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AUTHOR	Christie, Mary Ann
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ABSTRACT

The experiences and responses of high school biology students using the GenScope computer program are described. GenScope represents genetic concepts in a linked multilevel fashion to teach students to think like scientists. Many GenScope problems use a fictitious dragon species to illustrate genetics. Students can manipulate the dragons' genes to produce offspring with particular characteristics. Students in the two high school biology classes responded enthusiastically to using the computers and to the dragon "design" problems. The freedom to operate outside of typical instructional routines and related teaching methods appeared to begin a transformative experience for these students. Participating in learning through action also engaged students and changed their attitudes about biology. An appendix describes the GenScope problem about the genetics of the dragons' horns. (Contains three references.) (SLD)

"We Understood It More 'Cause We Were Doin' It Ourself": Students' Self-described Connections Between Participation and Learning

Mary Ann Christie

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"We understood it more 'cause we were doin' it ourself": Students' self-described connections between participation and learning.

Mary Ann Christie
The Concord Consortium, Concord, Massachusetts, maryann@concord.org
Harvard Graduate School of Education, Cambridge, Massachusetts, maryann_christie@harvard.edu

It is our first day visiting Mr. E's biology class. Mr. E., the teacher, stands facing the students so that his desk is behind him, centered at the front of the room, just in front of the blackboard. Students are quietly seated at their desks. Five student desks are lined up on either side of the room, each with space for three students. The classroom can seat thirty or more students, though only fifteen or so are present this morning. I notice that student postures appear to recline more and more the farther away they sit from Mr. E. and the front of the room. Some students sit up very straight with hands folded in front, some slump down in their chairs, while others appear as if it is their arms flung over the desk that are the only things preventing them from sliding off the chair and landing horizontally on the floor. Finally, in the last row, a couple of students rest their heads down on the desk. I wonder if they are sleeping. The shades on the five windows that line the far side of the room are more than halfway drawn. I suspect this is to accommodate the lighting needs for our video camera. To me, it feels strangely dark and quiet as we make the introductions. Mr. E. explains that we will be working with him and his class in the genetics unit in biology this year. We will be introducing GenScope, a computer program originally developed at Bolt, Beranek, & Newman (BBN), for primary instructional use instead of the textbook.

Mr. E. tells his students that we would like to know what they think of Biology. I join in and quickly add: "Be honest. It's OK. Just say what you really think. That's what we really want to know." A few students volunteer by raising their hand in the air. Mr. E. calls on them to reply. One boy (I later learn his name is Andy) folds his hands on top of his desk, looks straight at me and politely says, " I particularly don't like Biology 'cause it does not interest me." Reisha, a female student laughs and looks down as the video camera moves in to record her responses. She looks up and says: "No [I do not like biology] 'cause biology is just boring!" Lawrence, a boy who sits in the back of the classroom is asked for his opinion. He replies: "Biology? It just don't click." Of those few who did answer, not surprisingly, many students did not really like Biology-a view shared by many high school students, including myself when I was in high school. When the voice of one student spoke out that she in fact, did like Biology, she was teased by other students "Oh yeah? Then how come you failed last year?" She replies in a somewhat softer tone " I didn't fail, I transferred [from another school]." With that, students began to call her Einstein (a label that appeared likely to stick over the next several weeks based on the accusatory tone of the other students).

We leave after these initial introductions and return to the office to prepare for the next day-our first in the computer room with Mr. E's class. The next morning, we leave our office later than we should have and hit every red light between Cambridge and Dorchester. We arrive at the school about five minutes into the period. The front door is locked. We need to ring the bell in order to get in. After what felt like an additional five minutes, a tall, silent man lets us in. He sees that we are juggling boxes, cameras, and coats, and points to the sign up sheet at the check-

in desk just beyond the front door. I quickly sign in for all four of us and then rush to catch up to the others- as they rush toward the stairwell. We run up the three flights of stairs, juggling camera equipment, coats, boxes of notebooks, disks, and handouts, trying desperately not to drop anything. Once at the top of the stairs, we rush into the classroom breathless. Once again, students are seated straight and not so straight, but quietly. They watch us get settled as Mr. E. quietly reports to us that his students were upset. They thought we weren't coming back and kept asking, "Where are the people?" I wondered what our involvement meant to these students-many of whom "do not like biology".

It is the last day of class in Ms. M's class. With Ms. M.'s permission, we are throwing a party for the kids to thank them for allowing us to work with them. We explain this to the students as we set up for the party. Joyce brings chips and pretzels; Paul brings juice and soda. I bring the dragon cookies that I had been baking until midnight last night. We set up videotape of various shots we had recorded over the last several weeks. We thought it'd just play in the background during the party amidst other joyful noises. We put it on and the noise level drops immediately. Students sit still in their seats. They giggle when their classmates are the central focus on the tape and gasp when they see their own faces (though they ask us to rewind it many times and they watch themselves again!). After we play the short tape several times, students begin to get up out of their seats and mill around-even to eat some of those dragon cookies!

The rest of the time seems to go so quickly. We're not talking about dragons (other than the cookies), test scores, school, or other classes. We are having one-one-one conversations with the kids, primarily social. Then we talk with Ms. M. and amongst ourselves. The kids don't seem to notice, they're playing music, eating, laughing, flirting. We tell Ms. M. how amazed we are at how quickly the students presented observable behavior changes. At the beginning, they barely spoke to us, to Ms. M., or to each other. When asked what they thought, students often said, "I don't know", stared at us, or at the floor; mostly, they just stared at us and at the teacher as well. One girl, Keniesha, would trace the large scar on the inside of her left hand every time she was called on; she never even looked up. We weren't sure what they had learned yet (Ms. M. hadn't graded their final exams) but we were sure impressed with the increasingly "grown-up" ways in which they had interacted with us over the last eight weeks. Even so, nothing prepared us for what came next.

