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Experienced Middle School Science Teachers' Assessment Literacy: Investigating Knowledge of Students' Conceptions in Genetics and Ways to Shape Instruction

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Abstract Using a framework of assessment literacy that included teachers' view of learning, knowledge of assessment tools, and knowledge of assessment interpretation and action taking, this study explored the assessment literacy of five experienced middle school teachers. Multiple sources of data were: teachers' predictions about students' ideas, students' written and verbal responses to assessment tasks, teacher background questionnaire, and a videotaped teacher focus group. We investigated middle school teachers' predictions, interpretations, and recommended actions for formative assessment in genetics. Results documented a variety of ways that teachers would elicit students' ideas in genetics, focusing on discussion strategies. Findings showed how well teachers predicted student conceptions compared to actual student conceptions. We also found that teachers mostly described general topics they would use to address students' alternative conceptions. Less often, they explained specific content they would use to challenge ideas or pedagogical strategies for conceptual change. Teachers also discussed barriers to addressing ideas. Teacher professional development should provide more support in helping teachers close the formative assessment cycle by addressing conceptions that are elicited with assessments.

Keywords Assessment · Genetics · Teacher knowledge · Middle school

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Introduction

We aim to understand how experienced teachers assess students' prior knowledge, and how they mold their instruction and facilitate conceptual learning. Assessing student learning formatively is one of the most important skills that science teachers need to develop (Mertler and Campbell 2005) to make informed decisions in the classroom (Abell and Siegel 2011). Addressing students' prior knowledge helps foster learning. In order to address students' prior knowledge, science teachers must understand instructional methods for assessment and strategies for using student data to shape scientifically accurate conceptions (Magnusson et al. 1999). Teachers need to be aware of students' common misconceptions within the topics that they teach, because it will allow them to further analyze and address students' ideas (Magnusson et al. 1999).

Researchers use different terminology when studying students' ideas, from "preconceptions" to "naïve ideas" to "misconceptions." In this study, we will refer to the more general "conceptions," and we will use "areas of student difficulty" or "alternative conceptions" to indicate that the conceptions are not scientifically accurate.

Relatively little research investigates science teachers' knowledge of areas of student difficulty. In one study of physics teachers' knowledge of students' understanding of force and gravity, researchers found that in a group, teachers were able to identify common alternative conceptions (Berg and Brouwer 1991). However, individually, teachers identified few of the common alternative conceptions and were not aware of those held by their own students (Berg and Brouwer 1991). In addition, individual teachers' explanations for students' reasoning errors varied, leading to disparate instructional responses (Magnusson et al. 1994). Further analysis showed that teachers who thought that particular errors were uncommon had students who exhibited those reasoning errors after instruction in the topic area (Magnusson et al. 1994).

Other studies have shown that knowledge of students' understanding does not guarantee that teachers can respond with appropriate instruction when students display alternative conceptions. Inservice professional development resulted in teachers becoming more knowledgeable of common alternative conceptions, yet the majority of teachers ignored these in the classroom, or struggled for ways to respond (Smith and Neale 1991). More recently, Morrison and Lederman (2003) worked with "experienced" and "exemplary" science teachers to assess their ability to diagnose "preconceptions," recognize the importance of doing so, and respond to preconceptions. The researchers found that although in interviews the teachers expressed critical reasons for diagnosing students' preconceptions, the participants did not use formal assessment tools to uncover students' preconceptions (2003). The teachers used questioning, but were observed asking low-level recall questions. When asked how they would use the information, teachers said they would employ the information to re-teach the material. However, none of the teachers were observed re-teaching this material in the classroom (Morrison and Lederman (2003).

Research on how experienced teachers understand assessment, use tools to diagnose students' conceptions, and understand how to take action in the classroom is an underrepresented area in the research literature (Abell 2007). To begin to address this gap, we studied middle school teachers' predictions, interpretations, and recommended actions for formative assessment.

Theoretical Framework: Assessment Literacy

Assessment literacy has been defined as the ability to develop assessments that transform learning goals into assessment activities that accurately reflect student understanding and achievement (Mertler and Campbell 2005; Stiggins 2002). We broaden this notion by proposing that teachers approach assessment based on their view of learning and that teachers require the ability to interpret assessment results and adapt instruction (Abell and Siegel 2011; Siegel and Wissehr 2011). In Abell and Siegel (2011), a model of assessment literacy is described based on the research literature and our own studies. This model proposes three main aspects of assessment literacy: view of learning, assessment principles, and four areas of knowledge (Fig. 1). Below, we describe the aspects of the model of assessment literacy most relevant to the current study.

View of Learning

A teacher's assessment philosophy is based on and connected to a teacher's view of student learning (Pellegrino et al. 2001; Shepard 2000). Views of learning are central to the model, shown in Fig. 1, because if a teacher views learning as memorizing what is told, s/he will assess students' recall of information. If a teacher views learning as constructing understanding, s/he will use formative assessments to establish a continuous flow of information about students' understanding to adapt effective instruction (Black 2003; Stiggins 2002). A teacher with assessment literacy can interpret assessment data, communicate with students about the status of their understanding, and employ this information to set short- and long-term learning goals. Surrounding the views of learning—the core of the model of assessment literacy—are two components that include the knowledge of tools and knowledge of interpretation and action taking.

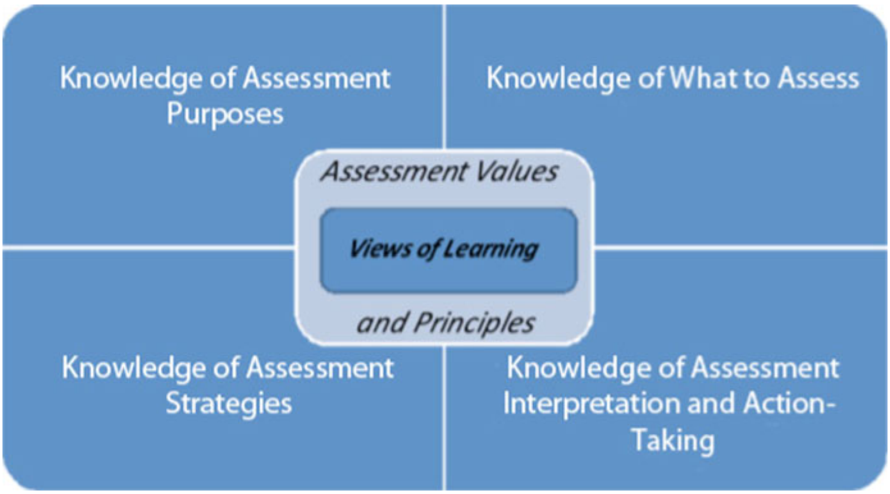

Fig. 1 A model for science teacher assessment literacy (from Abell and Siegel 2011)

