resulted in clarification of the coding category, re-coding of the assessment to another category, or clarification to the rater's satisfaction of the code that had been assigned. After these discussions, the assessments were reviewed again to determine if any other responses would be affected by any changes made to the coding scheme.

The coding rubric that was developed consisted of descriptive categories that were subsequently ranked from low (0) to high (4) based on explanatory power and relevance to canonical concepts. Each student's explanation for both patterns was coded according to this taxonomy, yielding pre and post values for each student. To determine change based on this taxonomy, a Sign test was used. This test is appropriate for dependent ordinal-level data. A significant value indicates that the pre to post values changed more than would be expected by chance.

Scientific reasoning

Analysis of student scientific reasoning consisted of examining the relative frequency of various types of student-generated hypotheses and tests.

Student-generated hypotheses. To analyze this set of data, categories of hypotheses were formed based on the data cards which were generated per dyad. These categories corresponded to the standarnd and anomalous inheritance patterns found in Mendelian genetics. The standard inheritance pattern was one in which fruit fly parents produced offspring with the same characteristics. Two types of standard hypotheses were coded. One hypothesis involved predicting that parents of the same type would produce only that type of offspring (e.g., red-eyed parents will produce only red-eyed children). The second hypothesis involved predicting that two parents of different types would produce offspring of both types (e.g., red- and white-eyed parents will produce both red- and white-eyed children).

Another main category was that of anomalous hypotheses. Anomalous hypotheses were those in which it was predicted that offspring would be produced who did not look like the parents or who looked like only one of the parents. Two types of anomalous hypotheses were coded. One hypothesis involved predicting that two parents of different types would produce only one type of offspring (e.g., red-eyed and white-eyed parents will produce only red-eyed children). This anomalous hypothesis is labeled with the analytic term of "dominant" hypothesis because it is accounted for by dominance. The second hypothesis involved predicting that parents of the same type would produce offspring of different types (e.g., two red-eyed parents will produce both red-eyed and white-eyed children). This anomalous hypothesis is labeled with the analytic term of "mixed breed" hypothesis because it is accounted for by the fact that the parent fruit flies carry both genetic forms of the trait. In addition to standard and anomalous hypotheses, blank hypotheses and incomplete hypotheses were also coded. Blank hypotheses were those in which students wrote no hypothesis. Incomplete hypotheses were those in which students began writing an hypothesis, but then stopped before a complete thought was written.

For each dyad, the total number of anomalous and standard hypotheses were compiled. These totals were analyzed using a Friedman analysis of variance to determine whether there was a difference in frequency with which students proposed the different types of hypotheses.

Student-generated tests. To analyze the type of tests that students constructed, three categories were formed from the computer logs of the tests that students had run. These three categories corresponded to the different possible combinations of the dominant and recessive forms. This breakdown was of interest because of the premise that anomalous outcomes were most likely to provoke cognitive conflict. The types of tests that could produce anomalous outcomes were those of the dominant form crossed with itself or the dominant form crossed with the recessive form. The recessive form crossed with itself would always produce itself, and therefore was not considered anomalous. Thus, it was of interest to note whether there was differential testing of the combinations that would tend to produce anomalous outcomes compared to the combination that was not likely to produce an anomalous outcome. Therefore, for each dyad the number of dominant x dominant, dominant x recessive, and recessive x recessive tests were recorded for each trait tested. These totals were analyzed using a Friedman analysis of variance to determine whether there was differential testing of the types of tests that could produce anomalous outcomes.

Results

Knowledge Construction

Social construction of knowledge

Based on a social constructivist framework, a reflexive process of knowledge construction can occur where individual students contribute to whole class discussion, and the ensuing discussion can contribute to individual student ideas. Therefore, it was hypothesized that in addition to exposure to anomalies during their investigations, social construction of ideas would occur during whole class discussion. The following excerpts illustrate such an exchange.

