Idit Harel helping fourth-grade Logo programmers at Project Headlight.
Stephen Sherman Photography

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Children Learning Through Consulting:
When Mathematical Ideas, Knowledge of Programming and Design, and Playful Discourse are Intertwined

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CHILDREN AS SOFTWARE CONSULTANTS

The "learning-by-teaching" aspect of the original ISDP (Harel & Papert, this volume) provided the students with a new kind of audience—the younger students, rather than the audience they usually have, their teacher. We chose to expand this feature in the following way: fifth graders designed software for fourth graders, established relationships with them, and then became consultants for the fourth graders as they designed software for third graders. In the process of consulting, mathematical ideas, programming knowledge, instructional design, and playful and social discourse became intertwined. In the following chapter we present an analysis of two consulting sessions and discuss this in relation to other relevant models of interaction.

In *cognitive apprenticeship* (e.g., Collins, Brown, & Newman, 1990), for example, the expert/adult models the important processes and makes them more transparent to the novice/apprentice. In addition to providing the apprentice with a clear conceptual model (or mental model) of the processes involved (and the desired product), the expert also helps to focus the apprentice/learner's attention, provides coaching for the important steps, and assists in certain problematic moments. This is done until the expert eventually fades away from the learner's activity completely. This interplay between observing an expert, being scaffolded, and becoming increasingly independent assists the learner/apprentice in developing self-monitoring and self-correction skills and supports the integration of the skills and conceptual knowledge needed to advance toward expertise. One concrete example of cognitive apprenticeship is the "reciprocal teaching" method (Palincsar & Brown, 1984), in which teachers/experts are explicitly modeling comprehension-monitoring and other sophisticated reading skills to their students/apprentices. The students' role is to internalize the teacher's questioning strategies and comprehension processes. Eventually students accomplish on their own what they previously could only achieve with their teachers. The cognitive change is taking place as part of the instructional interaction between teacher/expert and learner/apprentice.

In contrast to cognitive apprenticeship, *peer collaboration* (e.g., Daiute & Dalton, 1989) relies on student-to-student interaction (i.e., apprentice-to-apprentice), in which students engage in learning as they work and play together, reviewing, synthesizing, and elaborating what they have gathered from the world around them. One important feature in peer collaboration is the role of "cognitive conflict"—disagreeing, arguing, contesting—for the enhancement of knowledge and processes. In these collaborative situations, the roles among the collaborating students may switch between those of "experts" and "apprentices."

Here we explore a cocktail of the two approaches described above. In a nutshell, consulting is characterized here as a learning environment, in which older students are asked to become advisors for younger students. This context includes at least two learning agendas: the agenda of the younger students (consultees), and the agenda of the older students (consultants). The younger students (fourth graders) were working on programming a piece of instructional software to teach third graders about fractions; and the older (fifth grade) students' role was to help. It so happened that several months before these consulting sessions, the fifth graders themselves were involved in a similar software design project (e.g., see Kafai & Harel, 1990). Thus becoming advisors or helpers to the new group of software designers made a lot of sense to these children.

Learning-through-consulting shares several features with cognitive-apprenticeship and peer-collaboration approaches. At the same time, however, it is also distinguished from these approaches in the following ways.

1. *The nonexpert consultants activate and modify their knowledge through the process of modeling and teaching.* In the consulting situation the older students are placed in the role of an expert. However, they are only experts in a relative sense. To a certain degree, we see this context as facilitating a deeper learning experience for the older students than for the younger ones. Through the effort of searching for, and modeling, solutions to the consultees, the consultants reactivate and apply "old" knowledge as well as gain "new" understandings about concepts they could not fully explore and acquire previously.

2. *The student is the epistemologist who generates the "conceptual models."* Through their own software design process, the older student-consultants encountered design and programming problems, learned how to devise their own strategies, and explored ways to handle a variety of situations related to fractions-knowledge specifics, representing fractions ideas on computer screens, programming aspects, teaching and explaining, or reading and writing skills. We believe that these personal conceptual models serve as organizers, interpretative structures, and guides for the students-consultants in the interaction with their younger consultees during the sessions.

3. *The instructional interaction is an ill-defined and complex task.* Consulting confronts the older students with many complex problems. The consultees may present the older students with a wide range of problems—from Logo programming questions and design questions to teaching strategies or spelling and writing problems. Because the consultants may be confronted with several kinds of problems at once, it is their choice to determine what will be the most adequate or desirable aspect to deal with at any given moment.