The bell rings at the end of the period. Immediately, the kids, led by Marvin, form a huddle at the back of the classroom. We wonder what they are up to. They stand close together, they hunch over; a steady hum of whispering fills the room. Finally, Marvin's head appears above the crowd as he announces loudly (but not too loudly): "On behalf of my classmates, I'd like to thank all of you for working with us." Then dutifully, the students form a perfect line and begin to walk toward us. Sensing a performance, we (the research team) line up as well. The line of students begins to move past us slowly and purposefully. With heads held high and smiles wide, each student stops in front of each one of us. One by one, they look me in the eye, shake my hand (their grips almost as diverse as their clothes and hair colors and styles), and say "Thank you." They seem to grow taller as they leave us for the last time.

These snapshots of high school Biology students' beginnings and endings with the GenScope project frame a portrait of participation as defined by their words and behaviors. Their sense of anticipation, expectation, and heartfelt thanks also frame the affective phenomena I have been trying to understand through my work on the project in these last three years. The GenScope Project is educational technology research and development project sponsored by a grant from the National Science Foundation.[1] GenScope was originally conceived to address a need for an alternative to text-based instruction in science education. Textbook-based instruction typically represents genetic concepts in a linear fashion and attempts to develop cause-to-effect reasoning whereas GenScope represents genetic concepts in a linked multilevel fashion and attempts to develop effect-to-cause reasoning, much in the way scientists themselves learn. In fact, a stated goal of the GenScope project is to teach students to think like scientists.

The GenScope project has worked with various students and teachers over the last three years, primarily in urban high schools. In exchange for access to their classrooms, we have provided teachers with the software, training, and a set of increasingly complex puzzles for use in the high school Biology curriculum. Many of these puzzles use GenScope's fictitious dragon species. The dragon creatures appear in cartoon-like style although their genetic structure reflects real world knowledge of genetics. Initial puzzles focus on deductive reasoning of phenotype-genotype rules whereas more difficult puzzles focus the inductive reasoning necessary to solve pedigree puzzles (e.g. look at an organism and determine its genetic makeup, and the rule for the traits based distribution of traits in inheritance patterns). The transmission of recessive alleles, or how a baby dragon could show a trait neither of its parents show, is a good example of this kind of complex reasoning (a description of "The Horns Dilemma", one of the first complex inheritance puzzles attempted by students, is included in Appendix A).

[1] The GenScope project, titled "Turning Information into Knowledge: Hypermodels for Science Education, 1995-1998, " was funded by a grant from the National Science Foundation. NSF Grant # RED-95534.

As a staff member on this project, I have always been focused on the students. At first, I focused on the ways students used our software and curricular activities with an eye toward product improvement. More specifically, at first, I collected data on how students and teachers have used our software and translated this into software enhancements or functional design changes. I've evaluated our technology, contributed to software design, and created curricular puzzles and hands-on assessments. My gaze has since evolved into a focus on students as learners and a desire to understand the process of learning from their point of view. More recently, I have been interviewing and observing teachers and students. Some days, I simply sat in the back of the room, quietly observing and taking notes of the words and actions that surrounded me. Other days, I seemed to fly around the room from computer to computer, desk to desk, and kid to kid, handing out pencils, papers, computer disks, sympathy, empathy, and encouragement.

I am particularly interested in the concept of participation in an academic context, prompted, or at least influenced, by the integration of particular kinds of technology in the classroom, and perceived by students in the classroom. First, educators and psychologists agree that participation is an important prerequisite for learning. Second, teachers and students as actors in particular school cultures create participation structures in the classroom, in the form of learning opportunities. Finally, student perceptions of these learning experiences is key to understanding and improving education-critical as a point of view in its own right, and critical because it is often not solicited in educational practice or educational research.

Using the computer to solve puzzles in school was a new experience for many students. Whereas all students in the class were very familiar with technology, most of their technology experiences in school were focused around the "computer literacy" curriculum, of which "keyboarding" is one main goal, and exposure to productivity tools is another: word processing for resumes, spreadsheets for balancing checkbook, etc.

I sit down with Tina in the computer lab to talk to her about her experience with computers, here in school as well as other places. She explains " I got one [a computer] at home ... To tell the truth, I been playing games (laughs). But here in school, I have this class everyday after science - after y'all class - we do spreadsheets, we learn how to do business letters, how to do ... resumes and stuff for jobs and stuff like that. ... word processors, we use the books right here" [Cristina points to a typing book. It is exactly like the one my high school had used in the typing/business classes almost 20 years ago!].

Some students resisted the requests to solve the puzzles by refusing to do the work, trying-and sometimes succeeding-to distract their peers, playing the various computer games installed on the brand new hardware, and trying to get others to "goof off" with them. "Acting out" was often interpreted as disruptive (or perhaps disrespectful) by the teacher and met with powerful requests to "Sit down!" "Pay attention!" "Shape up or I'm gonna ship you out!" I later learn that students were "shipped" to special education classes. This in fact, had happened to one boy who never seemed to engage in the task at hand or heed any of the teacher's requests. He made it to the computer room once or twice before he was moved to Special Education. Whether in the lab or the classroom, Jason applied his energies in distancing himself from the teacher, from other students, from us, from science, from learning, and from participation. He often succeeded in gathering several other boys together in the back of the room, where they did their own thing, instead of what the teacher wanted them to do.

Teachers establish rules around participation in a given classroom; sometimes these rules are explicit, many times they are not. Certain behaviors are required, allowed, and preferred. Students often looked to teachers as authority figures, in areas of content (in this case, science) and behavior. Students know that they are supposed to speak when called on, listen when teacher is talking, or read and write when directed by the teacher. When asked, students articulate views of passive participation that appear to result directly from didactic pedagogy and view of teacher as teller: " They [teachers] just sit there and teach. And we just write ucchhh! It's aggravatin'! (sighs)."