Knowledge of Tools

Understanding of assessment tools (Fig. 1) includes knowledge of assessment formats, strategies, and specific instruments related to scientific concepts (Magnusson et al. 1999; Abell and Siegel 2011; Siegel and Wissehr 2011). Assessment literate teachers use strategies beyond the traditional multiple choice and true/false type of formats. The National Science Education Standards advocate using multiple strategies for assessing students' science understanding (NRC 1996). Familiarity with a variety of assessment tools helps teachers to select the most relevant and powerful instruments for particular learning goals. Limited research has examined science teachers' selection of certain assessment strategies (Duffee and Aikenhead 1992; Pine et al. 2001). Preservice teachers have also been found to have a thin cache of assessment strategies to choose from (Yilmaz-Tuzun 2008). The affordances and drawbacks of various assessments need to be considered in terms of instruction and learning (Sundberg 2002). In one study of middle school teachers' formative assessment practices, Ruiz-Primo and Furtak (2007) demonstrated that a teacher who asked the most conceptual questions and had the largest variety of ways of adapting instruction based on assessment data, also had the highest level of student performance.

Knowledge of Assessment Interpretation and Action Taking

Another essential aspect of assessment literacy is teacher understanding for interpreting and acting on assessment information, shown in Fig. 1. Teachers "need to know not only what, when, how, and why to assess, but also what do to with the assessment data" (Abell and Siegel 2011).

Interpretation is often overlooked in studies of assessment. To emphasize the importance of making sense of assessment data in a National Research Council report, Pellegrino et al. (2001) identified interpretation as one of the three keys to assessment (the other two being cognition, or theory of learning, and observation, or collection of assessment data). Not many studies have investigated how teachers interpret classroom assessment data (cf. Kokkotas et al. 1998; Lannin et al. 2008). In Lannin et al.'s study, science teacher knowledge was categorized to include predictions about ways students would respond to assessments.

Once teachers interpret assessment results, developing an instructional strategy to address the findings is necessary. Reforms have not provided science teachers many resources for accomplishing this. One resource, Diagnoser, provides elicitation questions to uncover ideas, counterexamples and targeted feedback, and pointers to instructional activities based on the assessment data (Hunt and Minstrell 1994). However, the few lessons in life sciences are still under development. In another major project, teachers learned additional ways to respond to students' difficulties, based on assessment evidence (Gearhart et al. 2006). Yet, teachers required additional resources to guide their interpretation of growth in student understanding over time (Gearhart et al. 2006). In limited studies, researchers examined ways teachers could adapt instruction based on assessment evidence (Lannin et al. 2008; Mulholland and Wallace 2005).

Research Questions

The investigation focused on what experienced life science teachers know about students' conceptions in genetics and how they use students' prior knowledge to shape their instruction. We developed Genetics Assessment Tasks for teachers to use during the focus groups to predict students' conceptions and discuss ways to address them—components of assessment literacy. During the focus groups, first I (first author) asked teachers about the assessment tools they already use in the classroom. Then, I showed them the Genetics Assessment Tasks and the standards and asked them to predict areas of student difficulty. Finally, we discussed ways to address ideas through instruction. The research questions were:

1. What assessment tools do experienced life science teachers use to elicit students' conceptions?
2. What do experienced life science teachers predict will be areas of student difficulty on the topic of genetics? How does this compare to student difficulties found on given assessment questions?
   - Based on the genetics content standards, what alternative conceptions do teachers predict?
   - Based on the Genetics Assessment Tasks, what alternative conceptions do teachers predict?
3. Based on students' conceptions revealed in the assessment questions, what topic-specific instructional strategies do teachers recommend?

Method

Multiple sources of data for the study included teachers' predictions about students' conceptions, students' written and verbal responses to assessment items, teacher background questionnaire, and a videotaped teacher focus group. Next, we introduce the five teacher participants, with pseudonyms to protect anonymity and then describe the data sources and analysis.

Participants

The five participants were selected based on their professional experience and a willingness to volunteer their time for the study. Professional experience was defined by: number of years teaching science, educational background (both in the fields of biology and education), and involvement in professional development or teacher organizations.

Mary has taught high school biology for 7 years in a city. Mary is the Co-director of her school's Health Academy and teaches the Health Laboratory class required for the program. Mary graduated from a 4-year university with a Bachelor's of Arts in Biology and a minor in Health Care Systems. She completed graduate work in Foods and Nutrition research and subsequently earned her Single Subject Credential in Biology with English language development emphasis. Mary is a member of several teacher associations and has participated in summer project-based learning and integrated project workshops.

Sonia has taught life sciences for 18 years. She has worked in both urban and suburban environments. Currently, she teaches in a suburban middle school. Sonia received her Bachelor's of Science in Zoology from an international university with minors in Botany, Biochemistry, and Philosophy. Sonia has completed a Master's in Education Administration and holds state credentials in both Life Science and Administration. She has participated in several educational research projects some of which involve assessing constructivist teaching practices. She has presented her research at major teacher conventions and led teacher workshops on the topic of promoting constructivist teaching practices. Sonia is a member of several teacher organizations and has participated in the professional development committee for elementary science at her school site. Sonia has also worked as a curriculum developer at a research university.

Caroline has taught sixth- and seventh-grade science in a suburban public school for the past 11 years. Previously, she was the owner and director of an Early Childhood outdoor education program. Caroline has worked at a science museum as a science teacher coach. Caroline received her Bachelor's of Arts in Philosophy with a minor in Biology from a major four-year university. She has a state teaching credential in math. Caroline is a member of several professional education organizations and also represents teachers in several workers' unions.

Laura taught secondary science for 14 years in urban school settings before becoming a supervisor for pre-instructional teachers. She taught a Supervised Teaching class and a Teaching Methods class for 6 years in a teacher preparation program at a university. Laura received her Bachelor's of Arts in Biology from a four-year university, holds a credential in the subject of life science, and is a member of national teaching organizations.

Katrina has been teaching science for the past 23 years in an urban district. She began her career as a science teacher for an elementary school and later taught middle school earth science for 2 years. For the past 20 years, Katrina has taught an accelerated high school biology course. In addition, she has simultaneously taught one section of Advanced Placement (AP: college equivalent) biology for the past 6 years. Katrina holds a Bachelor's of Science in Biology from a four-year university and also has a degree in Special Education. She earned a teaching credential in biology and recently achieved National Board Certification in four teaching areas. Katrina has attended workshops on Biotechnology integration and becoming an effective Advanced Placement teacher. She is also a member of several science teacher organizations.