4. *It is easier to solve a problem when it is "someone else's problem."* Since the consultants work on someone else's product, the problems they encounter are not their own. However, quite often, they may be similar to those problems they themselves have encountered in their own projects. Working on another student's project gives the consultants a second chance to deal with these problems. We believe it is easier for them to delve into another student's problems than into their own. We also believe that they can relate to the other student's problem because it is one they have previously encountered themselves.

5. *Learning-through-consulting is similar to "playing doctor."* For various psychological reasons this microworld is similar to "playing doctor." First, it allows learners to explore the role of consultants/teachers in the much-disliked terrain of fractions (as much as going to the doctor is also disliked and feared by children). Second, learning-through-consulting places learners in a playful mode in which they can explore their intellectual confusions, overcome doubts, and release fears related to social roles and mathematical understandings (they can "undress" their thoughts about fractions). The student-consultants can create their own terms and rules with their consultees. Drawing from a large spectrum of possible issues, they can elect to investigate topics that are important to them. Above all, within this framework, they can assume a position of control.

One of our main purposes in ISDP-II was to explore the processes involved in the consulting context, *from the point of view of the consultants*, and to study how these relate to the claims and ideas presented above. At this point, we initiated and examined only two consulting sessions, which we carefully observed and videotaped. Our research aimed to explore different aspects of these sessions and to gain insight on issues such as the children's modes of interaction, the contents of their discourse, the topics of their learning and thinking, and the

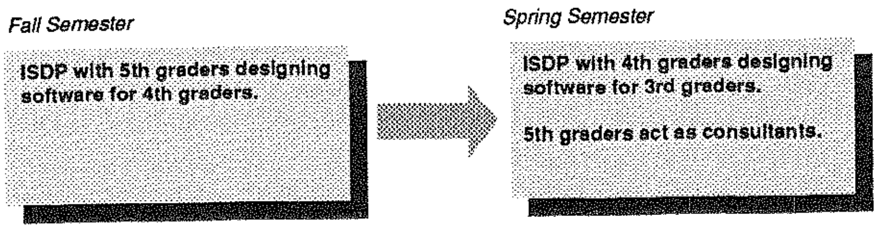

Figure 1. Research procedure in ISDP-II.

kinds of problems they chose to work on. Several questions guided our analysis of the data from our observations and from the videotapes:

- What *kind of knowledge* do fifth graders activate and communicate when talking with the fourth graders about their software projects? Do they choose to discuss the programming aspects? Do they focus on the fractions representations? Or, do they discuss the fourth graders approaches to teaching and explaining?
- What *modes of interaction* do the consultants use with the fourth graders? In what ways do they identify and understand the consultee's ideas, notions, or problems? Which interactive strategy do the fifth graders use: do they give "clues" about what to do, or "do it for" the younger students?
- What do the fifth grade students *learn* through engaging in the activity of software-design consulting? (It should be noted that it was not in the aim of this study to focus on the learning experiences of the student-consultees, although we see it as an interesting aspect in itself.)

The investigation of learning-by-consulting is situated in our year-long study called ISDP-II (see Kafai & Harel, 1990, and in this volume. See Figure 1 for the year-long research procedure). In addition to the data we collected during the consulting sessions, we have observed these students over a period of 1 year and collected many in-depth interviews with the students and their teacher; we also recorded several classroom discussions and saved the students' daily work (designs, writing, programming). Many of our interpretations of the consulting sessions are based on this larger body of data.

PROCEDURE OF CONSULTING SESSIONS

The first consulting session took place 3 months after the fifth-grade students had completed their software projects, and after the fourth-grade students had spent 3 weeks on their projects. The second session took place 3 weeks later. As we describe the procedure of each of the consulting sessions in the following

paragraphs, we shall also explain: (a) how the idea of consulting was introduced to the student-consultants, (b) how the activity itself took place during the two consulting sessions, and (c) what the students reported about their consulting experiences in the follow-up classroom discussions.