However, the disruption of typical instructional routines created by the GenScope project made space for student voices to take shape in the classroom. Making room for voice, whether explicit or implicit, is critically important for young people not just educationally, but developmentally; losing voice is often characteristic of adolescent development, sometimes with deep psychological consequences. Rather than respond to the teacher only when asked to do so (which often prompted replies of "I don't know", "I gotta go the bathroom", "I gotta go the nurse", or silent stares), students began speak out. In their words, they were "talkin', "doin' different things", and "givin' our opinion".

When one student describes her experience, she tells me that "We talked yet we were still learnin'." Her words seem to portray a view of talking as separate from learning-perhaps even mutually exclusive. As I reflect on this quote, I wonder if this student is substituting learning to the ways in which she is taught. It does not surprise me that student views of expected behaviors, or ways to participate, are entangled with views on learning. After all, teacher views on expected student participation and classroom behavior are very much entangled with views on teaching. I think back to Magda's victory, which happened back in the classroom during one of Ms. M.'s lectures.

Students had been working on inheritance puzzles for the last few days, involving dragon color, a sex-linked trait. Approximately fifteen students are seated quietly at their desks while the teacher, Ms. M, stands at the front of the room with an overhead projector. Ms. M. is giving a lecture on the dragon genome, reviewing the possible genetic information in the dragon species and how it expresses itself in various dragon colors: emerald, azure, bronze, topaz, gold, and amethyst. Ms. M. presents overhead slides of a dragon's genotype (genes and chromosomes) and calls on students to provide the phenotype (expression of the traits determined by the genetic makeup on the overhead). Although Ms. M. leads the discussion initially, she begins prompting students to agree or disagree with her "This is still going to be bronze, right?" When students do

not respond, the teacher answers her own question in the affirmative saying "A bronze father can only have Aa bB [alleles on color chromosomes organized in a particular sequence]."

Magda interrupts the teacher: "No. I don't understand .... it's not that way on the computer .... on the computer [Magda begins to cross her arms in front of her] you can have Aa Bb ..... they [the alleles B and b] can be switched." (Magda is referring to crossover, a "gene-switching" process that happens randomly to chromosomes through meiosis, though this is both random and user-controlled in the GenScope program). At this point, a dead silence covers the room as the students waited for the teacher's reaction. Even I feel the tension! The teacher stands speechless and motionless for a few seconds. She appears to be thinking about Magda's interruption. Then, she slowly replies "You're right (another silent pause). Thank you Magda". As a big smile begins to cover Magda's face, Marvin, another student seated in the back of the room, begins to clap his hands as he gasps out an exclamation of surprise-even disbelief. The noise level begins to pick up as others join in the applause. Magda yells "You're welcome!" above the rising laughter and applause as she smiles another big smile.

I am also reminded of Danny's first steps to the front of the room. One day, Ms. M. gave the GenScope team permission to break the class into groups of five in order to facilitate a student-directed discussion of the sex-linked trait problems they had worked on recently. When asked "What will you write on the board?", Danny's face takes on an incredulous look. Another student in his group, perhaps recognizing the confused look on the face of my colleague, Catalina, explains a clear view of who does what in the classroom: "We don't write on the board ... she [the teacher] just asks us questions". The blackboard, like the knowledge, belongs to the teacher. The teacher makes decisions about who has access to tools and knowledge in the classroom. Catalina responds, "Well I think you should write on the board and I am going to ask her [Ms. M.] if it is OK". As she gets up to ask the teacher you can see Maria and Danny smile at the prospect of using the board. Danny actually says, "Cool!"

I had Danny rehearse in front of us what he was going to say. I told him that he should take the piece of paper he had been working on to support his presentation (this is to me an instance when literacy supports a mostly oral performance). As Danny rehearsed, he started to grope for 'the right' words. "Is this a chromosome?... a gene?" Someone in the group said gene. I took Danny's piece of paper and wrote gene on it. I told Danny that he would want to have that word scribbled down in case he forgot it when he got to the board. He continued his rehearsal and came across another word he was going to need 'meiosis.' He came up with the word himself, and then scribbled it on the piece of paper, himself! He was both appropriating scientific vocabulary and a way to organize his performance. ... As he finished he felt confident he had

both the understanding and the words to talk about this understanding. I asked him a few questions, explaining that he had to be ready for questions. (I guess that's why he ended the performance by asking: are there any questions?) From my perspective he was moving from learning by doing (which gave him confidence in his understanding) to verbalizing to himself and others and in doing so appropriating key scientific vocabulary. That's what you see in the performance. The class claps at his performance. I think we were all impressed.

Hermando, whose usual interactions with Mr. E. are usually limited to requests for the bathroom pass, is a quiet and withdrawn student who has very little interaction with his classmates or his teacher. In fact, Hermando rarely speaks at all except to Andy, a classmate and friend. In the classroom, Hermando sits with his head down most of the time; he does not actively participate. In the computer lab, there are days when Hermando does not work but quite often (more than half the time) he does. In this example, Hermando is trying to help Mr. E. explain to Andy how babies can express traits that their parents do not express.

Andy: (to Teacher) if your parents don't have somethin', how can you get it? [Teacher turns to nearby blackboard (near Andy's seat) and begins to draw a Punnett square]
Hermando: [gestures his hand over toward Teacher and Andy. He yells out to Teacher by his last name] E! E! Lookit... It's like this (pointing to the computer screen where he has created horned parents who have hornless offspring in GenScope). The parents have horns and they [baby dragons] don't-

Hermando clearly demonstrates his understanding about inheritance outcomes. Furthermore, he reaches his hand out and desperately tries to get Mr. E's attention so that he can explain it to Andy. Unfortunately, the teacher either ignores Hermando or doesn't hear him, but the fact remains that Hermando inserted himself into the discussion between Mr. E. and his friend. That is, when he hears Andy pose a question to the teacher that reflects what he has already learned, he makes an effort to explain what he knows.

