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ABSTRACT

This paper introduces the biology laboratory as a learning project. Biology laboratories provide unique learning opportunities to students as traditional achievement outcome measures, and play an important role in the development of process skills, manual skills, and attitudes. However, there is insufficient data on undergraduate students majoring in biology. The biology laboratory learning project aims to provide detailed data on undergraduate biology students, their interactions with peers and teaching assistants, and their learning. (Contains 39 references.) (YDS)

Conceptual Change in the Undergraduate Biology Teaching Laboratory: A "Type Specimen" Case Study

by

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Undergraduate biology laboratories offer unique learning opportunities which are only partially reflected in traditional achievement outcome measures. There is a need for naturalistic case studies that provide thick descriptive data about the processes of student biology laboratory learning that occur in class through interactions with peers, with laboratory objects, and with teaching assistants. To our knowledge, no such studies exist for undergraduate introductory biology students in courses for biology majors. Because it is unique, this study constitutes a "type specimen" for collaborative group learning in such a context.

One objective of the biology laboratory learning project was to provide a detailed description of the way undergraduate students worked together in a biology teaching laboratory over one semester. A second objective was to construct an interpretation of the nature of biology laboratory learning. Because different tasks affect learning in different ways, this article confines its discussion to small group learning in laboratories devoted to cell division. The study may be seen as a single type specimen of collaborative learning in a midwest-university introductory biology teaching laboratory.

Significance and Theoretical Underpinnings

The Social Importance of Biology Laboratory Learning Research

Since the mid-1950's, teaching laboratories have been important to science courses (Keeves & Aikenhead, 1995). National calls for reform (American Association for the Advancement of Science, 1989; National Research Council, 1990, 1996) and animal rights activists (Balcombe, 1997) have challenged biology educators in the last decade. Responding to increasing budgetary constraints and litigious dissent, many universities have reduced their commitment to introductory teaching laboratories. In an extreme case, computer simulation courseware even took the place of labs that used natural materials (Ralph, 1996).

Yet there is national consensus that student engagement in hands-on science inquiry (laboratory) learning is valuable because it models and develops science research skills (Biological Sciences Curriculum Study, 1993; Dando, 1996). *Science for All Americans* (*SFAA*), issued by the American Association for the Advancement of Science, stressed that students should learn to work together. It emphasized sharing ideas and information freely, and using modern instrumentation (AAAS, 1989 p. viii).

In a recent review of educational research on science teaching in laboratories, Lazarowitz & Tamir (1994) noted, "Convincing data on the effectiveness of learning in the laboratory" has been in short supply. They attributed this to the complexity of laboratory experience, and to inadequate assessment procedures (Lazarowitz & Tamir, 1994, p. 94). A central and timely question, therefore, is whether student learners actually learn in teaching laboratories, and if so, what is the nature of their laboratory learning experiences?

University and college biology departments are experiencing a downturn in the percentage of students who wish to major in biology and other sciences after their freshman year (Fechter, 1990). Some research on college student biology learning in the United States has been done in courses not required of biology majors (Arambula-Greenfield, 1996; Crowther & Bonstetter, 1997). Many college biology laboratory learning studies have been quantitative, based on statistically analyzed survey and test score data (Fraser, Giddings & McRobbie, 1995; Lazarowitz & Tamir, 1994). Quantitative studies are useful for comparing student opinions and the products of science learning, but lab experience is multidimensional. Keeves & Aikenhead (1995) noted the role of laboratory work in the development of process skills, manual skills, attitudes, values, applications and also in conveying the limitations of science and the scientific method (p. 25). Test scores may reveal only a small fraction of what students have learned, and they tell little about the process of learning. There is an imperative need to examine the nature of student learning during biology teaching laboratories, so that most effective use may be made of the teaching laboratory.

Pedagogical Importance of Teaching Science Through Laboratory Work

Biology teaching laboratories offer direct encounters with living or prepared organism specimens and a context in which to practice safe and appropriate use of laboratory techniques and equipment. Concrete experiences with laboratory objects (live or preserved specimens, apparatus, instrumentation) help students confront their conceptions about the nature of life, and provide opportunities for diverse perceptual experiences, analogical modeling, and data analysis. Undergraduate university biology teaching laboratories also provide close and professional interaction with instructors and with other student learners. Laboratories in which students work cooperatively provide small group interaction with peer learners as lab partners. Negotiating knowledge and constructing meaning are part of small group interaction (Solomon, 1989). Introductory biology lab experiences thus offer scaffolding for the construction of meaningful biological understandings and apprenticeship opportunities in science research practices.

Design and Procedures

Inquiry Paradigm

Patton (1990), taking issue with Guba & Lincoln's position that educational research must be informed by one of four inquiry paradigms (Guba & Lincoln, 1994), noted, "I prefer pragmatism to one-sided paradigm allegiance," (p. 38) and suggested a "paradigm of choices" that would favor "*methodological appropriateness*" (p. 39). Several science education researchers have taken a constructivist approach to science learning in classroom groups. Eichinger, Anderson, Palincsar, & David (1991) noted the importance of "the idea of learning as an inherently cognitive and social activity " (p. 2). Cobern (1993) emphasized that science learning is embedded in cultural context. In a recent publication, Driver, Asoko, Leach, Mortimer, & Scott (1994) maintained that science knowledge,

> ...consists of formally specified entities and the relationships posited among them.... they are constructs that have been invented and imposed on

