Understanding Genetics: Analysis of Secondary Students’ Conceptual Status

Chi-Yan Tsui, David F. Treagust

Science and Mathematics Education Centre, Curtin University of Technology, Kent Street, Bentley, Perth, WA 6102, Australia

Received 4 February 2005; Accepted 6 July 2005

Abstract: This article explores the conceptual change of students in Grades 10 and 12 in three Australian senior high schools when the teachers included computer multimedia to a greater or lesser extent in their teaching of a genetics course. The study, underpinned by a multidimensional conceptual-change framework, used an interpretive approach and a case-based design with multiple data collection methods. Over 4–8 weeks, the students learned genetics in classroom lessons that included BioLogica activities, which feature multiple representations. Results of the online tests and interview tasks revealed that most students improved their understanding of genetics as evidenced in the development of genetics reasoning. However, using Thorley’s (1990) status analysis categories, a cross-case analysis of the gene conceptions of 9 of the 26 students interviewed indicated that only 4 students’ postinstructional conceptions were intelligible–plausible–fruitful. Students’ conceptual change was consistent with classroom teaching and learning. Findings suggested that multiple representations supported conceptual understanding of genetics but not in all students. It was also shown that status can be a viable hallmark enabling researchers to identify students’ conceptual change that would otherwise be less accessible. Thorley’s method for analyzing conceptual status is discussed. © 2006 Wiley Periodicals, Inc. J Res Sci Teach 44: 205–235, 2007

This article is a cross-case analysis of students’ conceptual learning in Grade 10 and 12 classes taught by four teachers in three Australian senior high schools. During a genetics course in 2001 and 2002, these students’ classroom learning included computer-based activities of BioLogica (Concord Consortium, 2001) and other interactive multimedia that feature multiple representations.

Genetics, especially modern molecular genetics, is now central to learning and research in biomedical sciences and is essential for understanding the contemporary issues related to genetic modification, genomics, and cloning. In school biology, genetics is one of the few areas that encourage reasoning and problem solving (Stewart & Hafner, 1994). However, researchers over the past two decades have unanimously found that genetics remains conceptually and linguistically difficult to teach and learn in high schools (e.g., see Bahar, Johnstone, & Hansell, 2001).
Over the past two decades, science education approaches to conceptual change have undergone a shift from an epistemological or cognitive perspective to include other dimensions of learning such as the motivational and social/affective dimensions (Pintrich, Marx, & Boyle, 1993) and the ontological dimension (Chi, 1992; Chi, Slotta, & de Leeuw, 1994). Cognitive-developmental approaches to conceptual change also have undergone a shift from the dominant Piagetian developmental psychology that emphasizes stage-dependent and domain-general conceptual learning to other frameworks, such as Ausubel’s assimilation theory (Novak, 1978), the Vygotskian perspective that emphasizes social contexts (Vygotsky, 1978), and domain-specificity (Carey, 1985) in conceptual learning.

Two trends in conceptual-change research are relevant to this study. First, as already discussed, conceptual-change research has been advancing beyond the epistemological dimension since the early 1990s. Second, the role of intentional learning (Bereiter & Scardamalia, 1989) has become a new direction for conceptual-change research (Sinatra & Pintrich, 2003). Bereiter and Scardamalia used the term intentional learning to refer to “cognitive processes that have learning as a goal rather than an incidental outcome” (p. 363), and claimed that intentional learners embrace “learning as problem solving” beyond “learning through problem solving” (p. 265) as they intend to solve other unassigned, real-world problems based on their understanding of the phenomena. According to Bereiter and Scardamalia, intentional learners consider: (1) learning as problem solving; (2) learning how to learn; and (3) learning to know what one does not know.

There is a general consensus among the conceptual-change researchers that the learners’ conceptual ecology or their prior knowledge, including ideas, commitments, beliefs, and so on, provides the context within which conceptual change occurs (Hewson, 1981, 1982; Hewson & Hennessey, 1992; Posner, Strike, Hewson, & Gertzog, 1982). The key factor to conceptual change is the status of a new conception held or considered by a learner according to three conditions for conceptual change. The status measures the extent to which the learner: knows what the new conception means and can represent it; believes the new conception to be true and finds it consistent with or is able to reconcile with it other accepted ideas; and finds the new conception of value useful in solving problems or suggesting new possibilities and directions. These three conditions are intelligibility, plausibility, and fruitfulness (Hewson, 1981, 1982; Hewson, Beeth, & Thorley, 1998; Hewson & Hennessey, 1992; Posner et al., 1982). Accordingly, learners must also have dissatisfaction, another condition for change, with their old conceptions. The status of a new conception can be not intelligible or “no status” (Hewson, 1982, p. 64), intelligible (I), intelligible–plausible (IP), or intelligible–plausible–fruitful (IPF), leading to satisfaction. A fall in the status of a learner’s conception—as intelligibility, plausibility, and/or fruitfulness, respectively, decreases within the learner’s conceptual ecology—leads to dissatisfaction, which, as Hewson and Lemberger (2000) recently clarified, is “a psychological response to the other, epistemological, conditions” and “a psychological state, not to be confused with status itself” (p. 111). Although the analysis of students’ conceptual status enables researchers to identify deep conceptual change, very few studies have analyzed students’ conceptual status.

As learning always involves some ways of representing information, science teachers have long been using different representational techniques in the classroom to communicate ideas to students by voice, writing, images, gestures, and so on. Representations are simply the ways we communicate ideas or concepts by representing them either externally—taking the form of spoken language (verbal), written symbols (textual), pictures, physical objects, or a combination of these forms—or internally when we think about these ideas (Hiebert & Carpenter, 1992). Conceptions
can be regarded as the learner’s internal representations constructed from the external representations of entities constructed by other people, such as teachers or software designers (Thorley, 1990). Duit and Glynn (1996) considered conceptions as learners’ mental models of an object or an event. From the conceptual-change learning perspective, representability is essential for making difficult concepts more intelligible (Thorley, 1990).

As a complement to the many empirical and theoretical studies of analogies and metaphors in science education, the increasingly sophisticated learning technologies have necessitated new perspectives for better analyses and interpretations of the unprecedented new opportunities and challenges for teachers and researchers (e.g., see Jacobson & Kozma, 2000). Recently, researchers in the cognitive–computational sciences have investigated the pedagogical functions of using more than one form of computer-based representation in educational software or multiple external representations (van Someren, Reimann, Boshuizen, & de Jong, 1998).

de Jong et al. (1998) proposed three reasons for using more than one representation in computer-based learning environments. First, specific information can best be conveyed in a specific representation. A combination of several representations is therefore necessary to display learning material that contains a variety of information. Second, expertise in problem solving depends very much on having a large repertoire of multiple representations of the same domain, switching between them, and selecting the most appropriate ones for use in problem solving. Third, a specified sequence of learning material is beneficial for the learning process. These multiple representations, as some researchers claimed, can support learning by providing/supporting complementary information and/or cognitive processes, by constraining interpretations or misinterpretations of phenomena, and by promoting the construction of a deeper understanding of concepts through: abstraction, such as detecting and extracting a subset of relevant elements from a representation; extension or extending knowledge learned in one representation to new situations with other representations; and relations, such as translating between two or more unfamiliar representations (Ainsworth, 1999). Unfortunately, learning with multiple representations may not always be useful because of the new costs and challenges (Ainsworth, Bibby, & Wood, 1997). Ainsworth (in press) recently proposed, in the DeFT (Design, Function, Tasks) framework, that, to understand the effectiveness of learning with multiple representations, considerations must be given to three aspects: design parameters unique to learning with multiple representations; the functions of multiple representations that support the learning; and the cognitive tasks undertaken by a learner interacting with multiple representations. Multiple representations appear to be a promising construct for improving learning of complex concepts in science. Indeed, some studies have shown that the notion of multiple representations, when used in normal classroom teaching, can also be useful for analyzing and solving problems in physics and mathematics (e.g., see Dufresne, Gerace, & Leonard, 1997).

In this investigation we report on a study involving student engagement in computer-based activities of BioLogica (Concord Consortium, 2001) that features multiple representations. BioLogica is an example of hypermodels, which are software environments that allow users to interact with a manipulable model of a phenomenon in a domain (Horwitz, 1995). The BioLogica hypermodel is designed for learning introductory genetics in high schools. Unlike other less interactive simulation programs, BioLogica allows students to manipulate objects of genetics represented at different levels of biological organization—DNA, genes, chromosomes, gametes, cells, organisms, and pedigrees—and observe their behavior constrained by the Mendelian model of genetics and molecular/cellular mechanism. All representation levels are linked so that changes in one level are reflected in all the other levels. Activity scripts mediate learners’ interaction with the hypermodel through a sequence of challenges, monitor their progress, and provide them with feedback and helpful hints as they work through the activities (Buckley et al.,

As Horwitz and Tinker (2001) predicted, the use of powerful, content-based modeling and data analysis tools such as BioLogica is likely to help improve science learning, and the hypermodel “could be the key to realizing this dream in real classrooms” (p. 5). Indeed, two other hypermodel examples have been created recently by the Concord Consortium: Connected Chemistry and Dynamica (Physics) (http://mac.concord.org/curriculum/). In 2000 and 2001, the Concord Consortium’s research group studying modeling across the curriculum conducted a large-scale study on model-based learning using BioLogica in 15 schools in the United States (Buckley, Gobert, & Christie, 2002; Buckley et al., 2004). The preliminary findings are encouraging in that students’ learning outcomes indicated that the experimental groups outperformed the control groups.