Learning by doing is a theme that appeared in student interviews as well as observations. One student describes her experience by comparing it an implicit understanding of what it means to learn: "It was like an activity more than learnin'." Another student explains "Now I seen the stuff [genetic inheritance] bein' done before I just read about it." Again, these statements reflect

a level of interaction, or doing, not previously present in their classroom participation. However, students did not always appear entirely comfortable with this "new" responsibility borne out through self-directed, rather than teacher-directed, activities.

One of the more persistent phrases uttered by students during text-based lessons has been "What do we gotta do?" usually followed by "Tell me the answer". These requests for direction and answers occurred in the computer lab as well. Students often sat at the computers and waved their hands or papers in the air asking "What I gotta do?" Many times, students would flatly announce "I don't know" or "I can't". This fragile orientation appeared to affect their levels of participation. Whereas "I don't know" or "I can't" coupled with passive behavior may seem to suggest a strong defensive posture, many times it only took gentle encouragement for students to engage and ultimately demonstrate-to themselves and to others-their more than ample ability to work on these problems.

For example, Janice works alone at the computer. She has figured out how which chromosomes are required to make a male baby dragon and a female baby dragon. She now wants something more to do: "The male has two Xs and the girl has X and a Y. That's how I know it's a girl or boy. So now it tells me to do four babies in a row, I do four babies in a row. Now what?" One of the GenScope team responds with "OK. I'll give you a harder thing to do". Janice smiles nervously and asks softly "Why a harder one? This was difficult for me (nervous laugh)." She reverts to a phenotype-genotype task, an easier task which most of the class had mastered on the first day.

The team member returns with another handout. Janice begins to read: "What are the possible combinations (inaudible). Ahhhhhh! Help. [keeps reading softly]" A team member comes over to help and asks: What do you gotta do with that?". Janice responds by silently presenting her handout. The team member reads aloud: "Try to make a firebreathing dragon ... Understand the question?"

J: Nope.
V: yeah you do, don't you?
J: [shakes head no] I gotta see which one [gene combination] is gonna make them have fire?
V: [reads question then explains to Janice] OK What they're telling you is that firebreathing is on the X chromosome.
J: Mmmhmmm.
V: So if the female breathes fire, what are her possible genes?
J: [points to the paper and sits back in her chair as she makes a face by crinkling her forehead and nose. She then turns back, points to the paper and asks] Big F, little f?
V: I'm not sure.
J: (loudly) You gotta tell me!!!
V: No. No. I don't have to tell you.
J: Yes, you do!

When *Janice* does not receive help, she works on her own. She figures out that firebreathing is a recessive trait and that a female firebreathing dragon would need to inherit 1 little f (on her X chromosome) whereas male firebreathers would need to inherit two little fs: "Females only 1 f - male is two fs- two little fs. Ha! Ha! ... [Calls out to GenScope member] Miss! Finished! [holds up her paper]." She then turns to the team member she had pressed for the answer only minutes before, laughs, and says: "You didn't help me - I did it by myself." At this, Janice begins to dance around on her chair and sing about her success.

However, not all students are as self-assured in their own ideas, independent of whether they are "right" or "wrong" about the content. In sharp contrast to Janice, Hermando does not trust his own answer enough to do it by himself. He is trying to answer a paper-and-pencil question by selecting the two pictures that represent "homologous chromosomes". At first, he answers the question correctly, by explaining to Mr. E. which two are homologous, but then circles the wrong pair of chromosomes. When Mr. E. asks Hermando why he selected X and Y (instead of the X and X pair that he had just described orally) Hermando explains that he circled "that one [the Y] because I thought you [the teacher] made an 'Mmmmhmmm' noise when I had my pencil near it." After a brief pause, Mr. E. tells Hermando to circle what he thinks is right and walks away. Hermando quickly erases his answer, then purposefully brushes the little pink debris away. He

takes a few seconds to look at the (now blank) paper, then quickly moves on to the next handout; he never commits his answer to the homologous question on paper.

On another day, we held a review session for the students in the computer lab. Five students appeared in the lab while approximately five others were in the classroom attending the teacher's review of the material. In the lab, students were not given a handout in the lab detailing the instructions for the computer puzzle. Instead, they were asked to make two parents all of whose kids will have two legs. First they were to predict (in writing) their hypothesis about the genetic makeup of the parent dragons. They were then asked to construct an experiment (on the computer) to test their hypothesis.[2]

As I expect, many of the kids start off believing that two-legged parents will have exclusively two-legged kids -- that two-leggedness, in other words, will "breed true." They are rather surprised, in fact, to discover that they're wrong, but all of them seem to be able to figure out why, and to come up with the solution I seek -- namely, a "marriage" of a zero-legged and a four-legged dragon. (Mark is at some pains to explain to me that it doesn't matter whether the mother has no legs and the father four, or the other way around.)

Lawrence, who had come in late, sat alone facing the computer; its screen was turned off. I approached him and lowered my body so that we were looking at each other eye-to-eye. I told him that the task was up on the board and asked if he had any questions. He just looked at me and said "I can't do it." He then went on to apologize "for not knowing much", pointing out that he hasn't been in the class continually and "when I was, I wasn't always paying attention." He seems not only apologetic, but sad. I tell him that he does know quite a bit, based on my own observation of his work when we was around right here in this room, and that I am sure he can answer this question. He gets to work right away.

From field notes that were recorded the very next day when students took the post-test, I know that Lawrence successfully completed the legs puzzle he "couldn't do" above. I wrote:

Lawrence flat out told me - "I'm not doing it [the test] - I don't know nothing." I had to remind him that he knew more than he was giving himself credit for and that he had explained himself pretty well in the review session on the computer. I also told him that he was selling himself short but choosing not to do it at all. Then Mr. E. and the rest of us would never know what he could've done - and neither would he! I also told him a little technique that I use myself: Iif you don't know the answer and think you can't get it, circle the number of the question. When you

[2] The legs problem is slighty more complex that the horns problem. Legs is a codominant trait, which means that there are three possible combinations of genetic informational arrangements for legs (ll, Ll or lL, LL) resulting in three very different trait expressions (zero legs, two legs, and four legs, respectively).

finish the test - go back to the circled ones and try again. Lawrence took the test. He looked like he was working pretty hard ...