Development of Genetics Assessment Tasks

As part of a larger assessment study with a group of researchers, we developed questions that aim to address middle school students' alternative conceptions of life science. Our goal was to write problems that assess students' pre-instructional ideas and intuitions rather than focusing on terminology and accuracy. We attempted to design questions to elicit the variety of conceptions students have of the living world. These assessment tasks were developed through an iterative process which involved: writing the problem based on content standards, peer review of the problem in research group, re-writing the problem based on suggestions, testing the problem with students, and lastly, a final re-write. Each of the four questions used in this study was initially written following this process, and subsequently, multiple versions of each question were written in order to pose the questions in different contexts. The assessment tasks address the topics of sex determination, heredity, and environmental and genetic influences on characteristics. Listed in "Appendix" are the versions of each question used in this study. Along with each question is a description of which alternative conceptions the question addresses and the referenced national content standards.

Teacher Data: Background Questionnaire, Predictions, Videotaped Focus Group

Before the teacher focus group occurred, each participant completed a background questionnaire designed to detail their teaching experience. The questionnaire asked teachers to describe their professional teaching experience, their educational background, their participation in teacher organizations or professional development, and any other information describing their experience as a science teacher or teacher educator.

The teacher focus group was designed to survey teachers' predictions about areas of student difficulty and their knowledge of topic-specific instructional strategies for genetics. The essence of the focus group is that it brings together a targeted group of teachers, in this case experienced science teachers, and allows them to reflect on their teaching practices in a way that initiates invention about the topic. While there are limitations to the focus group method (see pp. 26–27), interaction among participants often enhances the quality of data because the participants tend to provide checks and balances that diminish false views (Kreuger and Casey 2000). This study focused on the ideas of the group rather than pinpointing or comparing individual ideas, which would have necessitated individual interviews. Prior to the focus group, the researcher provided each participant with an overview of the study and some theoretical background. The 3-h focus group was video recorded and teachers' work was collected. The meeting was split into three sessions: an introduction to the research, a brainstorming session that included prediction of students' alternative conceptions, and a diagnostic session.

During the brief introduction, the teachers became acquainted and discussed two areas of pedagogical content knowledge—knowledge of student difficulties and instructional methods (Magnusson et al. 1999). After the introduction, the teachers began a brainstorming session with two main foci: first, participants were asked to list the instructional methods they use to assess students' prior knowledge. Second, based on the state and national standards for genetics, the teachers were asked to predict the types of alternative conceptions that might come up in a middle school classroom. The researcher participated in the session by recording the teachers' comments on a poster. The teachers' comments were posted on the wall for further reference throughout the evening. It should be noted that the prediction sessions did not just consist of the teachers listing strategies or alternative conceptions; often, comments led to deeper discussions about the topics that were mentioned. Due to time constraints, the researcher limited the discussion around each topic to 45 min.

The diagnostic session of the focus group involved teachers working with the student data that were collected a month prior using the Genetics Assessment Tasks (see below). The main goal of this session was to survey how experienced life science teachers use students' prior knowledge to shape their instruction. The teachers were split into two smaller groups; each group worked with a specific question type. To provide teachers with a diverse sample of student responses, the question types were selected based on the range of answers given in the interviews. For each group, four samples of student work were provided. Student work was selected based on the types of alternative conceptions students displayed, with the goal of the teachers being exposed to a range of answers. Before listening to the student interviews, the teachers read over all the versions of their question type, predicting what alternative conceptions they thought would exist in the interviews. Later, the participants listened and read the student work one by one, while taking notes on what types of alternative conceptions, the student displayed, how firmly student held to his/her ideas, and what instructional strategies might be useful for that specific student. After listening to four samples of student work, each group discussed which alternative conceptions they detected in the student work, how student confidence was related to students' naive explanations, and the types of instructional strategies they might employ with these students. The groups were asked to think of innovative ways to confront these students' alternative conceptions and ways to aid them in constructing more scientifically accurate notions. At the end of the diagnostic session, the groups reported back to each other with their findings.

Student Data: Secondary Data Source

In order to compare teachers' predictions to student understanding, students were interviewed using the assessment tools developed that address state and national standards. The 53 students from three life science classes at a middle school were: 80 % white, 14 % Asian, 3 % Hispanic, 1 % Filipino, 0.4 % African American, and 1.6 % other or no response (Ed-data 2002–2003). The audiotaped data were collected through one-on-one student interviews with seventh-grade students prior to instruction on the topic of genetics, over a span of 2 weeks. Participants were asked to read an assessment question (Appendix) and then write their answer on the piece of paper. When the student was finished working, the researcher read over the question and read aloud the students' answers. The students were asked to explain in further detail the reasons for their answers. Finally, the researcher asked each student to rank their level of confidence in their answers for each part of the problem. Students were asked to use a scale from one to ten—one meant that they were not at all confident and ten meant they were completely sure their answer was scientifically accurate.

Data Analysis

The video data from the teacher focus group were transcribed. The transcriptions were then used to extract key points based on the study's research questions (Hatch

2002). The transcriptions were coded inductively to identify patterns in the data (Patton 2002). After the inductive analysis, we compared the teacher's predictions and instructional strategies to students' actual alternative conceptions. Data from the secondary student interviews were summarized in a chart detailing question type, question version, student ID, student explanation, and student confidence level. The teachers' methods for assessing students' prior knowledge and their predictions of alternative conceptions for genetics were compiled into lists. The data from the diagnostic session were organized in two ways. First, the participants' predictions of alternative conceptions based on their question type were compared to the results gathered during the student interviews. Second, the four student explanations that each group analyzed were listed in a table alongside the teachers' suggestions for instruction.

To increase the reliability of the analysis, we utilized investigator triangulation (Patton 2002). Data were primarily coded by the first author, and random selections were checked by the second author. Discrepancies were discussed until reaching 100 % consensus. In addition, when a pattern emerged, we investigated the data closely for any evidence refuting the emergent pattern.

Results

Findings for RQ 1: What Assessment Tools do Experienced Life Science Teachers Use to Elicit Students' Conceptions?

During the brainstorming session, the focus group participants listed several methods they use to assess students' prior knowledge. Table 1 lists these methods. Mostly, the teachers had experience using small group discussions as a means to assess students' prior knowledge, and for this reason, the participants spent the majority of the allotted time discussing the benefits and drawbacks of small group discussions.

One of the benefits mentioned was that when students discuss questions in groups, their ideas build on one another's. Despite the fact that this benefit may lead students to new alternative conceptions, the teachers found that it spurred a discourse around the topic of interest. In this quote, Caroline captures the emotions she feels when students discuss an exciting topic in a group.