Description of the First Consulting Session

The idea of consulting was introduced to the student-consultants by one of the researchers (Kafai) and their teacher (Mrs. Mar) in their classroom. The intention was to have the students define what consulting could mean. For that purpose, we installed a poster asking "What is Consulting?" on the blackboard. One girl, Robin, volunteered to write the other students' suggestions on the poster. As she transcribed the students' ideas and wrote them on the poster, there was some confusion in the room: the students seemed to have an idea what consulting is, but were having difficulty expressing it in words. At about this time, Alicia asked to look in the dictionary for the word "consulting." She later read to everybody the definition she found. The teacher then suggested to think about concrete examples of "who a consultant can be." The students came up with the examples of "a lawyer," "a doctor," "a priest," and "a psychiatrist." The content of the poster at the end of the introduction session is shown in Figure 2.

Then we asked the students to think about what it could mean for them to become 'software design consultants' for the fourth graders. The students' ideas about the content of consulting were, for example: "You ask questions about software" and "Tell them what's wrong with it." The teacher modeled one kind of feedback the students could give to their consultees.

Mrs. Mar: One of the things to keep in mind . . . when you give somebody your opinion about it [about their software], you don't go 'That stinks.' [Laughter] It's called *constructive criticism.* Do you understand what I mean by constructive criticism?

Karen: You could say like 'Maybe you could change this to that?' or something like it.

Mrs. Mar: If you don't like it, if there is something in particular, you don't understand, you could give your idea about something in a nice way. Say, they have a screen that doesn't make sense to you, don't say 'That's garbage.' You could say 'This is really confusing, what are you trying to say?' And then, you can try and help that person to work it out. Okay. You should always try to be nice.

The rest of the introductory discussion was spent on the problem of how to say "critical things in an acceptable way." The students kept expressing one particular dilemma they encountered in their thinking about consulting: "If we really don't like it [the fourth graders' pieces of software] and they ask us "What do you think?"—what do we say?"

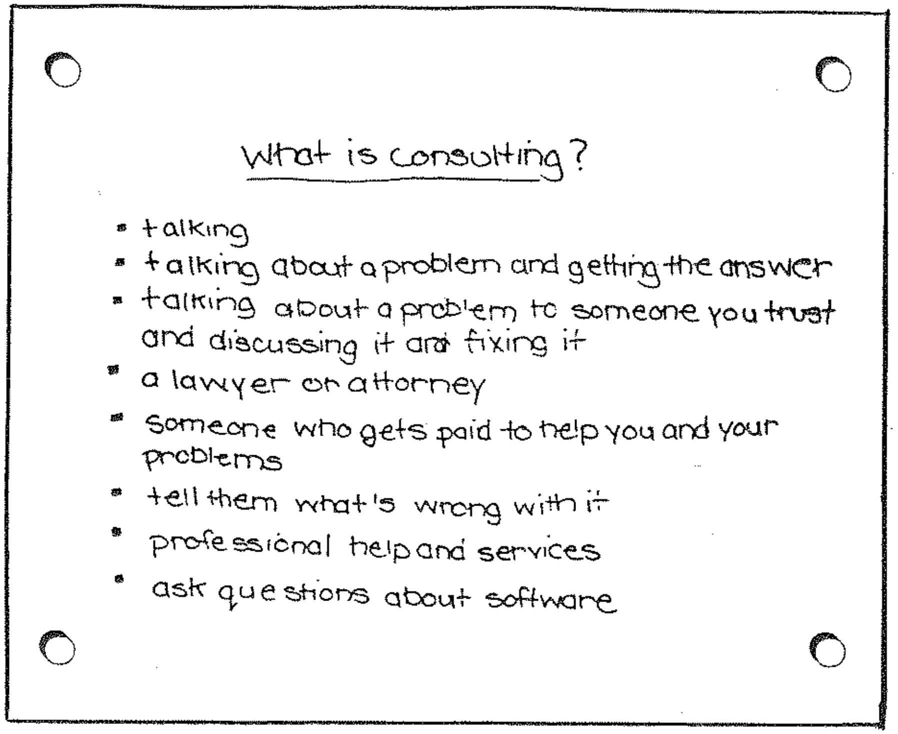

Figure 2. Students' poster after the consulting introduction.

In general, we had the feeling that all fifth-grade students were willing and eager to do the consulting with the fourth-grade students. After this 20-minute introductory discussion, we asked the children "Are you ready to go?" Fourteen voices answered: "Yeah!" and we all left the classroom to go to the computer pods.