In 2001 and 2002, we conducted a study in four Australian schools in which teachers included BioLogica activities in their teaching in authentic classroom settings. Our major objective was to investigate student learning from a conceptual-change perspective. We have already reported elsewhere about students’ conceptual learning with multiple representations along the epistemological/cognitive dimension (Tsui & Treagust, 2003), the social/affective dimension (Tsui & Treagust, 2004b), and the ontological dimension (Tsui & Treagust, 2004a).

Figure 1. A screenshot of the BioLogica Meiosis activity showing organism level, cell level, and chromosome level. (Reprinted with the kind permission of the Concord Consortium Educational Technology Laboratory, © 2001.)

The present study documents a cross-case analysis of conceptual learning in three of the four case schools in our original study. This part of the study was guided by the research question: How are the functions of multiple representations of genes related to students’ conceptual learning and the status of their conceptual learning measured by intelligibility, plausibility, and fruitfulness?

Methods

Research Approach

In this study we adopted an interpretive research approach (Erickson, 1986, 1998; Gallagher, 1991), which was deemed most suitable as it allows the researcher to explore research questions about the complexity of classroom learning that cannot be answered fully or satisfactorily using other research approaches. The interpretive approach used also involved case-study methods (Merriam, 1998; Stake, 1995; Yin, 1994). Merriam (1998) considered the case in a case study as a bounded system for studying a single entity such as a student, a teacher, or a principal; a unit with boundaries such as a program; or a group such as a class, a community, and so on. Three major features characterize a case study. First, a case study is particularistic in that it focuses on a particular situation, event, program, or phenomenon. Second, a case study is descriptive in that its end product is “a rich, ‘thick’ description” (p. 29) of the phenomenon being studied. Thick description, which is usually qualitative, means “the complete, literal description of the incident or entity being investigated” (pp. 28–29). Such description is often supported by direct quotes from transcripts or documents and other qualitative data. Third, a case study is heuristic in that it illuminates readers’ understanding of the phenomenon being studied by providing some new insights or extending their experience about the phenomenon.

School Context

The study reported in this article was conducted in three case schools—Forest High School (School F), Ocean Girls’ School (School O), and Urban High School (School U) (not their real names)—in the metropolitan area of Perth, Western Australia. The study was conducted in 2001 (School F) and 2002 (Schools O and U) during a genetics course when the teachers’ normal classroom teaching included student engagement in a set of BioLogica activities. Participants in this study were four biology teachers with teaching experiences ranging from 9 to 27 years, and their students (72 girls and 17 boys), aged from 14 to 18 years, in three Grade 10 and two Grade 12 classes (see Table 1). Most participating students were Australian-born. Participation in the study was voluntary with informed consent obtained from all participants or their parents/guardians (for those under 18); confidentiality and anonymity, of their participation and the data collected from them, were carefully maintained. Pseudonyms for all participants are used.

Although all participating teachers included BioLogica in their teaching and their major focus was on Mendelian genetics, they also introduced molecular genetics in their teaching. Table 2 shows a summary of the teaching schemes of the three schools, including the teachers’ use of BioLogica or other web-based interactive multimedia activities in their teaching. School O teachers, in particular, included some online interactive multimedia on molecular genetics (http://www.pbs.org/wgbh/aso/tryit/dna/shockwave.html) and human genetic disorders (http://www.ygyh.org). Students in Schools F and U used desktop computers in a computer room, whereas those in School O each owned a laptop computer, which they brought to every lesson in their classroom during the study.
Table 1
Summary of the case information reported in this article

<table>
<thead>
<tr>
<th>Time of Study</th>
<th>School</th>
<th>Type of School</th>
<th>Teaching Experience of the Class Teacher (Years)</th>
<th>Grade/Class</th>
<th>Number of Participating Students</th>
<th>Student Age (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>April to June 2001</td>
<td>Forest High School (School F)</td>
<td>State co-ed</td>
<td>27</td>
<td>10</td>
<td>24</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14–15</td>
</tr>
<tr>
<td>March to July 2002</td>
<td>Ocean Girls’ School (School O)</td>
<td>Independent girls</td>
<td>20</td>
<td>10/Class 1</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14–15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14–15</td>
</tr>
<tr>
<td>July to September 2002</td>
<td>Urban High School (School U)</td>
<td>State co-ed</td>
<td>9</td>
<td>12/Bio(^a)</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12/HBio(^b)</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16–18</td>
</tr>
</tbody>
</table>

\(^a\)Biology class for university entrance examinations.

\(^b\)Human biology class for university entrance examinations.
Table 2
Summary of teaching schemes during the genetics course in the five classrooms

<table>
<thead>
<tr>
<th>School/Grade (Class)</th>
<th>Teacher</th>
<th>Approach of Using Multimedia</th>
<th>No. of Teaching Weeks</th>
<th>Teaching Sequence (Sequence of Using Multimedia Activities Aligned to Teaching)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F/10</td>
<td>Mr. Anderson</td>
<td>BioLogica as a supplement</td>
<td>6</td>
<td>Reproduction → Cell structure → Cell divisions → DNA → Mendelian genetics → Biotechnology/bioethics (Introduction =&gt; Meiosis =&gt; Monohybrid)</td>
</tr>
<tr>
<td>O/10 (Classes 1 and 2)*</td>
<td>Ms. Claire and Mrs. Dawson</td>
<td>Multimedia to suit different learning styles</td>
<td>8</td>
<td>Cell structure → Reproduction → Cell division → Mendelian genetics → DNA and genetic engineering (Meiosis =&gt; Monohybrid) (online multimedia on human and molecular genetics; group presentations on human genetic disorders)</td>
</tr>
<tr>
<td>U/12 (H Bio class)</td>
<td>Ms. Elliott</td>
<td>BioLogica as a cognitive tool</td>
<td>4</td>
<td>Introduction → Meiosis → Pedigrees → Inheritance patterns → Mutations → Revision/pattern recognition (Introduction =&gt; Rules =&gt; Meiosis =&gt; Inheritance =&gt; Monohybrid =&gt; Sex linkage =&gt; Mutations)</td>
</tr>
<tr>
<td>(Bio class)</td>
<td></td>
<td></td>
<td>4</td>
<td>Similar topics and sequence as the H Bio class except that dihybrid cross was included (Meiosis =&gt; Monohybrid =&gt; Dihybrid =&gt; Sex Linkage =&gt; Inheritance =&gt; Rules =&gt; Mutations =&gt; Mutation Inheritance =&gt; Scales)</td>
</tr>
</tbody>
</table>

*aTeaching in the two classes was very similar.

*bThere were roughly 3–4 hours of teaching per week.

*cNames in italics are the names of the BioLogica activities.
Data Collection and Analysis

Data collection in the original study included data from multiple sources, both qualitative and quantitative, using three major data collection methods: interviewing students and teachers; observing classrooms; and collecting documents and other artifacts. The data sources included:

- Verbatim transcripts of semistructured interviews.
- Records of WebCT online two-tier test items (Treagust, 1988) and open-ended questionnaires.
- Computer data logging files or log files.¹
- Classroom observation field notes.
- Lesson transcripts from audiotapes and videotapes.
- First author’s reflective journals.
- Teachers’ handouts and other documents collected in the case schools.

Both the online tests and interview reasoning tasks were designed to evaluate students’ six types of genetics reasoning adapted from Hickey and Kindfield’s (1999) reasoning matrix (see Table 3). The analyses of the online questionnaire responses, interview transcripts, and other non-numerical unstructured data were aided by NUD*IST, a computer tool for analyzing qualitative data. Interview data were used as the major source of evidence in the part of the study reported herein.

Toward Increasing Qualitative Research Rigor

In keeping with the interpretive research paradigm, we used, as Guba and Lincoln (1989) suggested, credibility/transferability, dependability, and confirmability in place of internal/external validity, reliability, and objectivity, which experimental research uses. The first author had prolonged engagement and conducted persistent observation in the classrooms when he spent 4–10 weeks in each school observing most of the lessons, interviewing the teachers and the students, and collecting documents and other artifacts. Member checks were also used when the interview transcripts were sent to the teachers for verification and amendment. The analysis and interpretation of data generated explanations that led to formulation of assertions to be confirmed or disconfirmed through triangulations (e.g., data, methodological, and theoretical triangulation) (Denzin & Lincoln, 1994; Erickson, 1986, 1998; Fraser & Tobin, 1991; Gallagher, 1991). Such research strategies were used to improve the quality and credibility of the data collected in this study, address the research limitations, and thus increase the rigor of qualitative research.