During whole class discussion, students were asked to volunteer some of their patterns of data to share with the class. These patterns were written up on the board. In the following scenario, a student mentions that she had crossed two bobbed fruit flies to produce both bobbed and narrow fruit flies, this cross was depicted as B x B -> B, N. When I (I) prompt students for an explanation of this pattern, the following responses were offered by Amelia (A) and Brenda (B) in response to the question of why two bobbed abdomen fruit flies produced offspring that had both bobbed and narrow abdomens.

> A: Well when we took all the fruit flies from the field population, maybe the two that you crossed, maybe one of the fruit fly's parents was a different type, so that it's genes will be different, so that it produces some of the other type of species.
>
> I: So are you're saying that these [pointing to bobbed parents on chalkboard] might not be identical? What's going on with this bobbed?
>
> A: That would have to be, it's like, if you think of it, what chemicals it has, and say it has a little bit of chemical N in it.
>
> I: So it might have some narrow, some narrow might be in this? [in one of the bobbed parents] okay, other ideas? Brenda?
>
> B: It's like, that bobbed carried narrow, it didn't get that, but it still has that as part of its genes so it just carried through.

These explanations were significant because they were alluding to the idea that a fruit fly could carry both genetic variations of the trait, but only look like one variation. That is, a fruit fly could look like a bobbed fruit fly, but still carry the narrow genetic variation. This idea is canonically correct. A fruit fly that has a bobbed and narrow variation, where bobbed is dominant to narrow, will have the appearance of a bobbed fruit fly but will also carry the narrow variation that can be passed on to the offspring.

To follow up with this idea, I then ask the students why a bobbed fruit fly looks as it does if it has some narrow in it. Amelia (A) and Carrie (C) offer responses.

> I: Okay, why is it then, if this has some narrow in it, why does it look like a bobbed? Amelia?
>
> A: Well because the bobbed, the B or whatever, probably has stronger chemical genes in it so its appearance look like it's B, but it does have some of the N.
>
> I: Okay, so somehow it's stronger? Carrie?
>
> C: Well like I said, like one of the parents is probably bobbed, and it probably got like, like it is probably a stronger trait, and it probably got more of the bobbed trait in it and probably some of the trait from the narrow.

Here students refer to a stronger type of the gene, which is analogous to the dominant variation. They further imply that there is also a weaker type, which is analogous to the recessive type. Thus when a stronger type and a weaker type are paired, the fruit fly will have the appearance of the stronger type. These ideas are all approximations of canonically correct notions, and constituted part of the discussion of anomalies during the unit.

<u>Changes in content knowledge</u>

To determine whether a change in student ability to explain the anomalous data patterns had occurred, ranked categories of student responses to the pre-unit and post-unit explanation assessment were analyzed. These responses are summarized in Table 2. Of note in the categories depicted in Table 2 is the use of the term "mixed breed". This term was taken from whole class discussion in which I had noticed that in some cases students indicated that a fruit fly could carry both variations of a trait. This observation was brought up to the students and the term mixed breed was then coined to refer to this situation. In some cases, students also used that terminology in their explanations of the inheritance patterns. Thus, student responses coded as "mixed breed" indicated that the student thought that the one or both fruit fly parents carried both variations of the trait.

Table 2. Frequency of student explanations for anomalous inheritance patterns from pre-unit to post-unit (N=41)