At the computer pods, the teacher assigned the consultant–consultee pairs.[1] Since there were more consultees than consultants, some students did not have a consultant. Kafai walked around with the videocamera on her shoulder and recorded the activities. Many times she stopped next to one of the pairs and asked them to tell her about what their ideas were, and what they were working on. When asked, she also gave advice about issues the pairs could discuss, etc. The

[1] The teacher was concerned about the combination of certain consultant–consultee pairs. For example, she did not want to have particular students in her class work with the special needs students because she considered their interaction style not adequate for them ("too bully"). We, in fact, questioned this, and felt the students could have profited from these interactions in particular. However, we respected the teacher's decision.

two teachers were also walking around the computer pods and helping the students.

The general impression of this session is that all the pairs were engaged in their "job" but in different ways. Some of the fifth-grade students were watching the fourth graders' programs; some of them ran it by themselves; some were helping with programming problems; some focused on the fourth graders' explanation of fractions or the quality of their fraction games. The modes of interactions varied as well: some pairs sat next to each other with almost no talking, while others were actively involved in discussing things and changing things in the Logo programming code.

In the follow-up discussion, the teacher asked each student about his or her experience with consulting. The students briefly described what they had observed and what they had suggested to the fourth graders. In the beginning, most of the discussion focused on issues related to programming. One of the fifth graders said that her fourth-grade student used "no procedures." Another child reported that her consultee "did not know SETPOS," and another child added that his consultee did not know "how to use STARTUP."

Then Alicia brought up that she didn't understand one of the student's screens, and that she had simply "found one of the fraction representations wrong." An interesting discussion with the teacher and other students emerged (a more detailed discussion of this can be found in the next section). Another student continued with a further example of how "fractions can be wrong" (as described below in Episode 1). The students referred to the problem that some questions can have more than one right answer (as described below in Episode 2). One student introduced another problematic aspect: the phrasing of questions and spelling of words on the screen (as described in Episodes 5 and 6).

Towards the end of the discussion, the teacher asked the students if they would volunteer to continue helping the fourth graders on a regular basis. All the children agreed to do that and even requested to work with the same partners again.

Description of the Second Consulting Session

Three weeks later, we had the second session. The fourth graders' projects grew since the first consulting session, and they were ready for another round of consulting and feedback from the fifth graders. We did not have an introductory discussion, nor did we assign the consultant–consultee pairs for this second consulting session. After the student-consultants were told that the fourth graders were waiting for them at the computers, they walked out to the computer pods to find their partners.

All students were engaged in their consulting activity. The observations from the first consulting session are also applicable to the second consulting session. A particular 'consulting session' took place during this time between the teacher and one of her students discussing the teaching strategies used in his software. The students worked together for approximately 20 minutes before returning to their classroom. We used the remaining time for a general class discussion similar to the one we had had at the end of the first session.

Again, we asked the students to talk about what they had observed and what they had done as consultants to the fourth graders. Children's accounts of their consulting experiences in this second session were related to Logo programming problems, design issues, and teaching strategies. Unfortunately, we did not have enough time to get a report from all the consultants.

OBSERVATIONS AND DISCUSSION OF CONSULTING SITUATIONS

The following episodes indicate the potential role of consulting in the process of learning—at least for the consultants. Students applied different kinds of knowledge in this context: they were involved in several content areas such as fraction representations, programming issues, the correct spelling and phrasing of questions, teaching strategies, design issues, and so on. They were engaged in problem solving when helping the consultees debug the programming code, fix and clarify instructions, and fraction representations.

This gave students an opportunity to revisit and confront their own knowledge about fractions, programming, and software design 3 months after the completion of their own projects. The fifth graders could reevaluate their knowledge. They found that many of their own "misconceptions" were reflected in the fourth graders' pieces of software. They were also confronted with situations that made them observe problems that, in fact, they themselves had with fractions and Logo programming. For example, when referring to one fourth grader's particular screen showing a representation of 2/4, Karen said: "I know it could be 1/2, but that's not what is on [her] screen." This problem, in fact, existed already when the fifth graders were working on their own software. Students "knew" that 2/4 could also be 1/2. However, "knowing it" is not the same as "understanding it." This brings the reflective function of consulting into play. Through digging into the consultees' concepts, the student consultants could challenge their own understandings without a threat to their personal intellectual ability.