> phenomena in attempts to interpret and explain them, often as results of considerable intellectual struggles. Once such knowledge has been constructed and agreed on within the scientific community, it becomes part of the 'taken-for-granted'way of seeing things within that community....The symbolic world of science is now populated with entities such as... genes and chromosomes; it is organized by ideas such as evolution and encompasses procedures of measurement and experiment. These ontological entities, organizing concepts, and associated epistemology and practices of science are unlikely to be discovered by individuals through their own observations of the natural world. Scientific knowledge as public knowledge is constructed and communicated through the culture and social institutions of society. (p. 6)

The authors went on to say,

> ...a social constructivist perspective recognizes that learning involves being introduced to a symbolic world...scientific understandings are constructed when individuals engage socially in talk and activity about shared problems or tasks. Making meaning is thus a dialogic process involving persons-in-conversation, and learning is seen as the process by which individuals are introduced to a culture by more skilled members. As this happens they 'appropriate' the cultural tools through their involvement in the activities of the culture. (p. 7)

Following the work of Driver and her colleagues, we investigated the phenomenon of small group laboratory learning using a social constructivist framework, because it was methodologically most appropriate for interpreting interactive learning in this case study of a biology laboratory learning group.

Overview of the Research Design

For Yin (1994), case studies are empirical inquiries into contemporary phenomena in real-life contexts where phenomenon and context may not be clearly separable (p. 13). The present study is a qualitative embedded single case design, following the typology presented by Yin (1994). The case itself is a small working group of biology laboratory students. Subunits of analysis are individual student members of the working group.

We propose a multidimensional learning hypercyle framework (details on page 8) for data analysis. Our model emerged after painstaking and repeated review of collaborative lab group dialogue transcripts, teaching laboratory videotapes, student work products, laboratory text, and science educational research literature on conceptual change and collaborative learning.

Research Propositions

The overarching research question for the laboratory learning project was, "*What is the nature of small group learning in university introductory biology laboratory classes?*" In case study inquiry, theoretical propositions guide data collection and analysis and are stated at the outset (Yin, 1994, p. 13). The propositions that initially framed this research were:

Proposition 1. Student groups use laboratory materials, supplies, and equipment as aids to meaningful learning.

Proposition 2. Laboratory instructors and laboratory text are useful to student groups as aids to meaningful learning.

Proposition 3. Student conceptions and misconceptions are voiced, challenged, and modified through interaction with peers, materials, and instructors during biology teaching laboratory sessions.

Proposition 4. Laboratory experiences provide unique learning opportunities, central to instilling and enhancing students' internal drive to find out more about the natural world.

Site and Context

Site. The site was an introductory biology teaching laboratory classroom located in the biology building on the main campus of a large midwestern university. It was selected on the basis of its convenience, accessibility, and because it could be approved by the

Human Subjects Research Committee (HSRC). Access to this location was obtained through the cooperation of the laboratory administrator for the course. Research observations were made while laboratory classes were in session, over the course of an entire semester. This report will focus on two laboratories devoted to learning about cell division. A group of student volunteers was assembled in a single lab section. They worked at a lab table where a videocamera and table microphone recorded their work and conversations without disrupting the normal lab routine.

Participants. Volunteer student participants (4) were solicited by making a general announcement in lecture classes associated with the laboratory course. From 96 student volunteers who signed consent forms, 12 were selected to form three volunteer groups in 3 different lab divisions that met at times that fit the researcher's schedule. This paper addresses data from only one of the three groups, chosen because of gender balance (2 males, 2 females). The laboratory coordinator and two teaching assistants were participants, in that they interacted with the volunteer group during the laboratory. They were aware of the general objectives and rationale for this research, but agreed to the condition that all data sources remained confidential. To assure anonymity, male students in the group were identified as M1 and M2, female students as F1 and F2. The graduate teaching assistant was TA1, the undergraduate teaching assistant, TA2, and the laboratory coordinator, LC.

Role of the Researcher and the Data Gathered

The researcher took the role of a nonparticipant observer, working alone to take field notes, photocopy student lab work products, videotape the student group at work in lab, conduct interviews, transcribe tapes, and prepare research text in Microsoft Word through reductions of field notes and transcriptions. Transcriptions of lab group dialogues forms the bulk of the data for this paper. Audiotaped interviews with teaching assistants and laboratory administrator provided additional documentation of academic context. Other documents were student laboratory work products (quizzes, homework), the laboratory text, a corresponding lecture text, and official departmental and university documents.

Data Analysis

From field notes, transcripts, and documents, research text (125 pp) was prepared that included memoing and an audit trail of the researcher's thinking. As has been said, four propositions guided data collection and analysis. We analyzed small group learning processes in a teaching laboratory setting, to find out how undergraduate biology students interacted with each other, with their instructors and text, and with laboratory objects. Solomon (1989) described a dissertation study by June Wallace (1986) which distinguished the following types of talk in precollege science classes: (a) negotiating doing, (b) removing tension, (c) giving help and tutoring, (d) non-task talk, (e) negotiating knowledge, and (f) constructing meaning (Solomon, 1989, p. 129). A modified Wallace scheme drew our attention to the importance of contextually defining what we meant by *negotiating knowledge* and *constructing meaning*. Instances of knowledge negotiation included a) defining terms, b) comparing calculation answers, c) identifying images, and d) talk about spelling or pronunciation. Constructing meaning meant instances of higher order thinking- statements that revealed complex ideas which depended on or included other science ideas.

The Learning Hypercycle Model. To document salient instances of knowledge negotiation and science meaning construction, we developed an analytical model to interpret small group laboratory dialogue. (See Figures 1 & 2.) We constructed our model according to the following assumptions:

-Individuals construct their ideas on the basis of present and past experience.