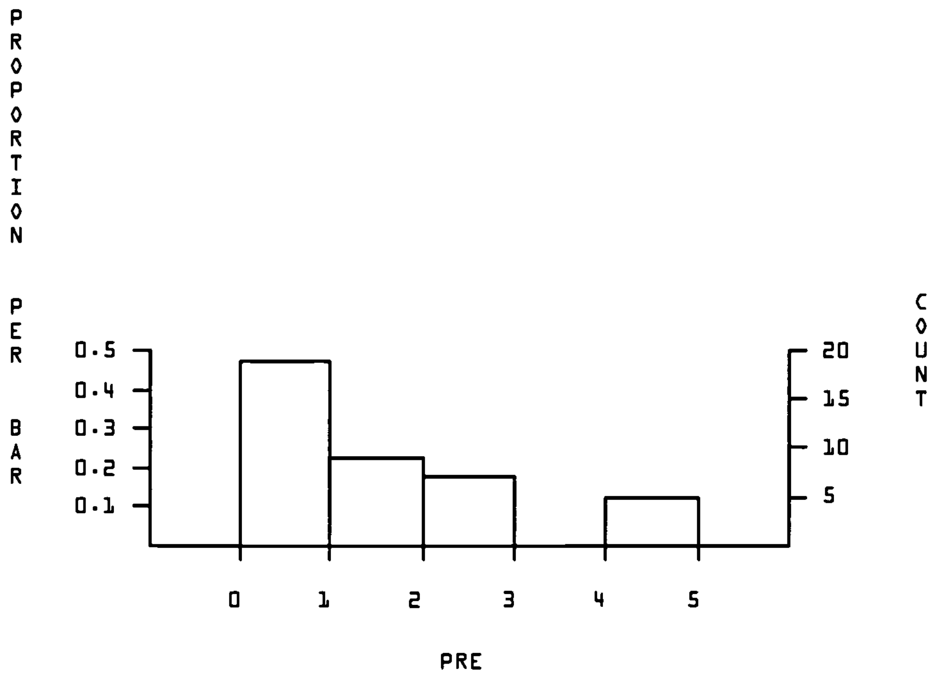
Score	Category	Pre Explanation* % (No)	Post Explanation* % (No)
4	Dominant/stronger vs. mixed breed	5% (2)	34% (14)
	Stronger vs. equal strength	8% (3)	12% (5)
3	Mixed breed/mixed breed		24% (10)
2	Dominant	17% (7)	5% (2)
	Mixed breed		7% (3)
1	Single characteristic	25% (10)	
0	Unintelligible	5% (2)	7% (3)
	Don't know	28% (11)	
	Environment	3% (1)	
	Gender		3% (1)
	Skips a generation /description	13% (5)	8% (3)

*$p<0.0005$

Responses in Table 2 that received a ranking of 0 were those that were descriptive rather than explanatory, non-genetic, unintelligible, or in which the student specifically stated that s/he didn't know how to explain the pattern. Responses that received a ranking of 1 were those that suggested that the offspring received characteristics from only one parent rather than both. This type of response was apparent only on the pre-unit assessment. Responses that received a ranking of 2 were those that explained either one type of anomalous pattern or another, but not both. Responses that received a ranking of 3 were those that explained both patterns using some form of a mixed breed explanation rather than citing dominance as an explanation. These responses were only apparent on the post-unit assessment. In this category, students suggested that either one or both fruit fly parents carried both variations of the trait, but that the offspring happened to come out bobbed. The mechanism underlying this category seemed to be that of chance. If the fruit fly carried both variations of the trait, it was a matter of chance whether the offspring would have the appearance of one variation or the other. Therefore, to explain the anomalous outcomes, students in this category simply assumed that by chance the offspring either came out bobbed or cut.

Responses that received a ranking of 4 were those that most closely approximated canonical explanations for both inheritance patterns, which included citing both dominance and parents that carried the other form of the trait (mixed breed) as rationales to explain the anomalous inheritance patterns. An alternative explanation that also approximated the canonical concept was the stronger vs. equal strength response in which students suggested that bobbed and cut fruit flies only produced bobbed offspring because bobbed was stronger than cut. In contrast, two bobbed parents produced bobbed and cut offspring because bobbed was relatively weaker in that situation which would "allow" both bobbed and cut offspring to be produced.

The change from pre-unit to post-unit rankings is graphed in Figure 3. A Sign test was used to analyze the ranked data. The results of this test indicated that student responses showed significantly more explanatory power on the post-unit assessment compared to the pre-unit assessment with respect to explaining anomalous genetic patterns (Sign=28, $p<.0005$).