> You know what, it's interesting if it's not an individual question, if it's to the group, the kids just do this free association (group agrees). (Mimicking

Table 1 Assessment tools listed by teachers during brainstorming session

Pre-instructional journals
KWL chart (What do you Know? What do you Want to know? What did you Learn?)
Concept mapping
Group discussions around question prompt
Class pre/post knowledge of subject on a large piece of butcher paper
Pre/post true or false questions at the start of a unit

> students) …sometimes that is very interesting to overhear and listen to (group agreeing)…So, the same thing tends to happen in a group, a kid will go, 'oh, I remember that light travels across the universe' and another kid will go 'oh!'… and off they go.—Caroline

Caroline's thoughts about students' natural instinct to build on each other's ideas were echoed by the rest of the focus group. The participants continued to discuss the difference between prompting groups with open-ended questions and asking more specific questions with a directed intention. Here, Caroline describes the different types of questions that she and her teaching partner, Sonia, use to elicit students' ideas.

> There's a lot of different ways of doing that (asking group questions). Sonia and I tend to be totally divergent on our techniques. Sonia tends to be totally open like 'what is light?' and I tend to go 'Can you explain to me how come the sunsets are red?' I try to be more specific. Or with genetics, 'How come if both parents have brown eyes, is that kid theirs? The blue eyed kid?' and then tackle it concrete. It is also interesting to see the wide open question because then you get stuff that you might not necessarily get with a more specific one.—Caroline

Caroline believes specific questions allow students to be more focused on a particular concept, while open-ended questions draw out more divergent answers. Open-ended questions may bring up more obscure conceptions but, as Sonia stated, it may also be difficult to direct the class discussion if a teacher has insufficient content knowledge.

The teachers in the focus group discuss the importance of avoiding terminology-rich questions when assessing students' prior knowledge. Mary describes how using scientific jargon while prompting students to discuss a topic may result in students being reluctant to participate.

> I think too, when introducing a new topic, rather than asking questions that include the terminology that you are moving towards, you ask questions that have to do with everyday life that is understandable. Rather than just hitting them with…scientific jargon.—Mary

The participants extend Mary's thought to explain how students' discourse can serve as a way for learners to discover or create a concept before learning its scientific term. This excerpt from the focus group discussion describes how three participants share their teaching experience and come to a conclusion about using prior knowledge to understand new vocabulary.

> **Caroline**: "I really like it that they struggle to say it before they have the term because then it's coming from I see this, I'm putting this together, and then you give them the term and they say oh that's what you call that. Because then it's like they put the observation with what they know and it's like 'Oh!'"
> **Katrina**: "So, it's kind of like discovery on their part."
> **Sonia**: "It's like learning vocabulary from a real background. Why do we need to know these stupid terms? It's not learning another language just for the sake of it.

But making the link to the relevance in their lives (group agreement) is very important at the beginning of a unit."

Here, the teachers described a process in which having students discuss a scientific concept, struggle with a definition, and then receive the scientific term, allow them to create their own knowledge. Summarizing Caroline's thoughts above, this process gives ownership of the knowledge to students.

In addition to avoiding terminology-rich questions, the teachers discussed the importance of providing students with a real-life context in which to understand a small group discussion prompt. Mary explained how students from different cultural backgrounds might make sense of problems in different ways. In order for her learners to respond, the problem must have a personal relevance. Instructional context may play an important role in designing effective prompts that will push students to talk about their prior knowledge.

The teachers also emphasized the benefit of structured activities to increase participation by allotting time for each student in a group to share their ideas. In addition to increasing participation, structured activities also give students the opportunity to develop their thoughts before sharing with the whole class. Here, Sonia describes the benefits of "Four Explore" a small group activity where partners express their ideas with one another and later share their findings with the whole class.

> We often use stuff like 'Four Explore' where we ask them stuff in their smaller groups so that shy kids share back and forth, and it gets them thinking. I go around the room and listen to what groups are saying, or in this case I would bring it to a class discussion so that we get somewhat more thought out ideas. And it seems to improve the level of discussion so that you don't get one dominant kid saying 'I hear your nails grow after you die' and you're thinking well what's that got to do with it.

A critical advantage of structured activities is that teachers are freed from leading a class discussion and have the autonomy to circulate through the groups, monitoring students' responses. This situation allows a teacher to assess far more students than she would in a whole class discussion. As Sonia states above, structured activities improve whole class discussions because they allow all students to prepare their contribution. Laura described another structured activity called "The Three Step Interview."

> **Laura**: "That's where, I think in that setting, is where that three step interview goes well. Where there is person A, B, C, and D and it's something that you're discussing for the first time, you tell her your idea and I tell him my idea and then we switch. Then when we report back you have to describe to everybody her idea. So that it…"
> **Caroline**: "You really have to listen!"
> **Mary**: "And then they have to report to the whole big group, or just to their small group?"
> **Laura**: "Yeah, you're reporting out what someone else believes, which is also a good scientific thing to do…you know read someone else's work and then you

have to describe it. And then that gets them listening and interpreting an idea. They might struggle a little bit in figuring out what they believe and telling another person. So, it makes them develop their idea before they say it."
Katrina: "But it's not threatening because you're doing it in such a small group."
Laura: "Yeah, it's just one on one. And then sometimes the person reporting back says their idea, fills in a little too, and already you have student developing it."

The "Three Step Interview" and "Four Explore" share similar virtues because they allow students to develop well thought out contributions prior to a whole group discussion, and they facilitate students speaking and listening to each other. In summary, the teachers in this study reported that using a small group discussion to assess students' ideas is effective because it allows the instructor to design a question tailored for her own instructional context and structure the discussion to promote a wide range of participation.

Findings for RQ 2: What Do Experienced Life Science Teachers Predict Will Be Areas of Student Difficulty on the Topic of Genetics? How Does This Compare to Student Difficulties Found on Given Assessment Questions?

We found that experienced teachers' predictions about students' difficulties were varied but only matched the most common student difficulties. In the second part of the brainstorming session, the teachers were asked to think of common alternative conceptions that students' might have about the topic of genetics. Teachers were provided with content standards (California State Board of Education 1998; National Research Council 1996) to prompt their discussion. Table 2 lists all of the responses of the participants. The teachers came up with a wide range of alternative conceptions, some of which matched the ones given by students in the interviews. It should be noted that the four question types used during the student interviews were aimed at specific conceptions, and therefore, it should not be expected that all the conceptions on the teachers' list be exhibited by students during the interviews. The teachers were able to identify several of the conceptions that have been documented in research articles (Deadman and Kelly 1978; Engel Clough and Wood-Robinson 1985; Kargbo et al. 1980), further supporting their overall understanding of areas of student difficulty.