-Meaningful understanding emerges out of a constantly dynamic process of assimilation and accommodation of ideas.

- Experiences that don't make sense (perturbations, discrepancies) may induce conceptual change.

-When a learner notices and then questions a discrepancy, answers may be assimilated or accommodated, and conceptual change may occur.

-Incipient conceptual change may be detected by paying attention to learner questions and responses to those questions .

Our analytical model built upon science education research ideas from several sources, the most recent of which was the multidimensional framework for conceptual change proposed by Tyson, Venville, Harrison, & Treagust (1997). These authors proposed three dimensions of conceptual change- epistemological, ontological, and social/affective, and emphasized that accommodation to new understandings doesn't necessarily extinguish prior conceptions. They noted " the rapidity and intensity of conceptual change is dependent on ...factors such as the instructional strategies utilized and the nature of the content." (p. 394)

Our model drew also from collaborative learning theory (Thelen, 1967; Stodolsky 1984) and from biofeedback models of interactive processing (Campbell, 1996). Multiple levels of interaction are common in collaborative learning (Cohen, 1994, 1995; Johnson & Johnson, (1994); Nevin, Smith, & Udvari-Solner, 1994; Thelen, 1967, Stodolsky, 1984). A laboratory context provides additional interaction with laboratory objects and data.

Positive and negative biofeedback mechanisms are constructs biologists use to explain biochemical and physiological interactive processes. It seemed logical to invoke these ideas for interpreting learning group interactions as well.

Our hypercycle model relates to the learning cycle in much the same way that hypertext or hypermedia relate to more traditional forms of communication. Speech and writing are linear forms of expression. One word follows another. Meaning derives from a single sequence of events, under culturally specified grammatical constraints. Hypertext, a computer language, includes multiple sequence options. At any point in a given linear sequence, a node may be inserted at which a choice between sequences becomes available. Nodes may be confined to either-or-choices, or multiple options may be available. Hypermedia extend options beyond language to static imagery, live-action video, sounds, and music.

We not only view conceptual change as multidimensional, we also view collaborative laboratory learning as multinodal. At any point in a question- answer cycle, feedback may arrive from peers, laboratory objects, instructor or lab text. Such input may lead to a new question, or may affect the way the original question is processed by a learner. Because we identified multinodal as well as multidimensional processing, we named our framework the Learning Hypercycle Model.

Following Tyson et al. (1997), we visualized learner questions and their potential answers in three important dimensions-epistemological, ontological, and social/affective. The question-answer mode was seen as reversibly cyclic: a question may be thought of as directed away from a learner. An answer may be thought of as being accepted by a learner. Answers may be assimilated, may cause accommodation (reconstruction of ideas, conceptual change), or be rejected by a learner. Also, accommodation may be provisional, contingent upon learner experiences in any or all of the three dimensions. In a laboratory context, answers may be accepted from peer learner, lab text, lab object, or instructor input. We documented instances of these various possibilities, taken verbatim from our case study transcripts. Using this new learning hypercycle model, we focused our theoretical propositions by inductive constant comparison, an adaptation of Strauss & Corbin's qualitative research technique (1990, 1994). Our interpretive narrative was submitted to participants for member check review.

Findings

We framed epistemological questions according to the model of conceptual change proposed by Strike & Posner (1985). Epistemological (E) questions sought intelligibility, plausibility, fruitfulness. Ontological questions, following Tyson et al. (1997), were questions of identity. Ontological (O) questions sought, for example, to discriminate between object and process, between static and dynamic entities. Social-affective (SA) questions we sought were questions of efficacy that asked, "Can I/we do this?" We found instances of question-answer cycles in each dimension, for individual learners, and also instances in which two or more dimensions were consonant simultaneously. We interpreted one segment of transcript dialogue as an instance of social knowledge construction which not only documented conceptual change occurring in an undergraduate biology teaching laboratory, but also illustrated metacognitive reverberations resulting from the change. To emphasize the cyclic nature of these interactions, we called them "loops."

Epistemological Q/A Loops

Intelligibility and plausibility questions were commonly voiced by participants during the cell division labs. We distinguished between negotiating knowledge loops and constructing meaning loops.

Negotiating Knowledge. Instances of knowledge negotiation included a) defining terms, b) comparing calculation answers, c) identifying images, and d) talk about spelling or pronunciation. Here are two examples of knowledge negotiation in the epistemological mode. Both come from a time in the laboratory session when the students were at work in a parallel mode that recalled Cohen's "collaborative seatwork " task orientation (1994) and Stodolsky's "helping permitted" group category (1984). At this time, each student had the same individual task to accomplish, which was assessed individually. With a compound microscope, a student had to identify cells in five stages of mitotic division (Interphase, Prophase, Metaphase, Anaphase, Telophase) in a preserved microscope slide of onion root tip. Later, the student tallied the number of cells in each phase from a one-hundred-cell count.

In this example, M1 was trying to identify telophase, the final stage of the cell division process. He sought to make the visual images he experienced intelligible in terms of the assignment. His first explanation was that the cells he saw were mutants. Meanwhile, M2 successfully located telophase cells on his own slide, saying,

> M1: Are these all, like, mutant cells, like? They look like six different bunch of stuff....