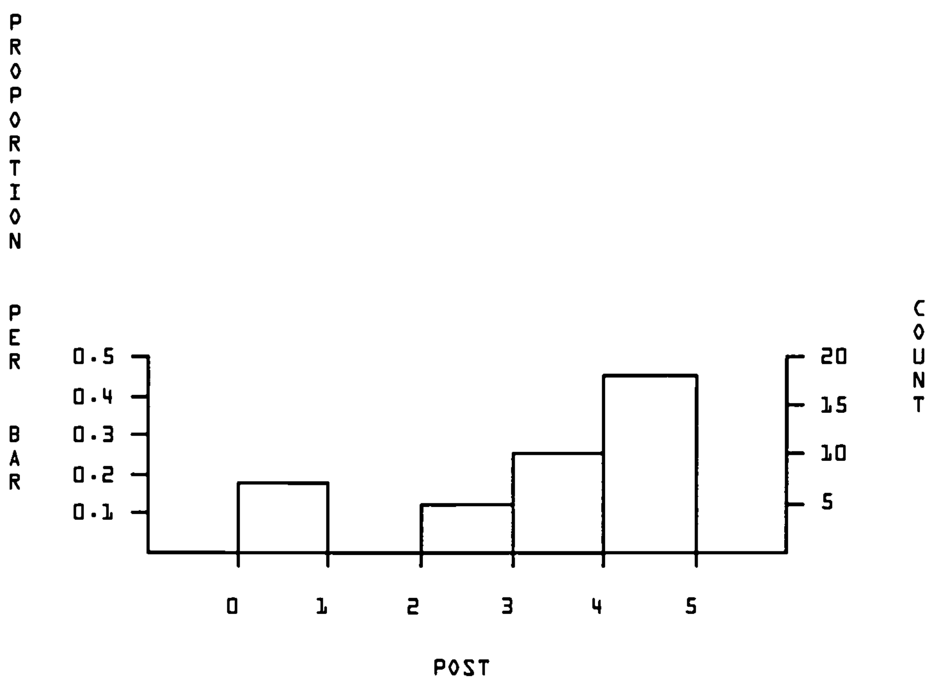


Figure 3. Frequency graph of pre/post explanation assessment scores (0=low, 4=high)

Asymmetry of explanations of anomalous patterns

While students apparently made a significant shift towards more explanatory power of anomalous outcomes, closer examination of their explanations indicated that they did not do so in a symmetrical manner. Specifically, examination of the post-unit explanation assessment indicated that 77% of the students were able to posit a mixed breed explanation for the occurrence of two bobbed fruit flies producing bobbed and cut offspring. In contrast, 53% of the students were able to posit a dominant explanation for the occurrence of a bobbed and a cut fruit fly producing only bobbed offspring. Another 28% of the students posited a mixed breed explanation for this same outcome, rather than positing dominance (See Tables 3 and 4). Why were 77% of the students able to construct the mixed breed explanation, whereas only 53% of the students were able to construct the dominance explanation?

Table 3. Responses to why two bobbed fruit flies produced both bobbed and cut offspring (N=43)

Explanations	% (No.)	Example response
Mixed breed	78% (33)	S1: The reason for this is probly [sic] because the parents of one had cut geens [sic] in it
Nongenetic		
Description	9% (4)	S10: Vial 4 has more types than Vial 7. Vial 7 has no cut.
Gender	2% (1)	S18: The bobbed was a female mabie [sic] in vial 2.
Unintelligible	12% (5)	S23: This happened because the dominate [sic] gene was more effective to the bobbed parents even though cut was involved.

Table 4. Responses to why a bobbed and a cut fruit fly would only produce bobbed offspring in vial 5 (N=40)

Explanations	% (No.)	Example response
Dominant	53% (21)	S17: In vial 5 bobbed was the dominant gene.
Mixed breed	28% (11)	S26: In vial 5 the cut parent had bobbed in it
Nongenetic		
Description	7% (3)	S10: Vial 6 has both types and vial 5 has only one type. They're both different.
Gender	2% (1)	S18: Maybe the female was the bobbed in vial 2 and the cut in vial 4.
Unintelligible	10% (4)	S36: In vial 5, the only bobbed were the offspring because the cut relationship was erased because of two sets of bobbed parents.