Looking at the individual questions as prompts, the focus group participants predicted several of the most common alternative conceptions students gave during their interviews, although teachers' predictions were somewhat limited in comparison with the actual diversity of student responses. Tables 3 and 4 compare the responses gathered during the student interviews to the responses that teachers gave during the focus group. Table 3 shows that four out of the twelve alternative conceptions were predicted by the teachers during the focus group. Of those four responses, two were exhibited by more than one student during the seventeen interviews that used Question Type I. Table 4 compares the findings for the group working with Question Type III. Table 4 shows that teachers predicted three of the

Table 2 List of expected conceptions based on content standards

(1) **Students might think dad's genes go to his son, mom's genes go to her daughter**
(2) **Students might think male's genes are more "powerful" than female's**
(3) Students might think the intensity of a characteristic makes a gene more powerful (e.g.: taller is more powerful than shorter gene)
(4) Students might think that dominant genes are more frequent in the gene pool
(5) Students may not know the link between DNA and genetics or that the nucleus is the carrier of the DNA and heredity information
(6) Students might have difficulty accepting the idea of microscopic biomolecules that cannot be seen by the naked eye (e.g., If you cannot see something (like DNA), how can it be there?)
(7) Students may not know what we mean by a "blueprint"
(8) Students might think DNA is not in somatic cells, and only in gametes
(9) Students may not know that chromosomes are large chunks of DNA that are made up of genes
(10) Students may think that all DNA codes for genes
(11) Students may think that you can cross two species to get a new species
(12) Students may get confused between a cladistic diagram and a pedigree
(13) **Students might not know that characteristics are determined by both environment and genetics**
(14) **Students may not know that plants reproduce sexually and asexually**
(15) Students may not be able to detach their socially constructed understanding of sex in order to understand its role in biology and more specifically evolution (rural vs. urban)

Bold alternative conceptions represent ones that have been well documented in research studies

eight given responses, and it is interesting to note that the teachers did not mention the most frequently given explanations: that offspring receive more genetic information from one parent than the other.

The evidence in these two tables supports the claim that the teachers in this study understand areas of student difficulty and can predict students' alternative conceptions, but they may not be able to predict the full range of answers that students will exhibit for a given problem. In the final part of the diagnostic session, the two groups worked with individual student data to recommend topic-specific instructional strategies that will help achieve conceptual change.

As teachers discussed the student data from the interviews, they often compared the students' conceptions to the common alternative ideas of their youth. We report this here because many of the common alternative conceptions that existed two generations ago have become less visible, causing a need to assess to find out what difficulties students currently have. Here, Caroline, Laura, Katrina, and the researcher have a discussion about an old alternative conception that was prevalent two generations ago.

Caroline: "My mom when she told me the facts of life… she told me, she said… Your dad plants a seed and because it's your blood to grow up, you can take after your mom but it's mainly your dad because he planted the seed."
Laura: "Did you get all mixed up?"
Caroline: "Farmers wife and they had not a clue… But she thought that was the influence of the gestation… and it was blood because mom gives her blood that was it, mom gives her blood but dad plants the seed so she's…"

Table 3 Comparison of teachers' predictions of students' conceptions to the data collected during student interviews

Topic summary Question Type I: How is gender determined in offspring?	
Teachers' predictions of student responses to Question I	Summary of students' naïve explanations exhibited during interviews using Question I
(1) Offspring gender is determined by same sex parents' genes	(1) God determines the sex of a child
(2) **One gender has weaker genes than the other, and therefore, phenotype is not present**	(2) **Amount of sperm that fertilizes the egg determines sex; different eggs need different amounts of sperm**
(3) **One gender has more determining factors in the gender of the offspring**	(3) Different people have different chance of having a male or female child
(4) **Mother determines the sex of the child**	(4) **Female is responsible because she has the baby inside of her**
(5) Always going to have an equal number of boys and girls (fairness factor)	(5) Different food for mother during pregnancy might change the gender of the offspring
	(6) **Female is responsible because the gender of the offspring is already determined in the egg**
	(7) Sperm is a certain kind that only gives one kind of offspring
	(8) Older eggs may be defective and results in only one gender for offspring
	(9) Gender problem passed on from parents' parents
	(10) Male is more responsible because he is the breeder
	(11) **One parent's genes might not be strong enough**
	(12) If a male is the only male in his family, this may cause him to have only female offspring

Bold text denotes alternative conceptions that appeared in both data sets

Laura: "The blood mixes."
…**Caroline**: "I'm surprised we don't hear more about the mix blood because a whole generation ago that was like a deal, (asking the researcher) I don't know did you get a whole bunch of mixed blood stuff?"
Researcher: "Not any mention really of that in the interviews."
Caroline: "That's maybe good then, because that was an idea that was worthy of dying."
…**Caroline**: "Like bad blood you know (Laura agreeing), oh you see he's too young to know there's bad blood. You know bad blood in your family?"
Laura: "You use to hear that common (Laura nods}."
…**Researcher**: "And that's where that comes from a misconception that blood…"
…**Laura**: "And that's inherited the blood influences your behavior."

The participants were surprised to find that the types of alternative conceptions that were prevalent in their youth were not mentioned during the student interviews (not to say that these alternative conceptions have ceased to exist). For the teachers in the

Table 4 Comparison of teachers' predictions of students' conceptions to the data collected during student interviews

Topic summary Question Type III: Explain how it is possible for a child to resemble one parent more than another?

Teachers' predictions of student responses to Question III	Summary of students' alternative conceptions exhibited during interviews using Question III
1. **Mom's genes go to the daughter; Dad's genes go to the son**	1. Offspring received more genetic information (genes, chromosomes, or sperm) from that parent
2. **Darker color phenotypes are dominant over lighter color phenotypes (eyes, hair, etc.)**	2. **If one child looks more like a parent than all the offspring will look like that parent**
3. Dominance of the individual determines offspring phenotype	3. Mom's body can be more or less experienced in child bearing; less experience results in less influence over offspring's phenotype and vice versa
4. If one child looks like Dad then the other must look like Mom (fairness factor)	4. Sperm is made up of more than one cell
5. **If one child looks more like a parent than all the offspring will look like that parent**	5. **Similar gendered parent and offspring will look alike**
	6. Chance determines how much genetic information is contributed by each parent
	7. After conception, phenotype may change over time to look more like the other parent
	8. **Darker color phenotypes are dominant over lighter color phenotypes (eyes, hair, etc.)**

Bold text denotes alternative conceptions that appeared in both data sets

focus group, this realization was important because it suggests that they may need to reconsider the types of alternative ideas they think students will have; assessing students' prior knowledge is now even more important because teachers need to uncover what new alternative conceptions exist.

Findings for RQ 3: Based on Students' Conceptions Revealed in the Assessment Questions, What Topic-Specific Instructional Strategies do Teachers Recommend?

Teachers had difficulty using students' naïve ideas diagnostically to prescribe instruction to address ideas. Teachers in Group One used the student data to suggest instructional direction but focused less than Group Two on the actual instructional strategies that might foster conceptual change for the specific alternative conceptions in their data set. Group One discussed the topics students should be taught in order to properly understand the concept, rather than offering-specific activities that would confront students' ideas.