Gene Conceptions and Thorley’s Status Analysis Categories

In this study we focus mainly on the students’ conceptual-learning outcomes through a cross-case analysis of the status of the gene conceptions of nine selected students across Schools F, O, and U. The major sources of data used for status analysis were from the preinstructional and postinstructional interviews, which included reasoning tasks and questions probing student gene conceptions. In another cross-case analysis of students’ gene conceptions before and after instruction based on their responses to an open-ended questionnaire (“What do you know about a gene?”) in the online pretest and posttest, we found five common gene conceptions, and that a student could hold more than one gene conception. The most common gene conception was: “A gene is from parents/grandparents” (see Table 4).
<table>
<thead>
<tr>
<th>Domain-specific dimension of reasoning (simple)</th>
<th>Between-generations</th>
<th>Within-generations</th>
<th>Cause-to-Effect Reasoning</th>
<th>Effect-to-Cause Reasoning</th>
<th>Process Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monohybrid inheritance:</td>
<td>Mapping genotype to phenotype (Type II)</td>
<td>Mapping genotype to phenotype (Type I)</td>
<td>Punnett squares (input/output reasoning):</td>
<td>Mapping phenotype to genotype (Type IV)</td>
<td>Meiosis process (event reasoning):</td>
</tr>
<tr>
<td>Mapping phenotype to genotype (Type IV)</td>
<td>Mapping phenotype to genotype (Type III)</td>
<td>Mitosis process (Type VI)</td>
<td>Mapping information in DNA base sequence (genotype) to amino acid sequence in protein synthesis (phenotype) (Type V)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Not included in Hickey and Kindfield’s (1999) original types.

bNot included in Hickey and Kindfield’s (1999) original types but adapted from Venville and Treagust’s (1998) sophisticated conception of the gene as being a productive sequence of instructions.
Table 4
Gene conceptions of participating students across Schools F, O, and U (Based on WebCT Data)

<table>
<thead>
<tr>
<th>Gene Conceptions</th>
<th>School F (Grade 10)</th>
<th>School O (Grade 10)</th>
<th>School U (Grade 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest&lt;sup&gt;a&lt;/sup&gt; (&lt;i&gt;n&lt;/i&gt; = 21)</td>
<td>Posttest&lt;sup&gt;b&lt;/sup&gt; (&lt;i&gt;n&lt;/i&gt; = 23)</td>
<td>Pretest (&lt;i&gt;n&lt;/i&gt; = 42)</td>
</tr>
<tr>
<td>A gene is from parents/grandparents</td>
<td>11&lt;sup&gt;c&lt;/sup&gt; (52)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>15 (65)</td>
<td>25 (61)</td>
</tr>
<tr>
<td>A gene determines a trait/characteristic</td>
<td>5 (24)</td>
<td>21 (91)</td>
<td>22 (54)</td>
</tr>
<tr>
<td>A gene is/part of a chromosome</td>
<td>3 (14)</td>
<td>9 (39)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>A gene is/part of DNA</td>
<td>2 (10)</td>
<td>1 (4)</td>
<td>14 (34)</td>
</tr>
<tr>
<td>A gene is information for making proteins&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2 (10)</td>
<td>1 (4)</td>
<td>1 (2)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Pretest online open-ended questionnaire: “What do you know about a gene?”; students submitted their responses by typing in a textbox.

<sup>b</sup>Posttest online open-ended questionnaire was the same as the pretest questionnaire.

<sup>c</sup>Number of students holding the conception (one student can have more than one conception).

<sup>d</sup>Percentage of students holding the conception.

<sup>e</sup>Based on subsuming three categories from within-case analyses: “A gene contains genetic code”, “A gene contains instruction”, and “Productive instruction for making protein”.

To more fully analyze the students’ conceptual status, we adopted Thorley’s (1990) status analysis categories (see Table 5), which Hewson and Lemberger (2000) used in their study. Thorley’s status analysis categories have status elements (in upper case) under each status of conceptions. These status elements provide an inventory for categorizing a student’s conception and judging whether the conception is of no status, intelligible, intelligible–plausible, or intelligible–plausible–fruitful. Hewson and Hewson (1992) clearly explained that the status of a person’s conception is the extent to which the conception meets the conditions of intelligibility, plausibility, and fruitfulness, and that the more conditions that a conception meets, the higher will be its status.

<table>
<thead>
<tr>
<th>Status of Conceptions</th>
<th>Status Elements (in Upper Case)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTELLIGIBILITY</strong></td>
<td>Representational modes:</td>
</tr>
<tr>
<td></td>
<td>INTELLIGIBILITY ANALOGY (analogy or metaphor to represent conception)</td>
</tr>
<tr>
<td></td>
<td>IMAGE (use of pictures or diagrams to represent conception)</td>
</tr>
<tr>
<td></td>
<td>EXEMPLARY (real-world exemplar of conception)</td>
</tr>
<tr>
<td></td>
<td>LANGUAGE (linguistic or symbolic representation of conception)</td>
</tr>
<tr>
<td><strong>PLAUSIBILITY</strong></td>
<td>Consistency factors:</td>
</tr>
<tr>
<td></td>
<td>OTHER KNOWLEDGE (‘reasoned’ consistency with other high-status knowledge)</td>
</tr>
<tr>
<td></td>
<td>LAB EXPERIENCE (consistency with laboratory data or observations)</td>
</tr>
<tr>
<td></td>
<td>PAST EXPERIENCE (particular events consistent with conception)</td>
</tr>
<tr>
<td></td>
<td>EPISTEMOLOGY (consistency with epistemological commitments)</td>
</tr>
<tr>
<td></td>
<td>METAPHYSICS (refer to ontological status of objects or beliefs)</td>
</tr>
<tr>
<td></td>
<td>PLAUSIBILITY ANALOGY or P ANALOGY (another conception is invoked)</td>
</tr>
<tr>
<td><strong>FRUITFULNESS</strong></td>
<td>Other factors:</td>
</tr>
<tr>
<td></td>
<td>REAL MECHANISM (causal mechanism invoked)</td>
</tr>
<tr>
<td></td>
<td>POWER (conception has wide applicability)</td>
</tr>
<tr>
<td></td>
<td>PROMISE (looking forward to what new conception might do)</td>
</tr>
<tr>
<td></td>
<td>COMPETE (explicitly compare two competing conceptions)</td>
</tr>
<tr>
<td></td>
<td>EXTRINSIC (associate new conception with experts)</td>
</tr>
</tbody>
</table>

To more fully analyze the students’ conceptual status, we adopted Thorley’s (1990) status analysis categories (see Table 5), which Hewson and Lemberger (2000) used in their study.

Thorley’s status analysis categories have status elements (in upper case) under each status of conceptions. These status elements provide an inventory for categorizing a student’s conception and judging whether the conception is of no status, intelligible, intelligible–plausible, or intelligible–plausible–fruitful. Hewson and Hewson (1992) clearly explained that the status of a person’s conception is the extent to which the conception meets the conditions of intelligibility, plausibility, and fruitfulness, and that the more conditions that a conception meets, the higher will be its status.

**Selection of Nine Interviewees**

We interviewed 26 target students: 13 students from Schools F and O, on the basis of their scores in the online pretests and posttests on genetics reasoning (see Tsui & Treagust, 2003), and all the students at School U who agreed to be interviewed (13 of the 17 students). Apart from parallel reasoning tasks for interviewees to do in the two interviews, a basic open-ended question was asked in each interview on what the students knew about the gene, followed by some questions to further probe their conceptions. For School U, where only the postinstructional interview was conducted, no reasoning tasks were included. According to Hewson and Hewson (1992), our interviews were “nontechnical” (p. 63) in that both the interviewer and interviewees did not use any technical terms about the conceptual-change model during the interview.

To select students for status analysis, we ordered the 26 interviewee students in a matrix by the pretest–posttest gains in their genetics reasoning scores (see Table 6). We used the scores of case-specific online tests (from 12 to 24 parallel two-tier multiple-choice items) instead of the global
online test scores based on the ten common items. Our criterion of ordering the interviewees in each case school for selection reflected the local learning outcomes of each case school. The case-specific online tests had been progressively improved and expanded to suit the case-specific or local context but the ten common items remained unchanged. This cross-analysis strategy was to keep “the local configuration of variables intact” (Miles & Huberman, 1994, p. 237).

From this case-ordered matrix, we selected nine students for conceptual status analysis—Matthew and Eric (School F); Andrea, Terri, and Elaine (School O); and Audrey, Helena, Phoebe, and John (School U)—based on their low pretest scores, substantial pretest–posttest gains, and complete interview data. This selection was underpinned by purposeful or theoretical sampling logic (Patton, 1990). These students also proportionately matched the gender ratio (six girls and three boys) and the ability range in the five classrooms across Schools F, O, and U. We chose more students in those classrooms from which we expected to obtain more information related to the research question. As for School U, we selected John who had lower prior knowledge and did not make any improvement in genetics reasoning (no pretest–posttest gains).