Scientific reasoning

Pattern of anomalous and non-anomalous hypotheses

To further elucidate the asymmetric pattern of knowledge construction, hypotheses generated by students during the unit were examined to determine the nature of the link between the knowledge constructed and types of hypotheses generated. The specific analysis of interest was to determine whether significant differences existed in the relative frequencies with which the different types of hypotheses were produced. To analyze these data, the number of each type of standard and anomalous hypothesis was tabulated per dyad. Average totals are shown in Table 5.

Table 5. Average number of anomalous and standard hypotheses generated per dyad (n=9)

Hypothesis Type	Avg/dyad	Example
Standard Hypotheses		
One type produces one type	6.7*	S26/S38: I think if you mix 2 scute you will get scute children
Two types produce two types	6.9	S12/S9: If I cross 1 waxy & 1 heldout the offspring will be both.
Anomalous Hypotheses		
Two types produce one type (dominant hypothesis)	0.4*+	S15/S25: I think when we cross both [types] it will have an offspring of only Aristaless
One type produces two type (mixed breed hypothesis)	3.1+	S46/S29: It will come out mixed [when crossing two grooveless]
Total	17.1	

*p=0.01
+p=0.04

Analysis of the total number of anomalous and standard hypotheses using a Friedman analysis of variance, indicated that significant differences existed between the production of the four types of hypotheses (X^2=10.0, df=3, p=.02). A follow up Wilcoxon ranked sums test was used to determine where the differences between the various types of hypotheses were. These analyses indicated that both types of standard hypotheses were produced significantly more frequently than the dominant hypotheses (Z=2.52, p=.01) and that the mixed breed hypotheses were also produced significantly more frequently than the dominant hypotheses (Z=2.043, p=.04). However, the mixed breed hypotheses were not produced significantly more frequently than the standard hypotheses.

What these results indicated was that, of the two anomalous hypotheses, only the dominant hypothesis was produced less frequently than the standard hypotheses. The mixed breed hypothesis was produced at a comparable level to the standard hypotheses. Thus, the production of hypotheses mirrored the asymmetry found on the post-unit explanation assessment with respect to the greater production of the mixed breed hypothesis relative to the dominant hypothesis.

Testing in response to anomalies

To further investigate the pattern of hypotheses generated by the students, testing patterns were then examined to determine the types of tests students elected to run. Specifically, it was of interest to determine whether the tests that could produce anomalous outcomes were tested more frequently than the test that could not produce an anomalous outcome. Table 6 shows the average number of each type of test run per dyad. Notice that anomalous outcomes could be produced if a fruit fly with a dominant appearance was crossed with another fruit fly that had a dominant appearance or with a fruit fly that had a recessive appearance. The cross of two fruit flies with the recessive appearance would only produce offspring with the same appearance, and thus would not constitute an anomalous outcome.

Table 6. Average number of each type of test run per dyad (N=22)

Test type	Average	Example test for eye color
Anomalous outcomes possible		
Dominant/Dominant	7.8*	Red x Red
Dominant/Recessive	7.6+	Red x White
Standard outcomes only		
Recessive/Recessive	5.5*+	White x White
Total tests	20.9	

*p=0.005
+p=0.10

Analysis of the frequencies with which each type of test was run using a Friedman analysis of variance, indicated significant differences (X^2=7.8, df=2, p=.02). Follow-up analyses with the Wilcoxon signed ranks test indicated that the dominant/dominant tests were conducted significantly more frequently than the recessive/recessive tests (Z=2.9, df=21, p=.005), but the dominant/recessive tests were not conducted significantly more frequently than the recessive/recessive tests (Z=1.6, df=21, p=.10).