In the introductory discussion (before the consulting session) they used words such as "not liking the game"; however, in the follow-up discussion (after the consulting session) there was a shift from the criterion of "liking–not liking" to deeper and more specific dimensions. Students referred, for example, to the quality of their consultees' programming knowledge, their fraction representations, the quality of explanations in the instructional screens, and issues related

to spelling and writing. The follow-up discussion also allowed the fifth-grade students to share and compare their past experiences in ISDP.

In addition, the follow-up discussions required complex teacher-intervention strategies. Though the time-frame in this study did not allow for an extended interaction among students and teachers on deep-structure knowledge, we see these follow-up sessions as providing a potentially rich opportunity for exploring the complexity of the *teacher's role* in constructionist learning environments. (We will discuss this aspect of our observations in greater detail in the conclusions.)

In the following subsections, we shall briefly present several model cases or episodes to show how the consulting process created a context that confronted the students with a multitude of problems. This context encouraged a large spectrum of 'cognitive conflicts' (e.g., Posner, Strike, Hewson, & Gertzog, 1982) among learners, forcing them to rethink and reconsider their own knowledge across the board.

Activating Knowledge of Fractions and their Representations

Episode 1. What Alicia discovered in her consulting session with Tracy: "How can 6/6, 7/7 and 8/8 be the same as 5/5?" Moreover, "How can one whole be made out of five discrete objects?" During the first session's follow-up discussion, Alicia (fifth grader) raised this important issue related to rational-number concepts and their representations: It took only one of Tracy's (fourth grader) screens to create a cognitive conflict in Alicia's mind. Her not-so-simple puzzle was related both to understanding part–whole relations and to understanding the concept of discrete and continuous fractions.

In general, this episode revealed several things. First, the fourth grader's (Tracy) screen was an excellent vehicle for eliciting the fifth grader's (Alicia) thinking about her own understandings. It created a situation where Alicia had a strong need to announce to her classmates and teacher what she could not understand—a rare situation in school practice. By doing so, Alicia also encouraged other students to report on similar cases.

Alicia: . . . And Claudia didn't have hers ready. So I looked at Tracy's. And Tracy, I couldn't understand hers [one of the screens].

Mrs. Mar: What couldn't you understand about Tracy's?

Alicia: She showed me one part of her screen, it had 5 diamonds with different colors and she said [printed on the top of her screen] 'What's this fraction?' And it had [as options for the user to choose as the correct answer] 6/6, 7/7 and 8/8. And there was no 5/5! And I said "I don't understand that." And she said "Oh, what didn't you [understand]?" And then I said "I still don't understand it.' And then they said "Time to logout."

Mrs. Mar: So you didn't have a chance to explain [to her], how she needed to make this [screen] more clear?

Alicia: But I [also] don't understand [in the first place] how can 5 pieces be a whole?

Mrs. Mar: Well, it can.

Alicia: It cannot.

Mrs. Mar: Yes, it could be if it is individual pieces. Because sometimes you can take fractions as [she pauses]. See, we haven't talked about fractions, and their class has done fractions. See, Mrs. Kin's class, are, is now doing fractions.

Some students: We did.

Mrs. Mar: [A bit uncomfortable] Maybe when we do fractions [in a few months, within the school's curriculum], we'll come back to this.
[Other children report on similar cases. There is noise in the class. The teacher says:]

Mrs. Mar: Advice. If you have a denominator and numerator of the same number, it equals to one whole.

Mira: Oh so it divides.

Stacey: You can divide it by the same number like 5/5 is divided by 5 and you get 1/1, you get a whole.

Mira: I told her too [Frida] about the one whole and she changed all 5/5 and 4/4 [to say '1 whole'].

Mrs. Mar: Well, technically, it's still correct [to say 5/5 and 1 whole] and usually, what you do is you reduce it to the lowest terms, but 5/5 has to be reduced to a whole.

Consulting is a very rich problem-finding environment. This discussion could have been the springboard for the teacher and students to create *conversational cycles* of finding ways to help children solve their puzzles. As we see in the transcript, the time constraints did not allow the group to engage in meaningful explorations of mathematical knowledge. We want to use this example to explain what we think Alicia is referring to—Tracy's computer screen (Figure 3).