The data collected for determining status in School U were slightly different. The 13 students were interviewed only once in a short postinstructional interview, with no reasoning tasks, to

<table>
<thead>
<tr>
<th>Student (Pseudonyms)</th>
<th>Grade</th>
<th>Gender</th>
<th>Age</th>
<th>School</th>
<th>Classa</th>
<th>Pretestb (%)</th>
<th>Posttestb (%)</th>
<th>Pretest–Posttest Gains (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matthew</td>
<td>10</td>
<td>M</td>
<td>15</td>
<td>F</td>
<td>—</td>
<td>33</td>
<td>100</td>
<td>+67</td>
</tr>
<tr>
<td>Eric</td>
<td>10</td>
<td>M</td>
<td>15</td>
<td>F</td>
<td>—</td>
<td>17</td>
<td>33</td>
<td>+16</td>
</tr>
<tr>
<td>Laurie</td>
<td>10</td>
<td>F</td>
<td>15</td>
<td>F</td>
<td>—</td>
<td>33</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Nelly</td>
<td>10</td>
<td>F</td>
<td>15</td>
<td>F</td>
<td>—</td>
<td>50</td>
<td>33</td>
<td>−17</td>
</tr>
<tr>
<td>Andrea</td>
<td>10</td>
<td>F</td>
<td>15</td>
<td>O</td>
<td>1</td>
<td>29</td>
<td>87</td>
<td>+58</td>
</tr>
<tr>
<td>Erika</td>
<td>10</td>
<td>F</td>
<td>14</td>
<td>O</td>
<td>1</td>
<td>0</td>
<td>57</td>
<td>+57</td>
</tr>
<tr>
<td>Terri</td>
<td>10</td>
<td>F</td>
<td>14</td>
<td>O</td>
<td>2</td>
<td>0</td>
<td>57</td>
<td>+57</td>
</tr>
<tr>
<td>Cindy</td>
<td>10</td>
<td>F</td>
<td>15</td>
<td>O</td>
<td>2</td>
<td>14</td>
<td>57</td>
<td>+43</td>
</tr>
<tr>
<td>Isabelle</td>
<td>10</td>
<td>F</td>
<td>15</td>
<td>O</td>
<td>1</td>
<td>29</td>
<td>71</td>
<td>+42</td>
</tr>
<tr>
<td>Rita</td>
<td>10</td>
<td>F</td>
<td>15</td>
<td>O</td>
<td>1</td>
<td>0</td>
<td>29</td>
<td>+29</td>
</tr>
<tr>
<td>Elaine</td>
<td>10</td>
<td>F</td>
<td>15</td>
<td>O</td>
<td>2</td>
<td>29</td>
<td>57</td>
<td>+28</td>
</tr>
<tr>
<td>Anne</td>
<td>10</td>
<td>F</td>
<td>14</td>
<td>O</td>
<td>2</td>
<td>29</td>
<td>57</td>
<td>+28</td>
</tr>
<tr>
<td>Etta</td>
<td>10</td>
<td>F</td>
<td>14</td>
<td>O</td>
<td>2</td>
<td>0</td>
<td>14</td>
<td>+14</td>
</tr>
<tr>
<td>Audrey</td>
<td>12</td>
<td>F</td>
<td>17</td>
<td>U</td>
<td>HB</td>
<td>15</td>
<td>62</td>
<td>+47</td>
</tr>
<tr>
<td>Elisa</td>
<td>12</td>
<td>F</td>
<td>17</td>
<td>U</td>
<td>HB</td>
<td>31</td>
<td>77</td>
<td>+46</td>
</tr>
<tr>
<td>Paul</td>
<td>12</td>
<td>M</td>
<td>17</td>
<td>U</td>
<td>HB</td>
<td>23</td>
<td>62</td>
<td>+39</td>
</tr>
<tr>
<td>Helena</td>
<td>12</td>
<td>F</td>
<td>16</td>
<td>U</td>
<td>HB</td>
<td>15</td>
<td>46</td>
<td>+31</td>
</tr>
<tr>
<td>Phoebe</td>
<td>12</td>
<td>F</td>
<td>17</td>
<td>U</td>
<td>HB</td>
<td>69</td>
<td>85</td>
<td>+16</td>
</tr>
<tr>
<td>Bob</td>
<td>12</td>
<td>M</td>
<td>17</td>
<td>U</td>
<td>B</td>
<td>77</td>
<td>85</td>
<td>+8</td>
</tr>
<tr>
<td>Hilary</td>
<td>12</td>
<td>M</td>
<td>17</td>
<td>U</td>
<td>B</td>
<td>54</td>
<td>62</td>
<td>+8</td>
</tr>
<tr>
<td>Margaret</td>
<td>12</td>
<td>F</td>
<td>17</td>
<td>U</td>
<td>B</td>
<td>46</td>
<td>69</td>
<td>+5</td>
</tr>
<tr>
<td>Alina</td>
<td>12</td>
<td>F</td>
<td>17</td>
<td>U</td>
<td>HB</td>
<td>31</td>
<td>31</td>
<td>0</td>
</tr>
<tr>
<td>John</td>
<td>12</td>
<td>M</td>
<td>17</td>
<td>U</td>
<td>B</td>
<td>39</td>
<td>39</td>
<td>0</td>
</tr>
<tr>
<td>Karl</td>
<td>12</td>
<td>M</td>
<td>17</td>
<td>U</td>
<td>B</td>
<td>100</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Ella</td>
<td>12</td>
<td>F</td>
<td>18</td>
<td>U</td>
<td>HB</td>
<td>54</td>
<td>54</td>
<td>0</td>
</tr>
<tr>
<td>Juvena</td>
<td>12</td>
<td>F</td>
<td>17</td>
<td>U</td>
<td>B</td>
<td>53</td>
<td>46</td>
<td>−7</td>
</tr>
</tbody>
</table>

a1 = Class 1; 2 = Class 2; B = Biology class; HB = Human Biology class.
bThe scores were based on the case-specific pretests and posttests (parallel items).
cErika and Etta did not turn up for the postinstructional interview.
respect their wish for a shorter interview, as these Grade 12 students were preparing for their university entrance examinations.

Status Analyses, Interpretations, and Results

In analyzing and interpreting the cross-case data, we attempted to relate student interactions with the multiple representations in *BioLogica*, and/or other interactive multimedia (in School O only), to students’ conceptual learning of genetics and to examine how multiple representations might have contributed to conceptual change. As suggested by Hewson and Hewson (1992), we interpreted the status of the interviewees’ gene conceptions from the verbal or written data using both the representations of their conceptions and the comments about their conceptions; that is, comments considered “metaconceptual” (Thorley, 1990, p. 116). According to Hewson and Lemberger’s (2000) method, we report on our analysis of some typical instances for each interviewee to illustrate the explicit inclusion or exclusion of an element of status (e.g., intelligibility and plausibility), as indicated with a “+” or “−” sign, respectively. For students at School U, where there were not enough interview data for determining status, we also analyzed their responses to the online open-ended questionnaire that solicited their gene conceptions and their answers to questions in *BioLogica* activities captured by computer log files.

**Intelligibility**

According to Thorley’s status analysis categories (see Table 5), there are four status elements about intelligibility or representational modes: *Intelligibility Analogy; Image; Exemplar; and Language*. Evidence from the interviews indicated that all nine selected interviewees had intelligible gene conceptions, although their modes of representations, identified from our analysis of the status elements, were different (see Table 7).

*Intelligibility Analogy.* In the interviews, we indicated that both Matthew (School F) and Andrea (School O) included this status element in their interview discourse. Matthew said in the postinstructional interview, “They [Genes] will just give different signals out to where cells are developing . . . ,” whereas Andrea said in the preinstructional interview, “A gene, um, I think it’s like, the plans for your characteristics and tells what each cell should do.” By using “signals” or “plans” as a metaphor to represent the gene, they both showed that their gene conceptions were intelligible (+*Intelligibility Analogy*). Indeed, Matthew and Andrea were two of the most outstanding fruitful learners in this study.

<table>
<thead>
<tr>
<th>Status Elements</th>
<th>Matthew</th>
<th>Eric</th>
<th>Andrea</th>
<th>Terri</th>
<th>Elaine</th>
<th>Audrey</th>
<th>Helena</th>
<th>Phoebe</th>
<th>John</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Intelligibility Analogy</em></td>
<td>+</td>
<td>+*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Image</td>
<td>+*</td>
<td>+*+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exemplar</td>
<td>+</td>
<td></td>
<td>+*</td>
<td></td>
<td>+</td>
<td>+*</td>
<td></td>
<td>+*</td>
<td></td>
</tr>
<tr>
<td>Language</td>
<td>+*</td>
<td>+*</td>
<td>+*</td>
<td>+*</td>
<td>+*</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

* indicates an instance of a high conceptual status in an intelligibility status element based on interview transcripts, online tests/questionnaires, or computer log files. +* indicates an instance in preinstructional interview or online pretest.

Of the nine selected interviewees, only Matthew and Eric (School F) made a drawing during the preinstructional interviews to represent their gene conceptions. Matthew explained to the interviewer while making a drawing to show the relationship between DNA, a gene, and a chromosome in which he visualized the double-helix of the DNA molecule, the particulate nature of the gene, and the wriggling shape of a pair of chromosomes joint at the centromere. As for Eric, he simply drew a double-helical structure of the DNA (see Figure 2). The visual–graphical representations using images are indeed an indication of genes being intelligible to Matthew and Eric (+Image).

Then, in the postinstructional interview, Eric provided a graphic description, when asked how genes are related to chromosomes and DNA, in a way very similar to his drawing in the preinstructional interview. He said, “There are 23 chromosomes. DNA looks like a twisted ladder when you look at it under a microscope…” (+Image).