M2: Mutants...(drops voice to deep low tone) Mutant cells.... Well, I can see my telophase, (laughs) 'cause that's cool. It has two co- two nucleuses in one cell! (laughs) Whoaooo.
M1: Mine had, like, six nucleuses in one cell.
M2: That's impossible.
M1: Here, let me see.
M2: It's a whole new cell. There it is, in the corner....you have to look for it. The one that has two nucleuses. Two nuclei.
M1: Narrow head! (laughs, Meaning that the binocular adjustment doesn't fit his eyes.) Oh. I think I see it. C'n I point to it?
M2: That's telophase.
F1: Yup.
M1: That one that I pointed to?
M2: I didn' point to it, yet.
M1: I did. That works. Yeah.
F1: Yeah. Groove, and it has 'em the little pieces....
M2: Cool.
M1: I don't have one of those in mine (undertone) ...Actually, yeah, I do!
(C4L51-2V, p. 11)

M1 interacted with lab text, lab objects (the microscope slides), and a peer (M2) in his attempt to make sense of what he saw. Searching for an image to match the photographed telophase example in his lab text, he found something he identified as a "bunch of stuff" with six nuclei. M1's interpretation was rejected by M2 as "impossible," that is, not plausible. M1 then looked at M2's microscope slide for the image interpreted by M2 as a cell in telophase. Having located the cell in question, M1 agreed that this image represented telophase, but stated his own microscope slide contained no such cells. After a quick check, however, he noticed that it did. Through the process of multinodal negotiation with lab text, lab objects, and peer learner, telophase became an accessible, intelligible construct for M1.

Constructing Meaning. Constructing meaning meant instances of higher order thinking- statements that revealed complex ideas which depended on or included other science ideas. In the following example, M2 was looking at a photographed spread of metaphase chromosomes (a karyotype). He saw stubby double-stranded figures, believing each to be a pair. He knew that there should be two chromosomes identifiable as chromosome 4, by size, centromere position, and banding pattern. Instead, he noticed that there were two similar double-stranded chromosomes, each of which he identified as chromosome 4. His question was posed as a statement of a perceived discrepancy. Group members responded, each commenting. (The group operated independently of TA2's announcements, interwoven with their dialogue.) M2 responded to group assistance, realizing that the karyotype, being from a human somatic cell, not a sex cell, must be diploid (have one chromosome from each parent). Looking at his photo, he noted it had "two of all of 'em." That is, he noticed there were two double-stranded figures for each chromosome number. He referred to a total of 48, "'cause this is the kid"- meaning it was a diploid individual resulting from the union of two parent sex cells. Formerly, scientists thought there were 48 chromosomes in human diploid cells. After the chromosome squash technique became available, it was found that the number is 46. (23 pairs).

M2: (still doing his karyotype) Got too many fours!
TA2(background) 'Cause that'll help you understand this better...
F1: 's Good.
TA2: ...When you come to the quiz, they'll help you understand mitosis better....If you have any questions,...
M2: What is that?
F1: you have one from each parent.
F2: Oh.
M1: Yeah. One from each parent.
M2: No, should it be?...Well...
F1: you got a bunch of stuff...(pages flipping)
M2: I guess you're right...You got two of all of 'em.
M1: Well. That's pro'lly more.
M2: ...'cause this is' the kid, huh?
F1: Hm?
M1: Wait a minute, let's just...like this..
M2: Two....
F1: What?
F2: With this.
M1: OK.(pages flipping)
M2: Kind of like, 48 chromosomes.
F1: Yeah. (C4L5-1V, pp. 6 & 7)

Several theoretical science entities underlay this peer dialogue. All students understood that the photograph M2 was looking at represented a spread of chromosomes taken by a pathologist from a human cell in mitosis metaphase. The karyotype assignment was to identify which of several possible chromosomal abnormalities was present. The idea that there were "too many fours" thus could mean an abnormal condition, or it could mean that M2 was mistakenly interpreting the photograph. Of the possible pathological conditions listed in the lab text, none included a situation in which there were more than two of chromosome 4. M2 couldn't make sense of what he saw and entered into negotiation with the group. F1 and M1 reminded him that he should have "one from each parent," meaning two chromosome 4's. M2 then checked over the karyotype, and noticed that other chromosomes were also represented by two such images, for a total of 48 double-stranded chromosomes at metaphase, prior to their separation.

The laboratory object (karyotype) appeared less discrepant -more intelligible- to M2, but he continued to confound pairing and doubling, a common cell division misconception identified by Smith (1991) among junior and senior biology students at a small liberal arts college.

Another illustration of an epistemological Q/A exchange began with a question posed by the lab text, and voiced by F1. The students were working together to model mitosis in a diploid cell in which 2N=4. There were to be 4 chromosomes, two homologous pairs. After the chromosomes replicated, they should be modeled as double-stranded. The group ignored some details of model construction, but produced four double strands of pop-it beads, one long white one, one short white one, one long blue one, one short blue one. The model still represented two homologous pairs of chromosomes (one short pair, one long pair). The group came to intelligible consensus with the same misconception that earlier troubled M2. Confounding pairs with double strands, they counted each double strand as one pair.

> F1: OK. "How many pairs of homologous chromosomes are in the cell now?" (pause) ...Isn't that where we are?
> F2: I have no idea... I'm lost.
> M2: This's a trick question...There would be four. I mean, is it a trick question? Or do we...
> F2: It wouldn't be a trick question...
> M2: Then the answer is four.
> M1: Four (in a hollow, joking tone). (C4L51-1V, p. 11)

Provisionally intelligible meaning was constructed by group consensus. M2 was uneasy with his own answer, but settled on it after being assured that it was plausible by the combined input of F2 and M1. The group was able to proceed on the basis of their misconception, but floundered a week later during the meiosis lab, where distinguishing between replicated chromosome and homologous pair was critical to understanding reduction division.