The dominant/dominant combination is the test that produces the mixed breed anomalous outcome. This combination was tested significantly more frequently than the recessive/recessive combination. The dominant/recessive combination is the test that produces the dominant anomalous outcome. This combination was not tested significantly more frequently than the recessive/recessive combination, although there was a trend in that direction. Thus, students were most frequently conducting the test that produced the mixed breed anomaly. Next in frequency they conducted the test that produced the dominant anomaly. Least frequently they conducted the test that produced no anomalies.

Differences in anomalous outcomes

To provide additional insight into student testing patterns, the frequency of anomalous outcomes for each type of test were examined to determine if differences in frequency of anomalous outcomes existed between the two types of tests. Using a Wilcoxon signed ranks test, the frequency of mixed breed anomalous outcomes as a proportion of the dominant/dominant tests conducted was calculated for each dyad and compared to the frequency of dominant anomalous outcomes as a proportion of the dominant/recessive tests conducted. The average percentages were 62% and 28% for the mixed breed and dominant anomalous outcomes, respectively. That is, on average 62% of the dominant/dominant tests conducted resulted in mixed breed anomalous outcomes, whereas on average 28% of the dominant/recessive tests conducted resulted in dominant anomalous outcomes. Analysis of this difference indicated that the mixed breed anomalous outcomes occurred significantly more frequently than the dominant anomalous outcomes (Z=3.1, df=21, p=.002). Therefore, when conducting a dominant/dominant test, which was the most frequently run test, students were significantly more likely to see an anomalous outcome than when running a dominant/recessive test.

Discussion

The intent of the current study was to examine the role of anomalies in an inquiry-oriented unit on genetics. Anomalies were intended as a catalyst for knowledge construction based on a social constructivist framework. Using this framework, it was hypothesized that exposure to anomalies in conjunction with whole class discussion would promote knowledge construction. Of additional interest, however, was the nature of students' scientific reasoning in response to the anomalies they encountered during their investigations.

With respect to students' intuitive ideas, it was hypothesized that students would start the genetics unit with the notion that parents with a particular appearance would produce offspring with that appearance. It was further hypothesized then that if parents produced offspring that had a different appearance, that would constitute a surprising or anomalous outcome. Based on this premise, one type of test that students could run during the unit would never produce an anomalous outcome – that of a fruit fly with a recessive appearance being crossed with another fruit fly with a recessive appearance. However, the other two types of tests that students could run could produce anomalous outcomes, but did so to varying degrees. The dominant appearance fruit fly crossed with a recessive appearance fruit fly (e.g., red-eyed x white-eyed) produced an anomalous outcome 28% of the time (e.g., all red-eyed offspring). In contrast, the dominant appearance fruit fly crossed with another dominant appearance fruit fly (e.g., red-eyed x red-eyed) produced an anomalous outcome 62% of the time (e.g., red- and white-eyed offspring).

Both student knowledge construction and scientific reasoning were sensitive to the frequency of occurrence of these anomalies. With respect to knowledge construction, the results show that by the end of the unit students were more likely to construct a differentiated explanation for the more frequently occurring anomalous outcome relative to the less frequently occurring outcome (77% vs. 53%). An additional 28% of the students attempted to generalize the explanation that they had developed for the more frequently occurring outcome to the less frequently occurring outcome, rather than developing a separate explanation.

Student patterns of hypothesis generation and testing were also sensitive to the relative frequencies of anomalies encountered in the data. Students were significantly more likely to predict a mixed breed anomalous outcome than a dominant anomalous outcome. When conducting their tests, students showed a differentiation in which tests they chose to run. They were significantly more likely to run the test that produced the most anomalous outcomes (dominant/dominant) relative to the test that produced no anomalous outcomes (recessive/recessive). The dominant/dominant test is the test that produces the mixed breed anomalous outcome, and did so with a high frequency of occurrence. In contrast, the dominant/recessive test that produces the dominant anomalous outcome did so with a lower frequency. This test was not run significantly more often than the recessive/recessive test or significantly less often than the dominant/dominant test. Therefore, student patterns of testing appeared to be sensitive to whether or not anomalies were encountered. Most frequently they chose to run the test that produced the highest number of anomalous outcomes. Next in frequency they chose to run the test that produced fewer anomalous outcomes. Least frequently, they ran the test that produced no anomalous outcomes.