Exemplar. Three selected interviewees, Eric, Terri (School O), and Phoebe (School U), used Exemplars of common human hereditary characteristics, such as hair and eye color, to illustrate their gene conceptions as follows (+Exemplar):

The genes come from the sperm and the egg and then they’re joined together and they get one person. Yeah, it becomes Pierre [name of an individual in a pedigree of a preinstructional interview task]. It determines likes um… hair color, eye color. So if the father has blue eyes, and so does your mother, then you probably have more blue eyes than brown. Um… (Eric, preinstructional interview)

They [genes] like… um… they can determine like whether you’re going to have like blue eyes or brown eyes or what color hair [included two intelligibility status elements]. (Terri, preinstructional interview)

…they help determine your physiology, that is, height, body shape, hair/eye coloring, etc. they help determine your physiology, that is, height, body shape, hair/eye coloring, etc. they determine what diseases you’re prone to—if its (sic) genetic hereditry (sic). (Phoebe, online pretest posting)

Audrey (School U), who had little prior knowledge about genetics, found the examples in BioLogica Dragons interesting and easy for understanding the gene concept, as she said (+Exemplar):

Most the examples [color, wings, or legs], like with the Dragons, made it easier to understand, rather than just learning it in the classroom and, yeah, it was just fun to do… I liked it with the Dragons… I didn’t know anything about genetics. This is the first time that I’ve done it. And, I learned a lot from the computer. (Audrey, postinstructional interview)
Language. All nine selected interviewees were able to use language (linguistic or symbolic representations) to represent their gene conceptions, although they focused on the gene being a “thing” rather than a “process” (Chi et al., 1994). Some used genetic terminology to describe their difficulties in learning.

In the preinstructional interview, Matthew described his gene conception as follows: “In the chromosomes there are hundreds and thousands of these genes...and they each...might be dominant or recessive...determine the different characteristics” (+Language).

Eric represented genes by relating them to DNA and chromosomes, as said in the preinstructional interview, “DNA is made up of genes and chromosomes are made up into genes” (+Language).

In her preinstructional interview, Andrea showed how she conceptualized the gene by describing the process of meiosis: “Um, during meiosis the chromosomes from each parent mix together, and the sperm fertilizes with (sic) the egg...it forms a new human” (+Language).

Terri described genes in her preinstructional interview, “They [genes]...determine like whether you’re going to have like blue eyes or brown eyes...” (+Language).

Elaine said in her preinstructional interview that a gene can be “a physical feature, or it can be a um, like, not a personality but like a, it gets passed through families and generations and things like that” (+Language).

For those Grade 12 students from School U, they had already learned some genetics in Grade 10, and so all of them could use the language about genes well in the postinstructional interview. Audrey said, “I get confused with the sex-linked and autosome, stuff like that, and the dominant and recessive” (+Language). Helena also described where she had difficulty in understanding: “In the classroom that I didn’t understand. Um. Nah, not really, just the sex-linked and the autosome. That’s the only thing that I found hard in genetics” (+Language). Phoebe suggested that one part of the Meiosis activity needed more on-screen instruction. She said, “I just had problems with it...with the Meiosis Windows? Do you remember? ...It needed more explanation I think” (+Language).

Last, John, when asked whether BioLogica activities helped his understanding of genes, described what he had learned (+Language):

Well I guess yeah, it [BioLogica] showed us the effects of mixing genes from different parents, and we learned about the way dominant and recessive genes work, and the difference between autosomal and sex-linked [inheritance], and stuff like that. (John, postinstructional interview)

Plausibility

Of the seven plausibility status elements (see Table 5), only six were relevant to the analysis in this study—Lab Experience, Past Experience, Epistemology, Metaphysics, Plausibility Analogy, and Real Mechanism.

Analysis indicated that all selected interviewees except Eric (School F) had plausible or partly plausible gene conceptions, as evidenced by mapping their conceptions or their thinking about their conceptions to one or more of the six status elements in the following analyses and interpretations (see Table 8).

Lab Experience. The virtual experiments in the BioLogica activities were considered as Lab Experience. Most interviewees from School U described their learning experience of using BioLogica activities during the postinstructional interviews. For example, John referred to the
And I don’t think I would have, it wouldn’t have sunk into my head as much as if we just sat in class talking about it, rather than actually doing it on the computers, because you can actually see from the results of like a baby Dragon, the effects. (John, postinstructional interview)

Although this was the only supporting evidence for plausibility in John’s case, and he did not improve his genetics reasoning on his online tests (Table 6), we considered John’s conception as partly plausible after instruction (Lab Experience).

Like John, Helena claimed that her experience of interacting with BioLogica activities did help her understand the gene as she said in the postinstructional interview (Lab Experience):

Um, like, with BioLogica, I like, um, you know how we have to change the genes, the traits of them; that was really good. I liked doing that. And you can’t really do that in textbooks…. Um. I think it would help me learn better because, textbooks are just reading… what’s the word I’m looking for, um; it’s hands-on with the BioLogica. You can, you know, change stuff and write stuff… (Helena, postinstructional interview)

Past Experience. Very few selected interviewees made metaconceptual statements—that is, comments about their own conceptions. Andrea, when asked about the phenotype–genotype relationship during the preinstructional interview, had the following dialog with the interviewer:

Interviewer: Tongue-rolling is dominant. So if a girl has two genes, big R and small r, would the girl roll her tongue?
Andrea: Yeah. Yes? Don’t really know because we haven’t really learned that before… (Andrea, preinstructional interview)

Andrea’s metaconceptual statement is status-related and her conceptualization of the dominant and recessive gene alleles was driven by her past experience (Hewson & Lemberger, 2000). She thought that she had not understood this concept. This is an instance of an explicit exclusion of an element of status of plausibility (Past Experience).

---

**Table 8**

<table>
<thead>
<tr>
<th>Status Elements</th>
<th>Matthew</th>
<th>Eric</th>
<th>Andrea</th>
<th>Terri</th>
<th>Elaine</th>
<th>Audrey</th>
<th>Helena</th>
<th>Phoebe</th>
<th>John</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab Experience</td>
<td></td>
<td>þ</td>
<td></td>
<td>þ</td>
<td>þ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Past Experience</td>
<td></td>
<td>−*</td>
<td></td>
<td>þ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epistemology</td>
<td>þ</td>
<td></td>
<td></td>
<td>þ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metaphysics</td>
<td>þ</td>
<td>þ</td>
<td></td>
<td>þ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P Analogy</td>
<td>þ*</td>
<td>−</td>
<td>þ</td>
<td>þ</td>
<td>þ</td>
<td>þ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Mechanism</td>
<td>þ</td>
<td>þ</td>
<td>þ</td>
<td>þ</td>
<td>þ</td>
<td>þ</td>
<td>þ</td>
<td>þ</td>
<td></td>
</tr>
</tbody>
</table>

þ indicates an instance of a high conceptual status in a plausibility status element based on interview transcripts, online tests/questionnaires, or computer log files. − indicates an instance of a low conceptual status in a plausibility status element based on interview transcripts, online tests/questionnaires, or computer log files. þ* or −* indicates an instance of high or low status in preinstructional interview/online pretest.

Helena, however, mentioned in the postinstructional interview her past experience to compare it with her new experience of learning. She said: “I remember doing meiosis last year. I didn’t really understand it though. I understand it more this [year], like now because of the BioLogica program” (+Past Experience). This is also a metaconceptual statement.

**Epistemology.** According to Thorley (1990), Epistemology refers to “consistency with epistemological commitments, e.g., need for similar phenomena to have similar explanations” (p. 192). This epistemological belief is often about the significance of experimental proof of scientific theory.

We identified this status element in Matthew’s postinstructional interview transcript. His gene conceptions obviously appeared plausible to him as he interacted with the BioLogica hypermodel trying to design a computer Dragon with certain characteristics, using what he had learned from his teacher or textbook because he could observe the changes he had made and could check his understanding. He said:

Well in one of the problems [in the Meiosis activity] I think you had to make a certain type of Dragon with certain characteristics so you had to select certain chromosomes with dominant or recessive genes [alleles] on them to be used as gametes to make a new Dragon. So that was interactive there. (Matthew, postinstructional interview)

**Metaphysics.** The status element Metaphysics refers to the ontological status of objects or beliefs (Thorley, 1990). Very few students in the study included this status element in their interview discourse. Andrea’s interview transcript provides an example of this status element. She talked about what she believed about the function of genes or DNA (+Metaphysics):

Um. Well, genes . . . made up of the genetic code in the DNA, which tells the body to make proteins, and um, um, they just carry the information which tells the body how it should work and stuff and how it should develop. (Andrea, postinstructional interview)

Andrea’s conception of genes or DNA was that of a process rather than a thing or matter and that her conceptual change was from one ontological category to another or radical conceptual change (Chi, 1992). The key idea in her conception was that genes carry information for making proteins.

Helena also had similar ideas. She had the following dialog with the interviewer:

Interviewer: What do genes do to bring about the characteristic?
   Helena: Like protein synthesis.
Interviewer: What do you mean by protein synthesis?
   Helena: [A gene] . . . it has a code, like A, T, G, and C. And, they match up . . . . They’re like little genetic codes.
Interviewer: Coding for what?
   Helena: For nitrogen bases . . . for the double helix . . . proteins . . . like your hair, they [genes] make it . . .

Although she could not fully explain her understanding of genes being a process, she did mention “proteins . . . like your hair, they [genes] make it,” for which we categorized her conception as plausible. Her conception included her consideration of the ontological status of genes (+Metaphysics).