Many students valued the time they had to learn. As one student reports: "We had time yet we were still learnin'." Again, these words seem to pick out a crucial aspect of the experience that qualitatively differentiates it from "learnin'". Time may be valued simply for the sheer novelty of it (it is rare when students spend more than a couple of days on a topic much less eight weeks). But I believe that student words and actions point to another aspect of time: the opportunity to know something without really understanding it, the opportunity to speculate or to have a theory or hypothesis without being sure, coupled with time to further the understanding or to check a hypothesis. Extended time for learning was so valued that students often did not hear or acknowledge the piercing sound of the bell, signaling the end of the class period:

Then the bell rings. Many of the kids starts to get up but still have their hands on the keyboards as they are getting out of their seats. Today, it is Jen who stays at her seat when all the other kids have already gone. Seconds after the others leave, she yells something like "Got it! or I did it!" I go over to ask her what she did and how she did it. She tells me "I crossed it! I switched it! I have to go to class - I'll tell you later!" I say "Ok - but don't forget!" She looks at me as if I'm crazy to think such a thing possible and says "I won't! It took me hours!" Her sense of time is precious to me, particularly as she has really worked on this problem for one class period, so far--a total of fifty minutes.

The notion of time as a valued component of participation has implications for the oft-made connection in students own words between "I don't know", and "I can't know". For several students, incremental understanding was evident in their explanations. They began to see that "not knowing" was different from "cannot know". Instead of limiting themselves to answering teacher's questions or asking teacher for answers, students began formulating their own ideas, asking questions, and checking their own work.

For example, Clark and Mark sat down at the computer to think about sex-linkage. They were trying to answer the following questions: What determines a male zygote from a female? What would they need to do in order to purposefully select a sperm cell and an egg cell from parent

dragons to create a male baby dragon? After they made their selection of gametes (sperm and egg cells), I ask Clark if he is sure that it is going to be a boy. He responds: "He's sure [pointing to his partner Mark] it's gonna be a boy. I'm [taps his chest] making a hypothesis!"

I wondered if the hands-on participation, which was largely student-directed during the computer activities, may have been at times too open-ended. That is, perhaps for some students, this exploratory work was not explicit enough. I recall the time when I distributed a handout that pictured the genetic information contained in two dragon cells (two egg cells, both female) together with a question: "Can these two dragons have a baby?" Alan yells out: "This is boring!" When I asked him what he meant, he said, pointing to the handout: "There's no explanations on here." I told him that he was exactly right! No explanations! Except for the ones that he would write down.

However, the GenScope activities were much preferred by the students than seatwork in the classroom, even if the seatwork involved discussion or reflection of computer-based activities. I think back to the day when Mr. E. was beginning to worry about the purposefully-designed lack of exposure to scientific vocabulary words, two weeks into the session. He wanted students to begin to spend more time in the classroom, get them used to discussions in preparation for the vocabulary lesson. We thought it a good idea to link the dragon concepts and information with some classroom discussion and looked forward to seeing what students would do.

The class is noisy as students filter in. Mr. E. gets settled with the overhead projector. He asks Ladawn to go up to the blackboard and write down student responses. Mr. E. starts by saying: ""Let me ask you this. Did someone find out-are wings dominant or a recessive trait?" Several students shout out "recessive!" Mr. E. asks a specific question: "A Are they dominant or recessive?" One student says dominant while another says recessive. Ladawn stays on top of most of the shouts as represents them on the board. Mr. E. walks around the class asking various students what they think. Conflicting answers come back: "Dominant." "Recessive." As Mr. E, walks back toward front of class, Wanda yells out "Dominant! What's wrong with you people?" The discussion continues. One student yells out "Mr. E. I need to go the nurse." Wanda responds, her eyes still fixed to the blackboard, "C'mon, no you don't. Not right now. That ain't important." A few of the girls seem as engaged as Wanda is, whereas the boys are not really participating. ... For example, Mr. E. bargains with Hermando who asks for the bathroom pass. Mr. E. tells him "Deal. [give me the answer for] barbed tail, bathroom pass." Hermando

responds, sounding annoyed, and then says "Write me a pass man!" Midway through the class period, one of the girls gets up and begins to walk out. She announces: "We need to get of here! We need to be in that computer room, don't you all think?" Several students begin to gather up their belongings and to follow her of the room. After a brief pause, we adults collect our belongings and let the parade of students lead us down the hall to the computer lab where students continue to explore the dragon genome.

Other students expressed a desire to be "in that computer room" as well. Tony, a classmate of Alan's, pleaded with me one day in the classroom: "Why don't you guys stop giving us this stuff (off the computer), just tell us the instructions and then leave us alone!" For these and many other students, whose requests for direction dwindled over time, success was becoming recognizable by them-they did not have to ask the teacher if they were right or worry about "Mmmhmmm" noises. Perhaps, as one student said, "we understood it more 'cause we were doin' it ourself." Recognizing this increased understanding and their own success was cause for celebration at any point in the class period. As students solved problems, they would sing and dance in their chair, like Janice, they would smile, clap their hands, or make little exclamations ("Taa daa!!") to themselves or their partner. More dramatic expressions were also part of the celebration. Students would often yell out for the teacher so that they could explain their own work: "Come over here and see my success!"

Although there were many valid self-proclaimed "successes" of the kind just described, every student did not reach the same level of understanding. Some students could be overheard wishing or praying for the "right" outcome after they had selected their gametes (sperm and egg cells) and were running the animated meiosis process waiting for the baby dragon to be born: "Oh please be firebreathin'!" However, these imperfect steps may all be considered valid participation in the context of learning, particularly as they pertain to the development of incremental understanding. True understanding almost never comes on the first try-particularly in science.