Thus what appears to have occurred is that an explanation for the mixed breed outcome was constructed by more students by virtue of the fact that it was observed significantly more often than the dominant outcome. What further appears to have happened is that once students had constructed the notion of a mixed breed fly to explain the mixed breed anomalous outcome, they attempted to generalize that explanation to the dominant anomalous outcome, rather than constructing a different explanation for that outcome. This would explain why 28% of the students posited a mixed breed explanation for the dominant anomalous outcome on the end-of-unit explanation assessment.

That students were more likely to produce a mixed breed explanation relative to a dominant explanation appears to be linked to the relative frequency of each. To consistently produce dominant hypotheses, students may simply have needed to encounter more instances of dominant outcomes. Students encountered twice as many mixed breed anomalies as dominant anomalies. Not only were more mixed breed anomalies encountered, they constituted a majority (62%) of the outcomes seen for the dominant/dominant test. Therefore, there may need to be a preponderance of evidence to the contrary in order for students to construct an explanation for an outcome that is at odds with an existing theory.

In addition to encountering fewer dominant anomalous outcomes, a complementary explanation is that perhaps it was more difficult, and potentially less intuitive, to propose a dominant pattern relative to a mixed breed pattern. Specifically, it appeared that some students approached the investigation with the seemingly implicit assumption that both types of traits would behave in a similar manner. That is, students did not seem to assume that one trait should behave differently than another. This is a fair and logical initial assumption that was evident when students tried to apply the mixed breed hypothesis that held for the dominant trait to the recessive trait. For example, if students found that two red-eyed parents produced both red- and white-eyed offspring, in one case they then predicted that two white-eyed parents would also produce both red- and white-eyed offspring. This was an outcome that would have been impossible for them to observe because the recessive form crossed with itself can only produce itself. Therefore, some students were apparently attempting to generalize their mixed breed hypothesis from one form of the trait to the other, in effect assuming that both forms would behave similarly.

Assuming that both forms of the trait would behave similarly is an hypothesis conceivably based on a principle that "two similar things behave similarly" (Echevarria, 2000). That is, when confronted with two objects that look the same, the most common assumption is to assume that they will act the same as well. Therefore, when students were confronted with two variations of the same trait, their initial hypothesis was that both variations would behave in a similar manner. This mental model was flexible enough to be generalized to explain both anomalous outcomes by theorizing that flies always carried both forms of the trait, and that whichever variation appeared was a matter of chance. Once this theory had been used to explain both anomalous outcomes, it became unnecessary to construct a separate explanation for the dominant anomalous outcomes. In contrast, though, some students did recognize differences in the frequency with which each variation of the trait appeared. It is presumably these students who then constructed separate explanations for the dominant anomalous outcome.

Individual differences

While the data presented here present an overall picture of the response of the class as a whole, individual gains will clearly vary. Based on the data cards that students generated, it appeared that students varied with respect to how many instances of anomalous data would cause them to begin proposing anomalous hypotheses. One dyad (S10/S14) seemed to switch from the standard hypotheses after one instance of anomalous data, while another dyad persevered with the standard hypotheses regardless of anomalous data encountered across several traits, until finally relenting and proposing one anomalous hypothesis (S12/S9). Burbules and Linn (1988) report similar individual differences with respect to how many instances of contradictory evidence cause students to revise their hypotheses. Unfortunately in the current study it was not possible to examine individual differences with respect to both knowledge construction and scientific reasoning because students responded individually to the explanation assessments, but worked in pairs on their investigations. Therefore, it was not possible to unpack individual gains in knowledge construction in relation to testing patterns completed by the dyads. Rather, it was only possible to depict general patterns and trends in the data.