**Plausibility Analogy (P Analogy).** This status element, another consistent factor, is about the use of analogy in invoking another conception (see Table 5). Six of the nine selected interviewees
displayed such status element as evidenced by one or more types of data source. The best example
is from Matthew. While he was working on pedigree analysis in a reasoning or problem solving
 task during the preinstructional interview, the pedigree information had invoked his conception of
meiosis with which he then used to explain the phenomenon ($P$Analogy):

Well, the father may have had something like that [He wrote symbols on the task sheet] and
the mother would have been like that as well and when the cells were going through
meiosis it would have had a bunch of the cells that had just one big A and another bunch
that just had small a. So when Pierre’s [name of an individual in a pedigree of a
preinstructional interview task] egg was fertilized, Pierre might have got the big A and the
small “a” and Marianne might have got just two small “a’s.” (Matthew, preinstructional
interview)

Andrea also included this status element in developing her gene conceptions ($P$Analogy), as
she noted in the postinstructional interview:

Um. Well, genes . . . made up of the genetic code in the DNA, which tells the body to make
proteins, and um, um, they just carry the information which tells the body how it should
work and stuff and how it should develop. (Andrea, postinstructional interview)

Although this transcript segment can be mapped to Metaphysics, it can also be mapped to $P$
Analogy as the conception of genes being information invoked the conception of how this
information is used to make proteins leading to body development. This status element appeared to
increase the plausibility of Andrea’s gene conceptions.

Elaine, who had less prior knowledge and little understanding of the gene concept, still
found the gene intelligible using nonscientific language. She had the following dialog in the
postinstructional interview:

Interviewer: So what do you know about gene now?
   Elaine: Um. It’s like a little cell sort of thing that’s passed through, um, like from the
egg and the sperm, it passes through from generations, and um, it’s like, I
know what they are but . . .
Interviewer: Okay. So what do genes do in the body?
   Elaine: Um. They sort of, like, produce us, they sort of help um, the cells and they
help the body, sort of determine what you look like, and . . .
Interviewer: How do the genes determine what the body is like?
   Elaine: Um. Through, sort of like, um . . . Yeah, I’m not really that sure.

Elaine’s talk of “a sort of help” and the mention of “the cells” in determining “what you look
like” revealed her gene conception was “A gene from parents/grandparents,” the most common
gene conception in this study (see Table 4), which she repeated in both interviews. We thought that
this gene conception was plausible to her as it invoked another conception, “A gene determines a
trait/characteristic,” but she could not explain it further in terms of genes as information for
making proteins and so on. Her gene conceptions were thus plausible ($Plausibility$ Analogy).

Phoebe’s learning experience of relating Dragon genetics to the human situation is another
example, as shown by the following dialog in her postinstructional interview ($P$Analogy):

Interviewer: Can you relate what you learned with [BioLogica] Dragons to the human
condition?
   Phoebe: Yes. Yeah, I can.
Interviewer: In what ways?

Phoebe: Oh, um, in sex linkage. So we have, they have color and fire breathing, differences. I can relate that to say, hemophilia, and muscular dystrophy, in humans.

Here, Phoebe displayed her consistent understanding and her gene conceptions were plausible by relating two sex-linked characteristics in BioLogica Dragons to two sex-linked genetic diseases in humans.

Real Mechanism. The status element Real Mechanism is an invocation of the causal mechanism for a phenomenon. It is a “potentially powerful aspect of the ‘reality’ dimension, which was left unanalyzed by authors of the CCM [conceptual-change model]” (Thorley, 1990, p. 175). Evidence of Real Mechanism in students’ conceptions indicates a high status of plausibility. In this section, we discuss a few typical instances of this status element to illustrate the high plausibility status of the students’ conceptions.

Matthew could solve the problem in the reasoning task, a pedigree problem (see Figure 3), in the postinstructional interview and provided a plausible explanation for his answer that the given pedigree could not possibly show an inheritance pattern of sex linkage (+Real Mechanism):

A pedigree showing a common genetic disease in Australia

![Pedigree Diagram]

Figure 3. Completed reasoning task sheet in Matthew’s postinstructional interview.
Interviewer: So what I am saying is… would it be possible for this disease to be sex-linked?
Matthew: It would be possible. It’s not possible on the Y because…
Interviewer: Write something.
Matthew: No. [He was working on the problem by writing on the task sheet shown on Figure 3.]
Interviewer: Please describe your reasons why it is not possible for this disease to be sex-linked.
Matthew: Well for it to be sex-linked, Jane would have to have an X and a small d and an X and a small d and there is no way she can get two X’s with small d’s from either parents. She can only get an X big D, which would make her a carrier, or Y, which would make her a boy. So therefore it is not possible that it is sex-linked.

Unlike Matthew, the four other students, Eric, Andrea, Terri, and Elaine, could not clearly provide an explanation why it is impossible for the pattern of inheritance to be sex-linked in the same postinstructional interview task (see Figure 3). Nevertheless, Andrea, Terri, and Elaine could explain the recessive inheritance pattern in this task (+Real Mechanism). For example, Terri had the following dialog with the interviewer:

Interviewer: Yes. This is about a genetic disease very common in WA. So, look at it carefully and then tell me what sort of [inheritance pattern], I mean… Is it dominant or recessive?
Terri: [Reading off the sheet quietly.]
Interviewer: What do you think?
Terri: Hang on. [pause] Is it recessive?
Interviewer: Yes. Yeah, and I want you to explain…
Terri: Because, if it was dominant, it would be, um, one of them or two would have had it [the genetic disease], and it would shown up in each of the generations.

The only Grade 10 student whose gene conceptions were not plausible was Eric, who had the following dialog with the interviewer in the postinstructional interview while working on the same reasoning task (−Real Mechanism):

Interviewer: Is it possible for it [inheritance pattern] to be sex-linked and recessive?
Eric: Yes.
Interviewer: Why?
Eric: If you cross two people who don’t have the disease; the small g represents the people who don’t have the disease. When I cross them on the table [Punnett square] I get that none of them should have it, but that means one of them should be a carrier.

Eric did not understand the causal mechanism of sex linkage. Nor did he understand the real mechanism of the autosomal-recessive inheritance pattern. We did not find any more evidence for the other plausibility status elements in the interview transcript. Eric’s gene conceptions were thus categorized as intelligible but not plausible. Our categorization was consistent with his rather low genetics reasoning test scores with small gains on the posttest (see Table 6) and his gene conceptions on the pretest and posttest questionnaires, as evidenced by the WebCT records:

Questionnaire: What do you know about a gene?
Answer: Genes are from our mother and father, we have certain genes from each parent. (Eric, WebCT quiz—genetics pretest, 01-5-18, 12:49)
Questionnaire: After you have studied genetics for some weeks, what do you know about a gene now?
Answer: Genes can give you certain characteristics from your parents. They can give you eye color, hair color, and even traits like tongue rolling. (Eric, WebCT quiz—genetics posttest, 01-6-25, 17:42)

In the postinstructional interview, Andrea was the only Grade 10 interviewee who appeared to understand the causal mechanism of how gene information is used for protein synthesis (+Real Mechanism). She had the following dialog with the interviewer during the postinstructional interview:

Andrea: What do the genes do? Oh they um, they connect… contain the genetic codes that produce proteins, and they… which contain amino acids that you know help us.
Interviewer: So how are proteins made from, like DNA?
Andrea: Oh, yeah, um… when protein, um, is made from the DNA and er, how, I don’t know.
Interviewer: So what is messenger RNA?
Andrea: Oh well, um, the messenger RNA, they copy the DNA code, from the genes, and then they transfer it to the ribosomes. Is that it?

For School U, where we did not have any genetics reasoning tasks in the postinstructional interview, we identified some evidence in the computer log files that tracked students’ interactions with BioLogica. Audrey displayed her understanding by providing an explanation for the observation of many more horned than hornless baby Dragons from the breeding of two horned parent Dragons (+Real Mechanism). The following is Audrey’s computer log file, which recorded her interactions with the Inheritance activity on 5 August 2002:

<log>
<user> [real name deleted] </user>
<action>
    <date>2002.08.05.14.53.02 08/05/02 | 14:53:02</date>
    START OF ACTIVITY
</action>
<action>
    <date>2002.08.05.15.06.46 08/05/02 | 15:06:46</date>
    Answered: MOST of the offspring will have horns.
</action>
<question>
    <date>2002.08.05.15.09.44 08/05/02 | 15:09:44</date>
    Explain your understanding of why you got so many more horned babies than hornless ones in the space below.
</question>
<answer>
    there were so many more horned babies than hornless ones as horns were dominant and no horns was recessive
</answer>
</question>
<action>
    <date>2002.08.05.15.10.22 08/05/02 | 15:10:22</date>
    END OF ACTIVITY
</action>
</log>
Audrey’s use of two key concept words, dominant and recessive, in her explanation in lines 16 and 17 in the log file, appear to indicate that she had understood the inheritance pattern of a cross of “Hh × Hh,” where H, the dominant allele, is for the horned trait, and h, the recessive allele, is for the hornless trait. Our conjecture about her understanding was consistent with Audrey’s substantial gains (+47%) in genetics reasoning test scores (see Table 6).