Table 5 summarizes the findings from Group One's diagnostic session. The column on the left is the student example that the group was working with, and the column on the right represents what the teachers suggested for instruction based on that example. In Example 2, the teachers do give some suggestions for instructional strategies. In this case, the student answered that the gender of an offspring depends

Table 5 With Question Type 1, actions were based on topics suggested

Example alternative conceptions from interviews	Teachers' comments on instruction
(1) The amount of sperm that fertilizes the egg determines the gender; the amount of sperm needed is determined by the egg	Teach more about fertilization, Mendelian inheritance, and sex determination
	Two possible chromosomes from each parent and chance determines which one an offspring receives
	Punnett squares at the chromosome level showing sperm and egg
(2) Depends on which sperm reaches the egg first; chance. (Student is scientifically accurate.)	Reinforcement of student's ideas
	Two possible gametes
	Trial and error activities matching up different combinations of gametes → females can only donate Xs; males can donate X or Y
(3) Particular mating pairs may only produce certain types of offspring, depends more on the individuals than genetics. It may also depend on chance/day	Fertilization/conception is the moment of determination (when genes come together)
	Gamete formation/meiosis
	Embryology

However, participants generated less specific strategies for addressing alternative conceptions

on which sperm reaches the egg first, which is a scientifically accurate observation. In order to support this student's idea, the teachers suggested matching up different combinations of sex chromosomes and having students observe what gender the resulting offspring is. In this activity, students are presented with data that shows a female can only contribute an X chromosome while a male can contribute either an X or a Y. These instructional suggestions did not occur frequently, as this group tended to suggest curricular directions, such as which topics to teach or reinforce. The last example in Table 5 provides support for the claim that the teachers in this group suggest instructional direction rather than actual activities aimed at confronting students' alternative conceptions. The student in this example stated that the male's genes were not strong enough and that perhaps the mother had more influence over the gender of the baby because the baby is inside of her. The teachers suggested that the student needs more instruction on fertilization, meiosis, and embryology, which are wide-open topics. While the teachers are probably correct in suggesting those topics for further instruction, they made little attempt to discuss the instructional methods that could make teaching these subjects a worthwhile way of addressing the students' alternative conceptions.

When faced with the same diagnostic task as Group One, Group Two was more successful at considering the specific alternative conceptions in their data set and suggesting instructional strategies that aim to confront these ideas. Table 6 summarizes the findings from Group Two's diagnostic session. Again, the column on the left is the student example, and the column on the right represents the teachers' suggestions for instruction based on that example. In each student example they examined, Group Two suggested specific content-focused methods for addressing that students' alternative conception. For instance, in Example 2, the

Table 6 With Question Type 3, teachers suggested strategies for addressing alternative conceptions

Example alternative conceptions from interviews	Teachers' comments on instruction
(1) Two sperm from dad caused "more of his genetic match"; Dad is more overpowering; Sperm is made up of several cells; Mom's body becomes more "experienced" after first offspring and might be ready to express more genes in subsequent offspring	Visual approach (Punnet squares)
	Pedigree: have students examine for passing on of traits. After examining several pedigrees from different organisms ask students to consider their naïve explanation
(2) Offspring received more of one parent's gene; genes are passed down but not something you inherit	Comparing the amount of chromosomes in egg and sperm (look at microscopy/karyotype)
	Activities around meiosis, what would happen if their gametes were diploid → exponential growth?
	Activities that challenge more genes theory by presenting data in a simulation activity
	Variation on faces activity
(3) Some genes are stronger and those genes are shown; Dad's genes are dominant traits	Activities that challenge more genes theory by presenting data in a simulation activity
(4) One parent put in more chromosomes than the other. It is a chance of how many chromosomes are put into egg or sperm	Comparing the amount of chromosomes in egg and sperm (look at microscopy/karyotype)
	Activities that challenge more genes theory by presenting data in a simulation activity. Cross two species and observe outcome in offspring, students make prediction, and then present new outcome and ask students to reconsider their hypothesis

student states that a child can look more like one parent than another because the child received more of one parent's genes. In order to confront that notion, the participants recommend having students examine the karyotypes of the male and female gametes and compare the amount of chromosomes in each. When students observe the same number of chromosomes in an egg and sperm, they will need to reconsider their explanation and possibly form a new, more scientific, explanation based on this new evidence. By presenting evidence that disagrees with a student's alternative conception, a teacher can encourage a student to reconsider his ideas and develop more scientifically accurate views. Yet, teachers did not apply many pedagogical strategies to this area of genetics. For example, we did not see teachers discussing a conceptual technique, such as having students evaluate how much they believe an idea after content-specific instruction was provided.

Another topic discussed in the focus group was the ways in which instructional strategies that present anomalous data can be difficult to implement because teachers must be patient and let students uncover the contradictions to their ideas individually. In the following excerpt from the focus group, Sonia shares her experience of trying to teach an activity in which students progressively adjust their hypotheses based on new data.

> You're manipulating the counters and you're trying it in different ways. Does this work or does this work? Does this fit your hypothesis or your explanation? Or do

> you want to discard this one and try this one? So, it's quite laborious and it's quite stressful on the teacher sometimes because it's weird letting them play with ideas that you know to be false. You know you keep wanting to go over and say well… and you want to keep leading them but I'm learning to step back and let it run its course and let them discover for themselves that the most obvious idea is not.

Sonia describes a metacognitive practice in which she makes a conscious decision to restrain herself from helping students reach the correct finding. Sonia states that letting go of the traditional model of the teacher giving information to the students, and instead permitting students to form their own new knowledge can be stressful and difficult. These reflections helped Sonia and the other focus group members summarize what it means to complete the formative assessment cycle and use students' prior knowledge to build more scientific concepts.

One final observation from the teacher focus group was a bit surprising. Previously, the teachers had discussed that if a teacher has limited content knowledge in a particular domain, assessing students' prior knowledge through a group discussion may be difficult because the teacher will not know when the conversations are veering from the topic. Interestingly, the teachers also saw extensive knowledge of a domain as a possible obstacle to addressing alternative conceptions. For example:

> **Sonia**: "…. I can't understand how you could not understand natural selection and things like that. And having to go back and simplify it I find it quite difficult. And it's the same with genetics because I know too much about it. And you're always saying… Well on the other hand… and it's actually important for this unit not to do that until they understand the simple idea. And to table by saying, that's a very interesting idea we're going to talk about that later I want you to understand the simple thing first…."
> **Mary**: "Yeah, and the exception is often what they'll remember, right? The exception to the rule."