Like the scientist, who spends "his time discoverin'", students seemed to embrace this notion of not having to get it right the first time (when asked what they thought scientists did, students

usually responded that he-it's always a he-spends his time "discoverin'"). When asked to make predictions (about dragon traits or sex in inheritance outcomes), many students would smile and say "I'm guessin'. If I don't get it right, I'll just do it again until I do!" When Alan was asked if he was sure it would be a boy, he replies: "It's a boy! I'm sayin'! It's my [pats himself on chest] boy!" When pushed to explain how he knows it's gonna be a boy, Alan replies "Guess. ... You know, if you - good guesses - it'll come out a boy." When asked to explain further, he adds: "If you take good guesses - if you pay attention to what you gotta do, it's gonna come out a boy, see? [points to male dragon]." It's not clear whether Alan paid attention to what he had to do and purposefully created the male dragon or whether he was benefiting from the random distribution of sex traits among the dragon population. However, it is interesting to consider that Alan's "guessing" may not be guessing as we adults know it, but a form of emerging understanding on the part of the student.[3]

Students repeatedly spoke of incremental learning steps as they described their experiences "explainin'" and "talkin' and figurin' it out how to do it and everything". Tina explains the difference between knowing and explaining. She is careful to point out that this may not apply to all kids: "Well a lot of kids - each - every kid is different, so .. there's different ways. But me, it's like I know how to do somethin' but when it comes to explainin' it's just hard. " Not being able to explain does not always imply that students have understanding. For example, when asked how she made the hornless baby, Wanda says: "Oh my god! I don't remember. I was just doing stuff. .... All I did was take-um-I can't really explain it." From observational notes, I know that she never examined the genetic information contained in the gametes. In this case, Wanda's hornless baby dragon was a random event, the luck of the draw.

Many students expressed difficulty in explaining their understanding; they often equated this difficulty with phrases like "I don't know", "I can't do this", "I don't know anything". However,

[3]Although I have been unable to check this theory with Aaron, the possibility that guessing may be more meaningful to students than the ways we, as adults, may typically think about it in educational contexts is interesting to me, as are students' definitions of many other descriptive words heard in an educational context (for example, boring).

when encouraged to take time and work through the explanation, many students delivered beautiful demonstrations of scientific reasoning in their own words. One student describes the difficulty: "Yeah, we always had - there was like - there was always a connection to each puzzle but it was like different in its own way. It was hard that we had to figure out what we were talkin' about. And then we to explain it to you all. We knew how to get the answer but we just couldn't explain it so it made us think."

Explaining what you know (for young people and adults alike) often introduces a level of uncertainty, complexity, or discomfort. For example, Rhionna voices her initial reaction "I don't know what's goin' on" to another "horns problem", just loud enough for my colleague Paul to hear. Paul approaches and asks Rhionna what she thinks is going on. She begins to explain right away: "If the mother had big Hs - yeah - if she had big Hs and one she has a little h and the father and one he has a little h and when it comes together- the baby it will have no horns." (This is correct). Rhionna continues when Paul asks her to explain it again, this time emphasizing the terminology: "You have to look at the mother and father genes and see if they have 'h' in each of their genes. If they have little h in their genes, when they make the baby, the baby will have no horns." (This too is correct.). Next, Paul asks Rhionna to read the question on the handout, the challenge question that she was initially reacting to. Rhionna summarizes the challenge aloud: " Two parents neither of whom has horns. They have one kid without horns. They have fifty additional kids. Is it possible that any of those will have horns?" Within a few seconds of reading this question out loud, Rhionna begins to explain her thinking: "If they [parent dragons] don't have no horns, they'll both be little hs in both their genes and so they can't have kids (3 second pause) with horns. Right." She punctuates the end of her explanation with a big smile. Rhionna did, in fact, know "what's goin' on".

The awareness of incremental learning was for many students an inchoate understanding. Lila, one of the brightest students in the class, was overheard calling herself stupid because she could not remember the textbook definition for the vocabulary word "gene" when another student was

quizzing her (I found this quite amazing as she was able to explain the concept of a gene). The very next day, Lila, teams up with Mark and learns another lesson about learning. They are working on the Horns Dilemma problem, trying to predict and then construct two parent dragons that can display the horns trait and produce a baby who does not.

Lila has control of the mouse first, then gives up control and regrets it shortly afterwards as she figures out that the father, whom they had made homozygous dominant for horns (HH), could not possibly produce a hornless baby with a heterozygous mother (Hh). By then, Mark has control and is exploring different levels and examining the gametes that they have produced through the process of meiosis. By then, Mark has control and is exploring different levels and examining the gametes that they have produced through the process of meiosis. He won't give up control of the mouse, despite Lila's protests. Lila is unsuccessful at regaining control although she tries very hard to explain her reasoning to Mark. Finally, Mark agrees: "It can't happen", meaning they cannot produce a hornless baby from the parent organisms they have designed.

Lila and Mark did not initially design the parent dragons such that the offspring would be hornless. Mark appears concerned that they did not complete the activity as requested i.e. purposefully design the parent dragons so that you are sure to produce hornless offspring. He blames Lila for this as he explains to a GenScope team member: "She did it [designed the parent dragons]. She wouldn't let me have the mouse." Lila's response includes a recognition that learning is separate from the completion of a task: "It don't matter [that we didn't complete the task correctly], we learned somethin', that's what's important." Learning for learning's sake in terms of working toward understanding is a view of success that is very different from success as a form of demonstrating ability through task completion. Lila's philosophy of education is shrewdly delivered in one powerful thought-a critique of the democratic ideals of education, "Dewey's tomorrow", here today.