Ontological Q/A Loops

Ontological questions appeared less frequently in these laboratory transcripts than epistemological or social/affective questions. Although students were urged to view cell division as a dynamic process, static object recognition formed a large part of the assessed learning requirement. Students and instructors slipped easily between referring to "a metaphase," and "metaphase." The former indicated a visual static image of a cell fixed in a particular state. The latter implied an ongoing dynamic cell division process. Similarly, chromosomes and chromatids were referred to as static objects, more often than as different stages in an ongoing process.

By definition, a chromosome is a "long thread-like association of genes in the nucleus of all eukaryotic cells and most visible during mitosis and meiosis." (Campbell, 1996, p. G-5) After replication and before separation, chromosomes look like two-strands held together at a point called the centromere. Each of the two strands is called a chromatid.

We drew an ontological distinction not mentioned by Smith, when he noted "students often pair monads into dyads" (Smith, 1991, p. 31) Reporting on a series of interviews in which students were asked to diagram cell division and explain their diagrams, Smith noted, "misunderstandings in one of three phenomenal categories: chromosome doubling (replication), chromosome or chromatid separation (disjunction), or chromosome pairing (synapsis)." (p. 31)

The doubling = pairing misconception may come from thinking of a dynamic process by defining it as a set of objects. A double-stranded chromosome is a transient phenomenon. Hereditary material replicates only prior to cell division. At one place on each chromosome, the process of replication is radically slowed, so that replicated strands remain attached to one another. When double-stranded chromosomes appear, they are en route to completing the process of strand replication and separation. Centromeres, usually identified as objects, are places where replication is temporarily on hold. Chromatids, doubled thread-like objects, are manifestations of the replication process. As cell division proceeds toward anaphase, replication of centromere DNA occurs, and doubled strands separate from one another.

Homologous pairs, on the other hand, are object entities in the sense that whether cells are dividing or not, there exists a particular set of chromosomes typical for a species. The hereditary material is apportioned in a stable, predictable way, and any cell of any organism of any sexually reproducing species may be expected to house all chromosomes of the species set in each of its sex cells, and paired sets in its somatic cells and germ line stem cells. Whether the two members of any homologous pair align themselves closely (as in meiosis prophase I during synapsis) or remain randomly arranged (as in mitosis prophase), the pair is still in existence as long as there is a diploid nucleus in the cell.

The preceding discussion constitutes a warrant for identifying the following transcript passage as an instance of ontological knowledge negotiation. M1's question, "Now what is it?" returns to the problem of whether a replicated chromosome is a paired object, (a homologous pair) or a dynamic single object in the process of undergoing a radical change in its form. As in the second epistemological example above, learner questions were driven by lab text questions and the knowledge that a quiz was coming up.

> M1: OK. Now, what is it? I thought we started with eight.
> M2: Now...(reads) "Replication has occurred. How many chromatids are present in the cell?"...Chromatids....Four? No, wait a minute. It's eight.
> F1: Yeah. No, wait.
> M2: It's eight.(????)
> M2: I don' see no white ones...How many...(???)
> F2: (reads) "Remember that the two...".
> M1: We need more beads...so, there's actually...(???)
> M2: No, each...(laughs) OK. (reads) "How many chromo...homologous pairs of chromosomes are present in the cell?"... Four....(reads) "To help avoid confusion, remember that the number of centromeres equals the number of chromosomes..."
> F1: Eeeeh.
> M2: Now, Metaphase.
> F1: No.(reads) "How many double-stranded chromosomes are in the cell?" 's four? ..."and chromatids?"
> F2: What's a chromatid? ....
> F1: 's one of these, so there's eight of those...(pause)
> M1: (reads, soft) "... the number of chromatids equals..".
> F1: (reads, under her breath) "...homologous pairs...." What's the difference between a homologous pair...
> M2: Homologous, they're the same.
> F1: ...and...a double-stranded chromosome. Is that the same thing?
> M2: Think so. (Slowly raises arm, to signal TA for help.)
> (C4L51-1V, pp. 12,13)

The group struggled with homologous chromosomes, homologous pairs, double-stranded chromosomes, chromatids and centromeres as separate object entities. At least one member of the group was able to supply a text definition of any of the entities, when asked, but understanding the process of meiosis required a better definition of "homologous pair" than "they're the same." The two members of a homologous pair, being derived from different parents, are similar, but NOT the same. Replicates-sister chromatids- ARE the same, because they are one length of hereditary material in the processes of replication and separation. The group consensus once again remained with a definition based on the ontological misconception that pairs=doubles. M2, having argued his case, remained in doubt, and sought instructor assistance.

Social/Affective Q/A Loop

We used an efficacy lens to categorize social-affective interactions. Approaching the group task of modeling cell division, the group's sense of efficacy depended on working smoothly together. In the following example, M2 revised the lab text instructions for model construction and started off with pop-it beads, instead of yarn. F1 and F2 challenged his decision to do so, but M1 tentatively supported it. After a pause, the group adopted M2's decision, resolved their differences and worked effectively together, cohesion having been reestablished. A week later, in the meiosis lab, M2 still ignored lab text instructions to begin modeling chromosomes with yarn, and started off with pop-it beads (as did M1 and TA1, who was another male).