Sonia finds that having knowledge of the very fine details of a topic, for her, the topic of genetics, can tempt a teacher to tackle all the tiny exceptions that may come up during discussion with students. This can harm students who do not have a general groundwork of the basic principles of a topic. As Mary states, addressing the exceptions prior to instruction may result in students learning the exception rather than the rule. Sonia's advice is to lay the foundation first, and when students come across the exceptions in discussion, the instructor can acknowledge the comment and divert it to a subsequent class. Sonia's comments exemplify the type of knowledge that is specific to science teachers—pedagogical content knowledge—discussed in the focus group.

Discussion

This study revealed an image of experienced life science teachers' assessment literacy. In this section, we discuss the results in light of the model of assessment literacy (Fig. 1) and the research literature.

View of Learning

Throughout the focus group, participants commented on the need for teachers to address students' prior knowledge. The teachers were aware that students' alternative conceptions may be rooted in cultural beliefs and personal experiences and for these reasons, may be resistant to change. We also found that Sonia, especially, referred multiple times to her view of learning as helping students construct their own knowledge, and how this impacted her stress level, her metacognition, and her assessment practices.

Knowledge of Assessment Tools

As detailed in the "Results" section, the teachers in the focus group listed a few formal methods for assessing students' prior knowledge and spoke in detail about the method of small group discussion as an effective tool for assessment. The assessments teachers listed are specific ways of uncovering students' prior knowledge. In Morrison and Lederman's (2003) study, they also worked with "experienced" science teachers, but contrary to what this study shows, they found that teachers were not able to list specific assessment tools and instead reported using the method of "questioning" to assess students' existing knowledge. During classroom observations with these teachers, Morrison et al. (2003) found that "questioning" amounted to basic call-and-response instruction. Researchers have also demonstrated that teachers are not proficient at implementing a variety of classroom assessment tasks (Mertler 1999; Mertler and Campbell 2005). While we did not conduct classroom observations, our findings in Table 1 reveal that experienced teachers listed several assessment tools; yet, one might expect a group of veteran teachers to produce more than this list.

Knowledge of Assessment Interpretation

As a group, the teachers in this study identified areas of student difficulty in the topic of genetics. The teachers used content standards to brainstorm a list of possible student alternative conceptions. For Question Type I and III, the teachers were able to predict some of the most frequently occurring naive student explanations. For Question Type I and III, students displayed a larger range of responses than teachers were able to predict. These findings suggest that experienced teachers have some knowledge of topic-specific areas of difficulty in terms of the types of alternative conceptions students display. Berg and Brouwer (1991) came to similar conclusions in their study; they found that in a group, teachers were able to identify common alternative conceptions. However, in their study, when teachers worked alone, they identified few common alternative conceptions and were not aware of the alternative conceptions that existed in their own classrooms.

Knowledge of Actions

In the final diagnostic section of the focus group, most teachers responded to student data with suggestions of further content exploration. Despite the fact that the teachers were asked to think of instructional activities to address specific alternative conceptions, the majority of comments were ideas for what to teach next or the topics that need to be re-taught to students. This corroborates the findings of Morrison and Lederman (2003) who found that experienced science teachers suggested re-teaching subjects in response to students' preconceptions. One teacher in the focus group, Sonia, did propose specific instructional strategies for achieving conceptual change. Her activities involved presenting students with anomalous data that confronts students' naïve ideas and lets students construct new knowledge by viewing evidence that contradicts their own theory (see Table 6). In her pre-focus group questionnaire, Sonia listed her extensive participation in research around the topic of conceptual change and constructivism.

We found that teachers' knowledge in different areas of the assessment literacy model aligned. Amount of knowledge in one area—assessment tools to elicit ideas (few but lacking)—was also found to reflect the amount of knowledge in other areas—interpreting students' ideas and taking instructional action (limited). While the experienced teachers seemed to possess a constructivist view of learning, their arsenal of assessment techniques and strategies for addressing ideas was a bit limited. In the "Educational Implications" section, we discuss ways to improve this situation.

Limitations

Like many studies, this study took a close look at a few participants. We analyzed teachers' predictions about student ideas and their self-reported knowledge during focus groups, rather than observing practice. The focus group provided a platform for the teachers to discuss their experiences with addressing students' prior knowledge. Limitations of focus groups include possible censoring and conflict avoidance (Carey 1994). The moderator can play a role in reducing this outcome. While much research focuses on individuals, focus groups take a social approach. However, focus groups are not a technique that will produce quantitative data or generalizations about populations (Fern 2001).

Educational Implications

Teachers know that they can use assessment data to assign grades. More sophisticated assessment literacy includes knowing how to use assessment data to modify one's plans for instruction. Through the use of formative assessments, teachers gain information about student understanding that helps them to make instructional decisions, modify teaching and learning activities, and more accurately focus their teaching practices to support student learning (Black 2003; Bell and Cowie 2001). Helping teachers improve assessment literacy will take a major effort (Abell and Siegel 2011; Siegel and Wissehr 2011).

Life science teachers must recognize that the diversity of students' alternative conceptions can change with each topic. The findings from this study suggested that students possess a wide range of conceptions about certain topics but have fewer on others. While assessing students' alternative ideas, small group discussion may facilitate this process in an equitable way, providing each student with the opportunity to speak.

Bell's (2007) review stated that science teachers are increasingly using assessment tasks with a wide range of formats (e.g., concept maps, portfolios, interviews, observational methods, and self, peer, and group assessment). This study also suggested that carefully designed assessments are needed to elicit students' pre-instructional ideas. The assessments in this study were designed through an iterative process of writing, evaluating, and revising. Science teachers might not usually have time to design such assessments, but need skills to critically evaluate assessments and need an understanding of effective assessment design processes (Siegel and Wissehr 2011). Teachers require more assessment resources, including better ways of eliciting students' ideas and detailed examples of effective assessment practices.

Effective means of feedback for students and communicating about learning are also in demand for teachers. Few teacher educators are well trained in assessment (Popham 1999; Siegel and Wissehr 2011). Having more prepared teacher educators and professional developers, as well as effective assessment resources for working with teachers is needed in science education. As more teachers take on leadership roles in assessment reform, more teachers will be impacted.

This study revealed that experienced science teachers have some tools for eliciting and predicting students' ideas but that they may have difficulty in designing instructional strategies that challenge students' alternative conceptions. The one teacher who was successful at detailing topic-specific instructional activities had participated in numerous professional development and research activities around the subject. We believe much work is needed to provide teachers useful assessment resources to elicit, interpret, and address students' ideas most effectively.

Appendix: Genetics Assessment Tasks

Question Type I

Question Type I addresses students' knowledge of how sex is determined in offspring. More specifically, it asks students to consider which parent, male or female, is responsible for determining the sex of an offspring and how this determination process occurs. This question was designed around the observation that students think the female parent is responsible for determining the sex of the offspring because the offspring develops inside of her body. It addresses the following national standards.