"Learnin' somethin'" is important and explainin' is hard; it is also different from "knowin'". I can't help my amazement at students' discerning words, words that echo those of John Dewey. Dewey was one of the first American philosophers to propose that we change the way science is taught. He struggled to get educators to reflect on what it means to think. According to Dewey, "thinking with action" in the form of self-reflection is the key to all learning. This "critical thinking" is facilitated by uncertainty, discomfort, and inconsistency: Nothing is truly learned unless it is internally questioned and tested by our minds through processes of observation and deduction. Thinking without action, or simple acceptance of other's ideas, is not conducive to true learning. Dewey warned us of this simple acceptance by describing it as "easy beauty". Easy beauty may be effortless to spot (like the right answer, or a hand in the air) but it is a facile, superficial beauty when it comes to learning. Deep learning is messy, frustrating, and transformative; it takes work, sweat, worry, and wrong answers to get to the occasional right one, the "Aha!" moment.

The freedom to operate outside of typical instructional routines and related pedagogical strategies appeared to begin a transformative experience for many of the students. Perhaps it was these variant brushes with "Aha!" moments that inspired some students to come to see biology, or at least genetics, in a new light. For example, at the end of their GenScope experience, students spoke of science in very different ways from their initial views. As *Janice* describes: "I used to think that genetics was somethin' that .. - boring - somethin ' that I wouldn't be interested - somethin' that I would never have till like I'm old or somethin' but once I got it, it was it had influence cause I thought you know - once I saw it, it was somethin' good you know that I would learn and I have to learn you know? if you wanna have a career or somethin'".

Students' raw attempts to participate in learning through "doin' stuff" appeared equally transformative. Many students reconstructed themselves from quiet, passive learners, well-behaved learners or disruptive, disaffected, passive learners into active, minds-on learners. Their own words and phrases like "talkin'", "activity", "time", "doin different things," and "givin' our

opinion" expressed the diverse ways they participated. These words also expressed a different kind of relationship students had with the instructional task, each other, their teacher, and other adults in the room (the GenScope team). These diverse strategies appear to have been promoted in part by the presence of GenScope; its novelty alone was enough to shake up the normal routine. However, the most powerful consequences were gingerly tested and at times purposefully orchestrated by the students themselves. Their reflections, struggles, and tenuous steps toward problem-solving, prediction, and critical thinking breathe life into Dewey's educational vision, one which was derived from the purposeful involvement of students in their own learning.

Acknowledgements

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This narrative of students' perceptions of their GenScope classroom experiences was inspired by the work of Dr. Ricki Goldman-Segall, University of British Columbia and Drs. Janine Bempechat and Sara Lawrence-Lightfoot, Harvard University.

Bempechat, J. (1998). *Against the odds: How "at-risk" children exceed expectations*. San Francisco: Jossey-Bass.

Goldman-Segall, R. (1998). *Points of viewing children's thinking: A digital ethnographer's journey*. Mahwah, NJ: Lawrence Erlbaum.

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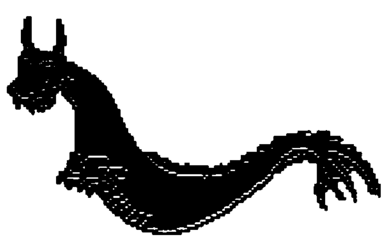
Appendix A

The Horns Dilemma: a GenScope puzzle that involves critical thinking.

In this problem, students are asked to predict and then construct the genotype of two horned parent organisms such that they may produce offspring who will not display the horns trait. In the Dragon species, horns is a dominant trait. Therefore, both parents would need to be heterozygous for the trait in order to display the trait and produce a baby who does not.