> M2: (reading) "... late G1, or early part of the S phase. OK. The second part of the interphase, the Ssss phase, is (???) So remove the uncoiled yarn," OK..."and, uh...make an exact copy of each of the four chromosomes in your cell...." this's exact copy of this one...
> F1: What are you doing?
> M2: Says, make an exact copy of your chromosomes.
> F2: Yeah. With the yarn, right?
> M2: I didn' read that.
> M1: I don't know if you have ta do it with the yarn, or..
> F2: Oh...I don't know...
> F1: (reads) "Join two light colored strands together.."
> M2: Oooooh...Where's the other one at? (rummages in supply box- a flat, low-sided cardboard tray.)
> F1: Strands...like, yarn strands.....Wait, wait...
> F2: (laughs)
> M2: ...need two more...
> M1: They didn't have the same one in every one...
> F1: Oh!
> M2: Oh! (pause, background sounds)
> F1: OK, now, everything that's together should have the same...number of beads...
> M2: Uhm hmm.(laughs softly)...have to fix that one....
> M1: 'Cause they're the same...
> F2: They're supposed to be the same color,...too...
> M2: Same color, so we put it the same....
> F1: ...Switch these...
> M1: OK.
> F1:What?
> M1: When you're done with that, can I have some...blue ones?
> F1: Yeh.

(C4L51-1V, pp. 9,10)

Conflict resolution is vital for group cohesion and a sense of efficacy, or confidence that the group can accomplish a task together. One way to resolve conflict is to accept the leadership decisions of a group member with high status. Although F1 cited lab text authority in challenging M2's approach to model-building, and was supported by F2 in her challenge, M2 simply denied what he had just read, and continued to build the model with beads instead of yarn. F2 laughed, and both F2 and F1 were won over to M2's strategy when he agreed to alter the bead model according to their specifications ("have to fix that one," and "same color, so we put it the same"). M2's leadership status derived partly from his cognitive grasp of cell division, but also from his flexibility and willingness to accept input from his fellow group members.

Loop Consonance

Although we categorized question-answer interactions as epistemological, ontological or social/affective, the most salient instance of socially constructed conceptual change that occurred in these two laboratories appeared to be one in which positive feedback occurred in all three dimensions at once. The knotty ontological problem of pairing and doubling lay at the heart of M2's confusion. Typically, he posed his question as an accusation against the lab text. Also typically, as soon as he did see what F1 meant, he turned around and explained it to M1, confident that he completely understood.

M2: (reads) ..."the separation differs from the ...mitosis"...the two chrom....I don' understand. It contradicts itself.
F1: How's that?
M2: It says the homologous chromosomes separate, right? An' then, down at the bottom it says, Anaphase I of meiosis, it says the chromatids remain attached at their centromeres and form a unit.
F1: That's because, like, when you're here?...(sound of pop-its on lab table top, as she demonstrates, using the model pieces.)
M2: uhm hm...
F1: ...you've got the chromosomes, you know, lined up next to each other, like this?
M2: Uhm hm.
F1: ...and then they separate...and go to these cells...
M2: OK, so each individual chromosome doesn't split into ...?
F1: Right.
M2: Like that? Like these stay together, right here?

F1: Right. It's like, one piece.
M2: But these right here would split?
F1: Yeh.
M2: Aaaaah.
M1: So, these right here...
M2: Aaaah. That helps. These are like the....homologous pairs..
F1: Well. There's many more....
M2: The homologous pairs of chromosomes split...But each sister chromosome....
M1: These little red things?
M2: Yeh. Well, the homologous pairs are gonna be here like this...(draws on lab manual page, demonstrating to M1)....These are connected, right? They split. But these don't split, as in, mitosis.
F2: Sister chromosomes stay together.
F1: Right. They stay together.
M2: Sister chromatids.
M1: They're here, then.
F1: Yeah.
M1: Wow! OK.
M2: Meiosis in a nutshell. There you go! Thank you. Now I understand.
F1: (laughs)
M2: Damn! I completely understand meiosis, now.
M1: It was, like....
F1: (laughs)
M2: You solved it for me. You cleared it up.
M1: So, these are mad. And they go, they both go like this....and they want to stay....
F2; And they go like that.
M1: And they go like this....blah!
F2; And then they go...
F1: (laughs) Blah!
M1: (poor sound)You like me!
M2: Mon cherie!
M1: (playing with pop-it models) You know you like me...
F1: (laughs)
M2: My mom'll say, I told you! (pause) Thank you!
F1: 'S all right. Glad to help. (laughs)
M2: Now I understand.

(C4L61-1V, p. 8, 9)

The preceding example can be interpreted epistemologically as M2's search for intelligible, plausible connections between the lab text statement and his misconception confounding homologous pairs with replicated chromosomes. The same example could be interpreted ontologically as an object question with a process answer. Finally, the example can also be interpreted as a social/affective loop, in which M2 experiences an intrinsic shift in his sense of efficacy from a state of doubt to one of confidence. The impact of this conceptual change event was shown in the group's exhuberant play, and also by metacognitive reverberations that appeared later in the transcript. For example,

M2: (reads) "Remember that the chromosomes at the end of meiosis I...".(pause)...(Says to F1)... That, that helped. I never understood it because of that one point.
F1: Wow.
M2: Not even in...high school...
F1: (laughs)
M2: Just didn't understand that. (laughs) And now I understand it! Simple. That one point. Took a couple of seconds to explain it to me. An idiot!
F1: (laughs)
M2: Then it goes...(sounds of pop-its) 'S cool! So lined up like that, and now, I line 'em like this....
F1: yeah.

(C4L61-1V, p. 11,12)

Still later, M2 not only reflected metacognitively on his own new conception, but referred to its broader meaning as part of the science community's theory of inheritance. (Here, when M2 refers to "one X" he means a double-stranded replicated chromosome, as diagrammed in the lab text, not a sex chromosome.)