- National Science Education Standards

> In many species, including humans, females produce eggs and males produce sperm. Plants also reproduce sexually—the egg and sperm are produced in the flowers of flowering plants. An egg and sperm unite to begin development of a new individual. That new individual receives genetic information from its mother (via the egg) and its father (via the sperm). Sexually produced offspring never are identical to either of their parents.

Question Type I Version 1

Greg and his wife Marsha have six children all of which are boys. They both really want to have a daughter, but they cannot understand why they always have boys. Marsha thinks that maybe it is her fault that she can only bear sons. The couple decides to go see their doctor in order to find out what they can do to have a girl.

1. Who do you think is responsible for determining the sex of the children (Marsha, Greg, or neither)? Explain.
2. Do you think Greg might have a better chance of having a daughter with another woman? Explain.
3. What do you think their doctor told them? Explain why.

Question Type I Version 2

Tom is a dog breeder who wants to raise a female German Sheppard. He tries to accomplish this by mating two adult German Sheppard dogs. In the first litter, there are five babies, all of which are male. Tom is not happy because he wants a female German Sheppard. Tom decides to ask a veterinarian whether there is any way to increase his chances of breeding a female German Sheppard.

1. Which dog do you think is responsible for determining the sex of the puppies (female, male, or neither)?
2. Do you think Tom might have a better chance of breeding a female German Sheppard if he mates two different adult dogs?
3. What do you think the veterinarian told Tom?

Question Type I Version 3

In a hope to breed a champion racehorse, breeders take a male horse that comes from a family of champion racehorses and mates it with a female horse that comes from a family of champions. Rachel is a breeder trying to breed two such horses in order to get a male offspring. After five attempts, Rachel has only managed to get female offspring. Rachel is not sure why she is only getting female offspring.

1. Why do you think this is happening?
2. Who do you think is responsible for determining the sex of the horse (the male parent, the female parent, or neither)? Explain.
3. Do you think Rachel might have better luck mating the male horse with a different female horse? Explain.

Question Type II

Question Type II assesses students' prior knowledge of the influence of genetics and environment on human characteristics. In the case of identical twins, we asked students to predict what effect long amounts of separation would have on human characteristics. This question was informed by observations that students have difficulty understanding the notion of phenotype being influenced by both genetics and environment. A common alternative conception might be that characteristics are only determined by genetics or through heredity. This question addresses the following national standards.

- National Science Education Standards

  The characteristics of an organism can be described in terms of a combination of traits. Some traits are inherited and others result from interactions with the environment.

Question Type II Version 1

Two identical twins, who share all the same genetic information, are separated at birth and adopted by different parents. They grow up apart from each other, but then are finally reunited after 30 years.

1. Do you think the siblings will look the same?
2. Do you think the siblings will act the same?

What if the two had never been apart and were raised by the same parents?

1. Do you think the siblings will look the same?
2. Do you think the siblings will act the same?

Question Type II Version 2

Two identical twins, who share all the same genetic information, are separated at birth and adopted by different parents. They grow up apart from each other, but then are finally reunited after 30 years.

1. Do you think the siblings will have the same color eyes?
2. Do you think the siblings will write with the same hand?
3. Do you think the siblings will enjoy the same types of music?
4. Do you think the siblings will like the same kinds of foods?

What if the two had never been apart and were raised by the same parents?

1. Do you think the siblings will have the same color eyes?
2. Do you think the siblings will write with the same hand?
3. Do you think the siblings will enjoy the same types of music?
4. Do you think the siblings will like the same kinds of foods?

Question Type III

Question Type III addresses students' knowledge of heredity. The question asks students to explain how it is possible for an offspring to look more like one parent than another. This question was designed around the observations that students' believe an offspring will resemble the same sex parent.

- National Science Education Standards

> In many species, including humans, females produce eggs and males produce sperm. Plants also reproduce sexually—the egg and sperm are produced in the flowers of flowering plants. An egg and sperm unite to begin development of a new individual. That new individual receives genetic information from its mother (via the egg) and its father (via the sperm). Sexually produced offspring never are identical to either of their parents.
> Every organism requires a set of instructions for specifying its traits. Heredity is the passage of these instructions from one generation to another.

Question Type III Version 1

Everyone tells Timmy that he looks so much like his Dad. Timmy has fair skin, blonde hair, and blue eyes just like his dad. Timmy's mom, who has brown hair, brown eyes, and dark skin, wonders why her son does not look like her. Can you help her understand?

1. Why do you think Timmy looks more like his dad than his mom?
2. If Timmy has a sister, do you think she will look more like her dad or mom?

Question Type III Version 2

Tom, the dog breeder, is trying to make a light colored German Shepherd by mating a German Shepherd with a Golden Retriever. Tom is once again disappointed when he finds that the puppies look like German Shepherd puppies and not a mix of the two breeds. Tom wants to know why the puppies did not come out like a mix of the two breeds.

1. Why do you think the puppies look more like the German Shepherd than the Golden Retriever?
2. If Tom mates the same German Shepherd with a different Golden Retriever, do you think the puppies would look more like a mix of the two breeds?

Question Type IV

Question IV combines two concepts: laws of heredity and the influence of environment and genetics on phenotype. Here, students must decide whether an organism which, through environmental factors has sustained damage to its body cells, is capable of passing that trait on to its offspring. This question is based on the observation of students responding that injuries sustained to body cells can be passed on to offspring.

- National Science Education Standards

The characteristics of an organism can be described in terms of a combination of traits. Some traits are inherited and others result from interactions with the environment.
In many species, including humans, females produce eggs and males produce sperm. Plants also reproduce sexually—the egg and sperm are produced in the flowers of flowering plants. An egg and sperm unite to begin development of a new individual. That new individual receives genetic information from its mother (via the egg) and its father (via the sperm). Sexually produced offspring never are identical to either of their parents.
The characteristics of an organism can be described in terms of a combination of traits. Some traits are inherited and others result from interactions with the environment.

Question Type IV Version 1

Susan wants to have children but she is afraid to. When Susan was a child, she got in a horrible car accident that caused her to walk with a limp for the rest of her life. Susan is afraid that if she has children, they will also have the same limp.

1. Do you think Susan should be worried her children might have the same limp she has? Explain why or why not?

Question Type IV Version 2

Sweetie Pie was a champion racehorse in her day, but due to an unfortunate accident, she has lost use of her legs. Sam, Sweetie Pie's owner wants to try and breed her in the hope that her offspring will also become a champion racehorse but Sam is concerned that the horse's injury will be passed on to her offspring.

1. Do you think Sam should be concerned about this? Explain.

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