○ **Dragon1**



Female, Emerald

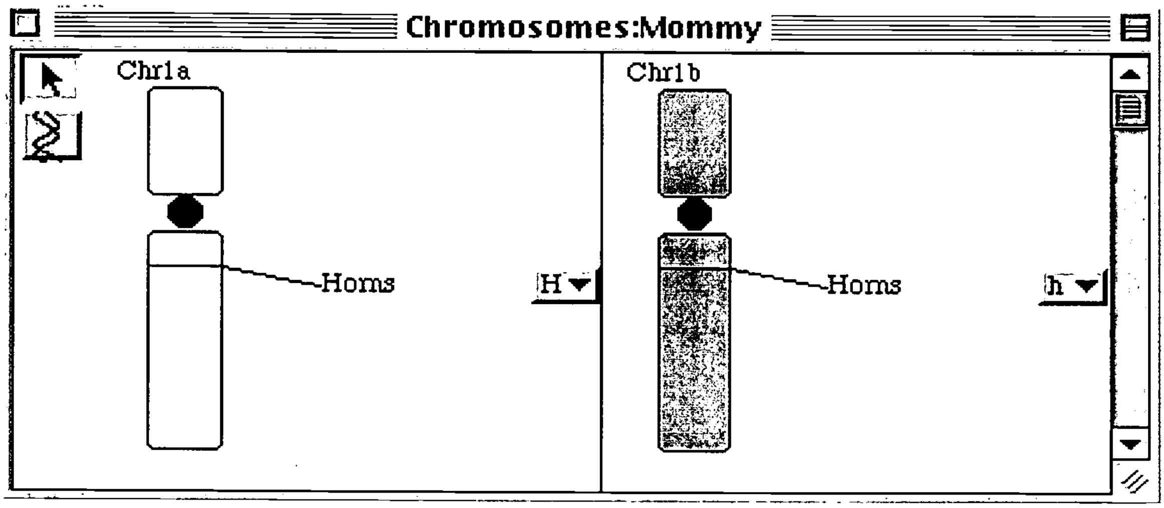
□ **Dragon2**

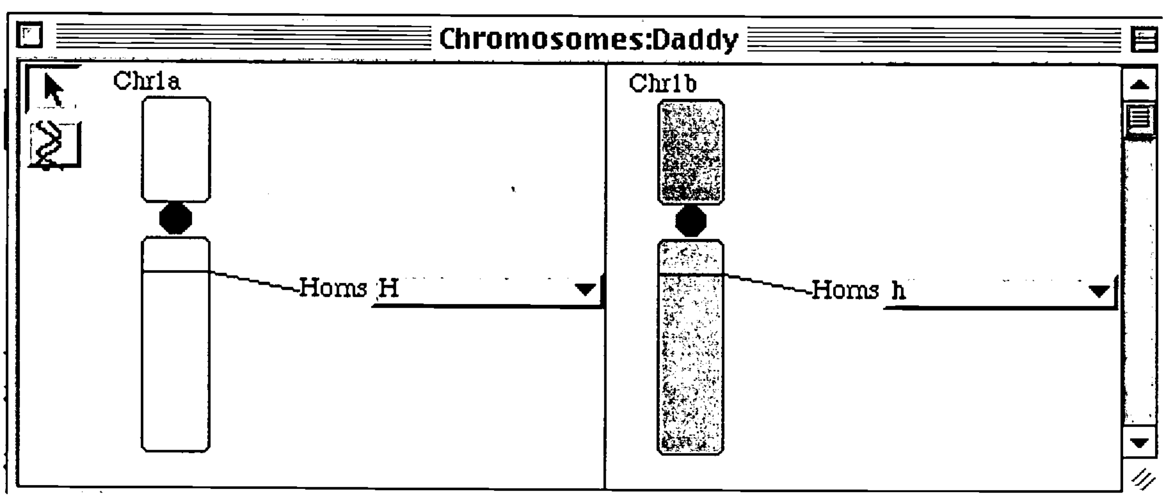
Male, Azure

In order to solve this problem correctly, students must understand the phenotype-genotype relationship, know the genotype for horns and no horns, know that horns is a dominant trait, understand that offspring get half of their genetic information from each parent, understand that both parents can either be homozygous or heterozygous for horns in order to display the trait, and understand that both parents *must* be heterozygous in order to display the horns trait *and* have offspring which does not.

Furthermore, students must also know how to use the appropriate tools in the software to make a male and female organism, examine the genes to make sure they are appropriate or manipulate them if they are not, take a cell from each parent organism, perform meiosis on both

cells, identify sperm and egg, examine gametes to find the appropriate pair which will produce a hornless baby (Hh or hH x Hh or hH), and fertilize the appropriate gametes to produce a zygote which is ultimately born.





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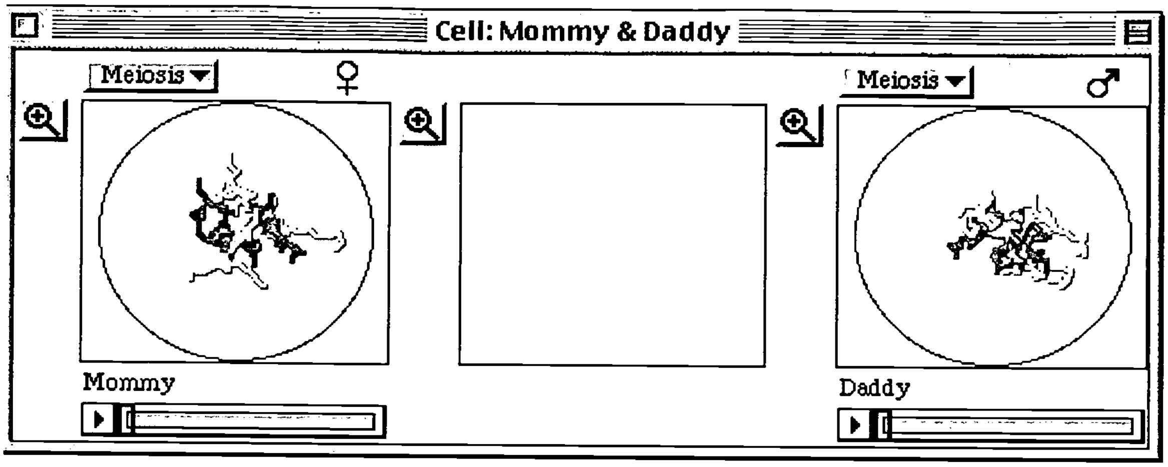
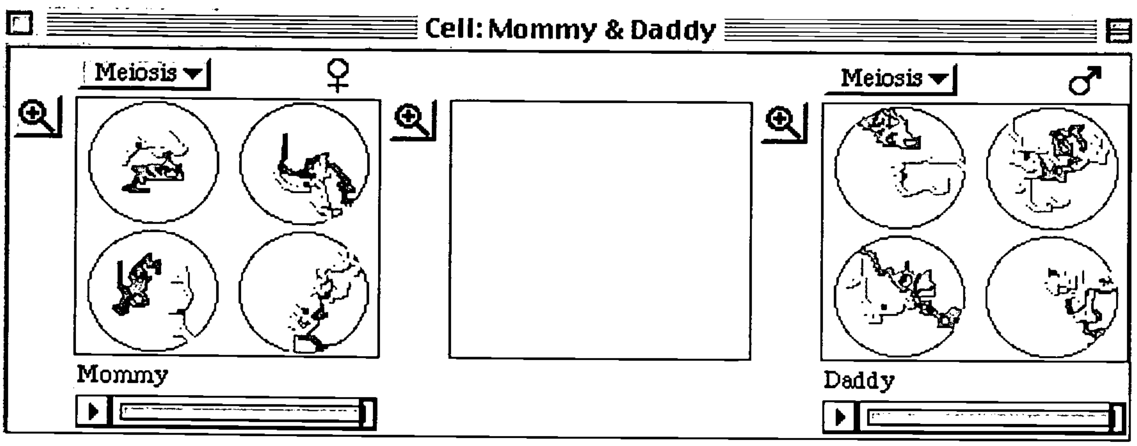
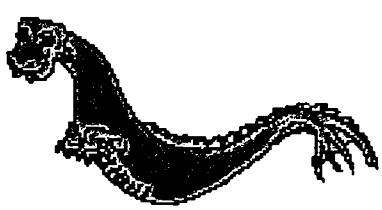




☐ **Dragon3**



Male, Bronze

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