M1: What is that...simulations..(reads under his breath).."Demonstrate, using the bead model... you should be able to show that 4 different gametes may be produced by..."
M2: (taps out a rhythm on lab table) What's one, one X by itself called?
F1: Chromosome.
M2: OK.
(pause, sounds of lab in background, including TA1 teaching a neighboring group)
F2: So, are we supposed to do this with the model?
M1: How do we demonstrate using the model? You mean that gametes may be produced? that sort them out...Is that what that means?
M2: Let's go over how that works. Somebody had to think of it. God! That's great!

(C4L61-1V, p. 12)

M2 continued to tinker with the "fit" of his new understanding, In this example, he invented a new term, a pun, which the group enjoyed,

M2: Hey, paired with its partner? How are we gonna do that one?
F1: I have no idea. I'm confused, now.
M1: I don't...understand...which part of this....
F1: Where do they come from, now?
F2: Yeah.
M2: One individual.
F1: That's the chromatid. Together. It's a chromatid.
M2: Whoaoh...
M1: It's a chromosome. Uh hunh....
M2: You think...chromosome is...Do you think chromosome is, like, chroma-sum? Two of em?
F1: Uh hunh. (laughs) That would work!
M1: Chromosome would be like this......
F1: Chromosome.
M1: ...two...
M2: (sound of pop-its) Uh, oh! That's part of it, see...
F2: You've got some sort of genetic....

F1: Oh! So, now, have you broken a chromotid or a chromosome?
M1: Chromo-tid.
M2: And a chromosome. Chromo-sum! (makes a silly sound, drawing in his breath) (laughs) I just...thought of that.
M1: Wha?...
F1: Chromo-sum. (laughs)
M2: Chromo-sum.(laughs again)
F1: (laughs) Chromo-sum!...
M2: .The sum of them...More than one...(laughs again) See? Eh?...(reads) You should have....four stranded...
F1: Now, see, number 4. You should have homologous chromosomes each paired with its partner....right?
M2: (Reassuringly) I'm thinkin'...
M1: Why don't we....I thought we would...
F1: I thought we would just take them apart.
M2: I'm thinkin'...
F2: These might be partners, now...
F1: No. 'Cause they're not the same thing...
M1: Yeah, they call...
F1:...they come from two different....
M1; Remember the square dance....How come these guys are like, three, two, and these ones are.... other ones are three, two.....
F1: Oh.. We messed it up.
(pause, sounds of pop-its) (C4L61-1V, pp. 14,15)

Trying to construct an understanding of meiosis through the model, the group struggled with distinguishing replicated chromosomes from homologous pairs, and eventually needed the assistance of TA1. M1's reference to the square dance referred to a lecture demonstration of mitosis in which students participated as chromosomes.

Dynamic understanding

In spite of the fact that M2 experienced a radical conceptual change, the new understanding wasn't fitted into his mental framework fully enough for him to avoid terminology traps. He was able to model reduction division in which homologous pairs separated, and mitotic division, in which replicated chromosomes separated, and to see the difference between the two events. He could *visualize* pairs as different from replicated chromosomes. But he still mixed up vocabulary. The following example showed how TA1, teaching by demonstrating and questioning, clarified the terms chromosome and chromatid.

TA1: OK. What's "S" stand for?
M2: Synthesis.
TA1: Synthesis. OK. So, now, I'm gonna get this wacky thing goin on, here, where I get, in synthesis...I'm gonna get....(sounds of pop-its) let's put dad's by dad's, and mom's by mom's...In synthesis, I get this. OK? So, after synthesis in

interphase, I have...how many chromosomes?
M2: Eight.
M1: Eight.
TA1: Wrong.
F1, M1: Four.
TA1: Four.
F2: But they're, like, doubled.
TA1: Right. OK? I have four chromosomes. One, two, three, four. How many chromatids do I have?
M2: OK. Eight.
TA1: One, two, three, four, five, six, seven, eight.. Eight chromatids. OK? Does that make sense?
M2: Uhm hm.
F2: Uhm hmm.
TA1: You're sittin there fidgeting. I wanna make sure it makes sense.
M2: OK. All right.

(C4L61-1V pp. 19, 20)

For M2, conceptual change was vivid and impressive, as has been shown. He had learned that when replicated chromosomes separate during mitotic division chromatids part, and when homologous pairs separate during reduction division, chromatids remain unparted. Yet here, under questioning by TA1, counted chromatids as chromosomes. Tyson et al. (1997) noted, "Conceptual change does not imply that initial conceptions are 'extinguished.'" (p. 402) As has been reported by other science educators, this case showed that conceptual change can be followed by a change back to prior thinking. M2, prodded by TA1, recognized his error.

Implications

Our transcript data document collaborative laboratory learning processes, interpreted as hypercycle phenomena, in a single case study of an undergraduate introductory biology course for majors. We cited instances in which learners negotiated knowledge and constructed meaning on the basis of feedback from lab text, lab objects, peers, and instructor. In one instance, major conceptual change was shown to have occured in the teaching laboratory context.

The findings of this study corroborate the claims of Wandersee, Mintzes, & Novak (1993), in that common misconceptions and terminology problems were voiced by the members of group regardless of gender boundaries. Some parallels were noted to historically held biological ideas. Much of the terminology that confused these students was introduced by nineteenth century microscopists who had no idea of DNA replication and the cell cycle. It could be argued that some of that terminology is unnecessary in an introductory teaching laboratory, but should be reserved for students who are likely to explore research literature for which that termnology would be important.