Conclusions

The research presented here provides some insight into how students can react to anomalies in the context of an inquiry-oriented investigation. These findings are relevant for the practice of conducting inquiry-oriented investigations in the classroom, as well as for expanding the knowledge base on responses to anomalous information by examining both knowledge construction and scientific reasoning together. The overall pattern of the data was that students generated hypotheses, ran tests, and constructed explanations in proportion to the extent to which they encountered anomalies. More anomalies meant that more hypotheses, tests, and explanations were generated. However, it was noted that there may be an interaction with the fact that the less frequently occurring anomaly may have also been less intuitive to explain. Another pattern of interest was the fact that the more frequently occurring anomaly occurred to such a high extent, comprising the majority of the outcomes for that test. Further research in other inquiry-oriented contexts is needed to provide more information as to the consistency of the patterns presented here, and to determine whether there are overall trends in approaches to scientific reasoning and knowledge construction that can be predicted when learners are presented with anomalous information.

References

Burbules, N. C., & Linn, M. C. (1988). Response to contradiction: Scientific reasoning during adolescence. Journal of Educational Psychology, 80(1), 67-75.

Carolina Biological Supply Company (1989). Wisconsin Fast Plants: Investigating Mendelian Genetics. Burlington, NC: Carolina Biological.

Chinn, C., & Brewer (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. Review of Educational Research, 63(1), 1-49.

Cobb, P., & Yackel, E. (1995). Constructivist, emergent, and sociocultural perspectives in the context of developmental research. Paper presented at the North American Chapter of the International Group for the Psychology of Mathematics Education, Columbus, OH.

Demastes, S. S., Good, R. G., & Peebles, P. (1996). Patterns of conceptual change in evolution. Journal of Research in Science Teaching, 33(4), 407-431.

Echevarria, M. (2000). Principles and ontological conceptions as a framework for middle school students' knowledge construction and scientific reasoning during inquiry. Submitted manuscript.

Friedler, Y., Nachmias, R., & Linn, M. C. (1990). Learning scientific reasoning skills in microcomputer-based laboratories. Journal of Research in Science Teaching, 27(2), 173-191.

Hafner, R., & Stewart, J. (1995). Revising explanatory models to accommodate anomalous genetic phenomena: Problem solving in the "context of discovery". Science Education, 79(2), 111-146.

Jungck, J.R., & Calley, J. (1993). Genetics Construction Kit. In J.R. Jungck, P. Soderberg, J. Calley, N. Peterson, & J.Stewart (Eds.), The BioQUEST library. College Park, MD: University of Maryland Press.

Kuhn, D., Garcia-Mila, M., Zohar, A., & Andersen, C. (1995). Strategies of knowledge acquisition, Monographs of the Society for Research in Child Development, 66(4 4).

Kuhn, D., Schauble, L., & Garcia-Mila, M. (1992). Cross-domain development of scientific reasoning. Cognition and Instruction, 9(4), 285-327.

Limon, M., & Carretero, M. (1997). Conceptual change and anomalous data: A case study in the domain of natural sciences. European Journal of Psychology in Education, 12(2), 213-230.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66, 211-227.

Roth, W. M., & Roychoudhury, A. (1993). The development of science process skills in authentic contexts. Journal of Research in Science Teaching, 30(2), 127-152.

Schauble, L. (1990). Belief revision in children: The role of prior knowledge and strategies for generating evidence. Journal of Experimental Child Psychology, 49, 31-57.

Schauble, L., Klopfer, L. E., & Raghavan, K. (1991). Students' transition from an engineering model to a science model of experimentation. Journal of Research in Science Teaching, 28(9), 859-882.

Shepardson, D.P., & Moje, E.B. (1999). The role of anomalous data in restructuring fourth graders' frameworks for understanding electric circuits. International Journal of Science Education, 21(1), 77-94.

Tao, P.K., & Gunstone, R.F. (1999). The process of conceptual change in force and motion during computer-supported physics instruction. Journal of Research in Science Teaching, 36(7), 859-882.

Vollmeyer, R., Burns, B. D., & Holyoak, K. J. (1996). The impact of goal specificity on strategy use and the acquisition of problem structure. Cognitive Science, 20, 75-100.

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