**Fruitfulness**

Whereas intelligibility and plausibility of a conception are likened to “representability” and “reality/truth,” fruitfulness confers the highest intellectual power of a conception to a person holding it (Hewson & Lemberger, 2000). Only when a conception is intelligible and plausible can it become fruitful. Two status elements, Power (conception has wide applicability) and Promise (looking forward to what new conception might do) (see Table 5), were relevant to this study. The mappings of the evidence to these two status elements for the selected interviewees are summarized in Table 9.

**Power.** In the postinstructional interview, Matthew confidently said that he found genetics useful, because “…it helped me to understand how children get certain things from their parents” (+Power) and “My opinions have changed because I now know what’s involved with genetically modified food and stuff like that” (+Power).

Andrea, too, when reading a newspaper clipping about genes in the postinstructional interview, said, “Ah. We understand much more about this, because they’re talking about genes and you know what genes are now” (+Power).

Audrey also said in a confident manner in the postinstructional interview, “I don’t know whether we’d use it [gene concept] again but at least we understand where we got our eye color from and stuff like that…” (+Power).

**Promise.** In the postinstructional interview, Matthew verbalized his aspiration of becoming a geneticist in the future, “It made me consider the career path of a genetic science as well” (+Promise). Similarly, Audrey looked forward to knowing more about genes: “It should be interesting to know [more about genes]… it’s good knowledge” (+Promise).

Phoebe found that her gene conceptions might be personally relevant and useful in the future and suggested that everyone should be taught about genetics to be informed about the available options (for an expectant mother) (+Promise):

Well, if say I was about to have a child or something, I’d know the precautions to take, or I’d know that there were options. So, it’s really useful. I think everyone should be taught about all those opinions in genetics. Should be mandatory . . . They [expectant mothers] should be informed about all the options that are available to them. (Phoebe, postinstructional interview)

Table 9

Analysis of conceptual status: Fruitfulness

<table>
<thead>
<tr>
<th>Status Elements</th>
<th>Fruitfulness of Student Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Matthew</td>
</tr>
<tr>
<td>Power</td>
<td>+</td>
</tr>
<tr>
<td>Promise</td>
<td>+</td>
</tr>
</tbody>
</table>

+ indicates an instance of a high conceptual status in a fruitfulness status element based on interview transcripts, online tests/questionnaires, or computer log files.

*Journal of Research in Science Teaching. DOI 10.1002/tea*
However, Helena did not find genetics useful after the examination (—Promise), and therefore her gene conceptions were not fruitful. She said:

After the exam, well, not for me, it [genetics] won’t [be useful] ’cause I’m not gonna be in that field but, I think it will be for other people. Yeah. Like, for example, Paul [her classmate]. He wants to be a doctor. (Helena, postinstructional interview)

**Genetics Reasoning, Status of Gene Conceptions, and Usage of BioLogica**

In the preceding sections, we have analyzed and interpreted nine selected interviewees’ gene conceptions using Thorley’s (1990) status analysis categories, and Hewson and Lemberger’s (2002) method. Table 10 shows a comparison of the nine students’ genetics reasoning based on online test scores; conception status based on the preceding analyses and interpretations; and usage of BioLogica based on data sources from students’ computer log files, classroom observations, and the first author’s reflective journals. We collected a complete set of log files from School U, which served as useful data for student usage of BioLogica activities. However, we could not collect all the log files from School F due to technical problems. Also, we could not collect all the log files from School O, where we had to seek teacher help for copying the files from the students’ laptop computers. Therefore, we did not have enough data for estimating BioLogica usage in Schools F and O.

The results of the analysis of the status of the nine selected students’ gene conceptions using Thorley’s categories indicated that only four students—Matthew (School F), Andrea (School O), Audrey (School U), and Phoebe (School U)—had intelligible–plausible–fruitful gene conceptions after instruction. The other four students’ conceptions were only intelligible–plausible. Eric’s gene conceptions were just intelligible. The findings about students’ conceptual learning in terms of intelligibility, plausibility, and fruitfulness were generally consistent with students’ development in genetics reasoning based on their online test scores and BioLogica usage (see Table 10).

We also found that active engagement in the BioLogica activities was necessary but not sufficient for the development of good genetics reasoning and fruitful gene conceptions in terms of status (see Table 10). If status is “the hallmark of all forms of conceptual learning” (Hewson & Lemberger, 2000, p. 123), then the time and effort of students spent in using the BioLogica activities did contribute to conceptual learning in some students but not in others.

**Discussion and Conclusions**

In this study we have reported on a cross-case analysis of the conceptual status of nine students selected from 26 interviewees across the five classrooms in Schools F, O, and U to measure their conceptual change using Thorley’s status analysis categories. We now try to explain the differences in nine students’ conceptual change when their learning included multiple representations of the genes. To do this, we must explain the similarities and differences of students’ conceptual learning involving computer-based multiple representations within different classroom contexts. In drawing conclusions for this study, we attempt to synthesize the analyses we have done in the preceding sections in response to the research question of this study—“How are the functions of multiple representations related to students’ learning and the conceptual status of their learning measured by intelligibility, plausibility, and fruitfulness?”—that has guided our analyses and interpretations in generating the major findings.

In response to the first part of the research question, the cross-case analyses in the preceding sections suggest that BioLogica and its multiple representations did provide students with
<table>
<thead>
<tr>
<th>Student (School/Grade (Class))</th>
<th>Pretest(^a) (%</th>
<th>Posttest(^a) (%)</th>
<th>Pretest-Posttest Gains (%)</th>
<th>Postinstructional Conceptual Status(^b) (Thorley, 1990)</th>
<th>Number Of BioLogica Activities Completed</th>
<th>Names of BioLogica Activities (Trials/Number of Log Files Collected)</th>
<th>Usage of BioLogica (Estimated Time in Hours(^c))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matthew (F/10)</td>
<td>33</td>
<td>100</td>
<td>+67</td>
<td>IPF</td>
<td>5</td>
<td>Introduction (1), Monohybrid (1), Meiosis (0), Horn Dilemma (1), Scales (1)</td>
<td>High (2)</td>
</tr>
<tr>
<td>Eric (F/10)</td>
<td>17</td>
<td>33</td>
<td>+16</td>
<td>I</td>
<td>3</td>
<td>Introduction (0), Monohybrid (0), Meiosis (1)</td>
<td>High (2)</td>
</tr>
<tr>
<td>Andrea (O/10/1)</td>
<td>29</td>
<td>87</td>
<td>+58</td>
<td>IPF</td>
<td>6</td>
<td>Introduction (0), Meiosis (1), Horn Dilemma (0), Monohybrid (1), Mutations (1), Mutation Inheritance (1)</td>
<td>High (2)</td>
</tr>
<tr>
<td>Terri (O/10/2)</td>
<td>0</td>
<td>57</td>
<td>+57</td>
<td>IP</td>
<td>5</td>
<td>Introduction (0), Meiosis (0), Monohybrid (2), Mutations (0), Inheritance (0)</td>
<td>Medium (1)</td>
</tr>
<tr>
<td>Elaine (O/10/2)</td>
<td>29</td>
<td>57</td>
<td>+28</td>
<td>IP</td>
<td>4</td>
<td>Introduction (0), Meiosis (0), Mutation (0), Mutation Inheritance (0)</td>
<td>Medium (1)</td>
</tr>
<tr>
<td>Audrey (U/12/HB(^d))</td>
<td>15</td>
<td>62</td>
<td>+47</td>
<td>IPF</td>
<td>7(^e)</td>
<td>9 log files (at least one per activity for School U)</td>
<td>High (4)</td>
</tr>
<tr>
<td>Helena (U/12/HB)</td>
<td>15</td>
<td>46</td>
<td>+31</td>
<td>IP</td>
<td>7</td>
<td>9 log files</td>
<td>High (4)</td>
</tr>
<tr>
<td>Phoebe (U/12/HB)</td>
<td>69</td>
<td>85</td>
<td>+16</td>
<td>IPF</td>
<td>7</td>
<td>18 log files</td>
<td>High (5)</td>
</tr>
<tr>
<td>John (U/12/B(^f))</td>
<td>39</td>
<td>39</td>
<td>0</td>
<td>IP</td>
<td>8(^g)</td>
<td>10 log files</td>
<td>High (4)</td>
</tr>
</tbody>
</table>

\(^a\)The scores were based on the case-specific pretests and posttests (parallel items).

\(^b\)Status is represented by I for intelligible, IP for intelligible–plausible, or IPF for intelligible–plausible–fruitful.

\(^c\)Based on video data (School F), online self-reports (School O), and computer log files (School U).

\(^d\)HB = human biology class.

\(^e\)Introduction, Rules, Inheritance, Meiosis, Monohybrid, Mutations, and Sex Linkage.

\(^f\)B = Biology class.