Also, voiced conceptions were rationalized and defended on the basis of previous experiences, (the students had "done" cell division several times in previous courses) and unintended learning outcomes were documented (M2 invented his own term-"chromosum"- for replicated chromosome.)

Instances of science learning conflicts cited by Duit and Treagust (1995, p. 60) were documented in transcripts of laboratory discourse in the present study. We also noted an instance of conceptual change accompanied by an "intrinsic shift," such as was proposed in the substantive theory of student progress presented by Crowther and Bonstetter (1997, pp. 11-12). In addition, we found indications of "hidden curriculum" (Millar, 1989, p. 2) in the way lab objects and peers reassured M2 that the lab text could be treated as a reliable authority, in spite of his voiced mistrust.

This case study of biology laboratory learning gives insight into students' conceptual ecology through discourse analysis. The social and physical milieu most germane for this research is the immediate academic culture of the university biology laboratory. However, beyond the university culture, and interwoven with it, is the strand of student subculture. We have proposed an analytical framework- the Learning Hypercycle Model- which we found fruitful for interpreting laboratory learning group dialogue. In revising the multidimensional framework for conceptual change already proposed by Tyson et al. (1997), we included a theoretical framework already commonly used for modeling interactive feedback processing in biological systems. We believe our hypercycle model may bear fruit not only for future research inquiry, but for curriculum design, as well. Awareness of the possibility of multidimensional, multinodal interactions may be expected to heighten instructors' ability to predict and facilitate such interaction. Most exciting for us is the idea of facilitating multidimensional consonance conceptual change events, such as the one we have described. Rather than ignoring or discouraging social/affective interactions, instructors could actually engineer or orchestrate them.

Orchestration of the ontological dimension requires instructors to have expert conceptual understanding. Curricular planners should not be watering down introductory course content, but should rather think about distilling it, to reveal the most essential concepts in ways that are accessible to novice learners. To do so requires sophisticated priority-setting.

There is a need for more qualitative studies of laboratory collaborative group learning. We are eager to test our analytical framework on other cases involving the same or different laboratory learning tasks. We look forward to receiving interactive multinodal feedback from other researchers, laboratory curriculum designers, student learners, and, of course, from laboratory objects.

Figure 1

3 Dimensions of Conceptual Change
Epistemological
Ontological
Social/Affective

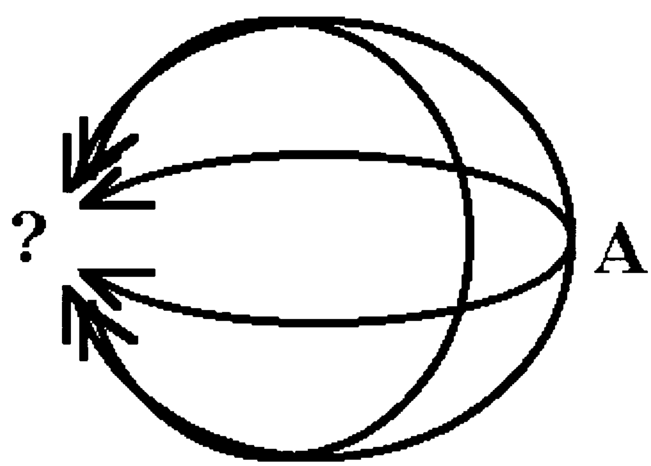
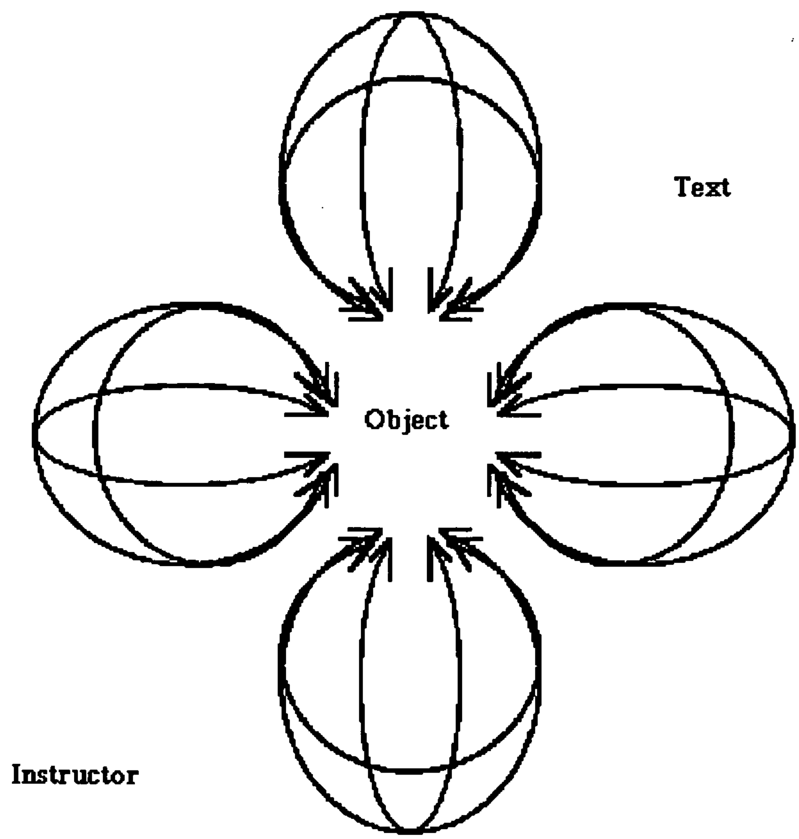


Figure 2

Collaborative Laboratory Group Learning Hypercycle



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