\(^g\)Rules, Inheritance, Meiosis, Monohybrid, Dihybrid, Mutations, Sex Linkage, and Scales.
complementary information and processes about genetics, particularly about the genotype–phenotype relationships. Across all three case schools, the role of visualization in learning was repeatedly mentioned by many students in their online test responses and in the interviews. In particular, when engaged in BioLogica activities, those students in Schools F and U generally found the multiple representations in BioLogica both intrinsically motivating and useful for understanding (see Tsui & Treagust, 2004b). Instead of using only the abstract terms of genetics, BioLogica features manipulable visual–graphical representations of the phenomenon that are co-deployed simultaneously with activity scripts that contain pedagogical elements—such as narratives, tasks and puzzles, representational assistance, reasoning models, explanations, and feedback on assessment questions—that mediate student learning (Buckley et al., 2004). For example, BioLogica activities feature animation of meiosis processes in progress in one Window and a question posed to the students in another Window juxtaposed with Buttons or Tools, which the students can use to interact with the BioLogica. They can make changes to the manipulable representations of objects (see Figure 1) and observe the change in their behavior at different levels of organization constrained by the Mendelian model of genetics and/or the molecular and cellular mechanisms. Different resources of data showed that the multiple representations of genes appeared to have intrinsically motivated many students across the three case schools. From the conceptual-learning perspective, the multiple representations increased the intelligibility of the concept of the gene so that students could continue to engage in their learning toward developing plausible and fruitful conceptions of the gene.

The participating teachers in the three schools took different approaches in using BioLogica activities in their teaching in keeping with their beliefs and styles of teaching. As such, each school provided different learning opportunities for students during the genetics course. In School F, the teacher, Mr. Anderson, used three BioLogica activities in his classroom teaching as a supplement to his teaching. In School O, the two teachers believed that students should be encouraged to use their preferred learning styles and did not wish to use BioLogica more often than other learning resources. The teachers used just two BioLogica activities in classroom teaching, but encouraged students to try other activities after school on their laptop computers. The students therefore did not use BioLogica in classroom learning as often as did the students in the other two schools. However, classroom learning also included other online multimedia on molecular and human genetics that feature multiple representations. One opportunity unique to School O students was that they had to make group presentations in class about human genetic disorders using the information on the website Your Genes, Your Health (http://www.ygyh.org/). From the social/affective perspective of conceptual change, we argue that the presentations in School O allowed the students to express their gene conceptions in class, share them with peers, and therefore be able to construct deeper understandings of the gene. In School U, Ms. Elliott believed that BioLogica can be used as a cognitive tool and that it might help student learning for examinations. She used BioLogica activities as an integral part of her teaching in almost every lesson for students to learn about problem solving. As can be seen in Table 10, data from School U show that the students used up to eight BioLogica activities regularly in their classroom learning. Classroom observations indicated that these students were highly motivated, intrinsically, because they found the computer activities interesting, and extrinsically, because they had to prepare for the university entrance examinations at the end of the Grade 12 school year. Therefore, these students were able to benefit more from the constraining function of multiple representations as their learning was geared toward problem solving. However, the pressure of the examinations and the tight time constraints might not have allowed School U students to enjoy learning with multiple representations as much as the students in Schools F and O did.

Active engagement in *BioLogica* activities or merely working hard may not necessarily improve student understanding. Despite being actively engaged in the computer activities, some students, such as Eric (School F) and John (School U), made little improvement in genetics reasoning and, as the status analysis indicated, they did not have fruitful gene conceptions (see Table 10). These students were not likely to be intentional learners (Bereiter & Scardamalia, 1989, p. 376). What should science teachers do to support students with lower prior knowledge who appear to be working hard while learning with interactive multimedia? Classroom teachers should provide students with scaffolding and encourage them to work together with others by emphasizing the social contexts of learning such as those advocated by Vygotsky (1978). They should also use teaching strategies to encourage intentional conceptual change. For example, teachers should encourage students to establish their *achievement goals* that involve: (1) *motivational* processes, including self-efficacy and interest; and (2) *engagement*, including persistence, effort, strategy use, deep processing, and self-regulation. These strategies are conducive to intentional conceptual change (Linnenbrink & Pintrich, 2003).

As for the second part of the research question about measuring conceptual status, the analysis of the nine selected interviewees’ gene conceptions using Thorley’s method has provided new insights into how to judge a high status of a new conception from a more multidimensional perspective (see Tyson, Venville, Harrison, & Treagust, 1997). For example, if we compare the conceptual learning of Audrey and Phoebe from School U, we can see that they had quite different prior knowledge (see Table 10) in terms of their online genetics reasoning test scores, even though they both made progress: Audrey improved from 15% (pretest) to 62% (posttest) and Phoebe from 69% (pretest) to 85% (posttest). If we assume that the online test items based on Treagust’s (1988) method provided a valid and reliable indication of student genetics reasoning, the major cognitive conceptual learning in school science, can we judge Audrey’s gene conceptions to be fruitful? Despite their differences in prior knowledge and progress, our status analysis of their gene conceptions—of data from interview, online postings, and computer log files using Thorley’s method—revealed that both students had an intelligible–plausible–fruitful conception after instruction. The analysis suggested that Thorley’s method allows the students’ conceptual learning to be interpreted in a more multidimensional way. In particular, we argue that the status elements for fruitfulness in Thorley’s categories, namely *Power* and *Promise*, are related to the social/affective dimension of conceptual learning (see Tsui & Treagust, 2004b).

Although our characterization of the gene conceptions in this article refers to the students’ mental models of the concept of the gene, such conceptions also involved the interaction of genes with processes and events across different levels of biological organization, including DNA, chromosomes, gametes, cells, organisms, and pedigrees. Each student could hold more than one gene conception as revealed by the online data in our original study (see Table 4). The gene conceptions of the four students in this study, categorized as intelligible–plausible–fruitful, might simply be about the concept of the gene being information for making of a protein with a life function. However, even though this appears now to be an oversimplified concept of the gene, based on recent research by Venville and Donovan (2005), this concept was what the teachers taught in the lessons observed. Venville and Donovan, who updated a literature review and interviewed nine expert geneticists in Australia, argued that the discrete concept of the gene—that is, a distinct causal agent that determines one characteristic—is outmoded, but suggested that simple messages about the gene are still helpful in any introductory genetics course in today’s schools for students’ understanding of the concept of the gene as part of their scientific literacy. The concept of the gene being information for making a protein remains one of the five simple messages for school teaching suggested by Venville and Donovan.

*Journal of Research in Science Teaching.* DOI 10.1002/tea
In conclusion, this study has two major findings about the pedagogical use of multiple representations of interactive multimedia: (1) when used to a lesser or greater extent, as in these biology classrooms, they appeared to provide different learning opportunities for students to undergo conceptual change toward constructing a deep understanding of the concept of the gene; and (2) their complementary and constraining functions, particularly, appeared to contribute to raising the status of students’ conceptions in one way or another in terms of their intelligibility, plausibility, and fruitfulness. We conjectured that some students, such as Matthew (School F), Andrea (School O), and Phoebe (School U), were able to construct a deeper understanding of the gene concept through their learning experiences with the activities of BioLogica, the interactive multirepresentational learning environment that explains the gene at different levels of biological organization. However, we do not know how students actually learned the gene concept with BioLogica. We suggest that more research be conducted on how students can better benefit in learning in terms of Ainsworth’s (1999) third function of multiple representations; that is, to construct deeper understanding (or fruitful conceptual learning) by promoting abstraction from representations, encouraging extension of a representation across domains, and developing relations between two or more representations.

This study is significant because its findings suggest that Thorley’s (1990) categories provide an informative method for analyzing conceptual status, which very few researchers have used before. The findings also provided new support for Hewson and Lemberger’s (2000) claim that status is a viable hallmark for all conceptual learning. Furthermore, our analyses using Thorley’s method are likely to enrich the multidimensional perspectives of the conceptual-change model (Tyson et al., 1997). At a time when there has been a declining interest and motivation for learning science in schools and universities in Australia and the United States (Hassan & Treagust, 2003; Stake & Mares, 2005), science educators and teachers should consider the social, affective, and motivational aspects of learning science to make learning of science more interesting and enjoyable (e.g., see Haggerty, 2005; House, 2002; Rothapfel, 2004; Simmons, 2005). Many of the students in the classes involved in this research would most likely not go on to study university science courses, but nevertheless they were able to develop an increased understanding of genetics when provided with opportunities for learning with multiple representations through hypermodels such as BioLogica. Consequently, we argue that, in teaching school science, engendering scientific literacy for all students is as important as nurturing future scientists. In conducting this research, it is our goal that the use of this methodology and the findings arouse the interest of science educators and researchers to use Thorley’s status categories for analyzing and identifying students’ conceptual changes that would otherwise be less accessible.

The authors thank the participating teachers and students from the three schools for their kind help and support during our research. We are grateful to Dr. Paul Horwitz of the Concord Consortium of the USA for granting us permission to use BioLogica for research in Australian schools and for providing us his kind support and useful advice. We also acknowledge the three anonymous reviewers for their critical comments and constructive suggestions on previous versions of this article.

Notes
1When students are using BioLogica activities, these data logging files capture the start and stop times and details of students’ interactions with the computer in each session; such log files provide useful data for researchers and feedback to teachers and students (see Buckley et al., 2004).

2In this article, the upper-case format is not used for Thorley’s status elements, instead lower-case and italics are used.
The interviewer, the first author, should have used “alleles” instead of “genes” in asking Andrea, but at the time of the interview the teacher had just started to teach genetics; the use of R and r should be clear enough to indicate that these are two members of one gene or alleles but not different genes.

References


Erickson, F. (1986). Qualitative methods in research on teaching. In M. Wittrock (Ed.), Handbook of research on teaching (pp. 119–161). New York: Macmillan.