We believe that Alicia's concern was twofold. First, she was simply confused because there were five diamonds on the screen, but no reference to the number 5 in any of the options Tracy gave to her users as the possible answers. So Alicia's first reaction was: *"And it had 6/6, 7/7, and 8/8. And there was no 5/5!"* Moreover—even if 5/5 was given as an option by Tracy—Alicia was not at all sure that 5/5 was the right answer: *"But I don't understand how can 5 pieces be a whole?"*

Alicia thinks that, since there are five objects on the screen, the corresponding symbolic representation has to have the number 5 in it in some way. However, at the same time, Alicia's frame of reference is a single diamond. And since there were five diamonds on the screen, they must be five wholes. But how can one whole be composed of five wholes? In her mind she cannot yet shift her frame of reference and consider a set of five objects as one whole. Recall her strong opinion:

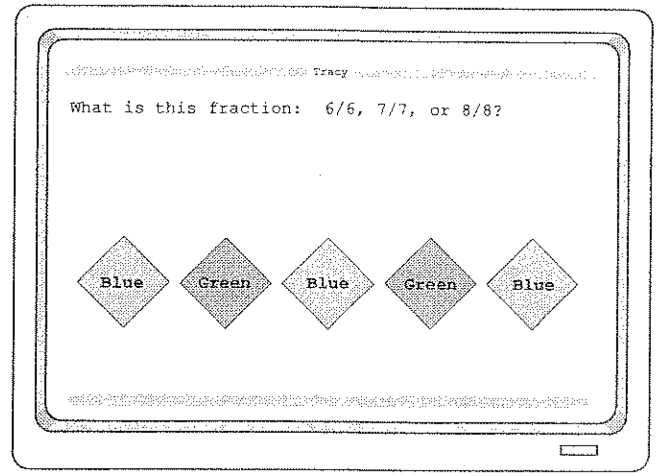

Figure 3. Tracy's screen of a representation with diamonds from April 27.

Alicia: But I don't understand how can 5 pieces be a whole?

Mrs. Mar: Well, it can.

Alicia: It cannot.

Pronouncing her different opinion so clearly for herself and to the teacher provided an entry for intervention. Although the teacher did not deepen the discussion around this issue, other students reported cases where they believed that the fourth graders had "similar problems" about fractions (e.g., Mira and Stacey in the above transcript). In the second consulting session, for example, Antonio (fifth grader) reported on a similar problem he had had with Annie's (fourth grader) software. He, however, was able to switch perspectives quite well:

Antonio: The girl's name is Annie. And then she had a big circle, right, and then she split it into halves. And two of them, two sides were painted in different colors. And then I put [answered] 'one whole.' That wasn't it. I put 'one-half.' That wasn't it. It was 2/2!

Yasmin: So how did you come to think that she thinks 2/2 is the right answer?

Antonio: I don't know. But it should have been one whole.

Gerald: Couldn't it be 2/2? It could. [Discussion in classroom, difficult to understand the tape.]

Alicia: You feel so stupid in front of a fourth grader [she then says with a funny voice:] 'I know it, but.'

Antonio: I was trying to figure it out [by myself, until I found what she meant:] 'Oh, I got it 2/2' and then she goes: 'Great job!' Then, the second one [another screen Annie programmed] had a split line and it messed up [the program crashed].

Episode 2. What Karen discovered in her Consulting Session with Alice: "How can a representation of 2/4 be equal to 1/2?" After the first consulting session the students also discussed two kinds of "frustrating situations" in their consultees' pieces of software. These were: (a) when there is more than one correct answer, and the designer chose (as the right one) something different than they did; and (b) when the 'right answer' does not correspond with the representation that is on the designer's screen. This led to the following discourse:

Karen:	So, if I have 2/4 on the screen [stopped by the teacher].
Mrs. Mar:	Or it could be 1/2.
Karen:	No. But if you are doing the fractions game and it's like . . . four pieces on the screen and two are colored in, and two aren't. How, can I know that it could be 1/2? But that's not really what is on the screen?!
Mrs. Mar:	Well . . . they give you a choice of answers, such as, 2/4, 1/2, or 5/8 or something. If they give you a choice of answers, then it makes it easier, for 2/4 is equal to 1/2. [It is not clear to us what the teacher meant to say here. But Stacey raised her hand and interrupted her talking. She looked at her and said:] Stacey?
Stacey:	I had the same thing in my program. But I had, I had 2/4 and 1/2 and chose one answer of it. And when they [the users] got the answer, I explained to them *why* I did that [i.e., why their answer is right or wrong].
Mrs. Mar:	But back to Karen's. It doesn't come into Karen's. It's the same thing [2/4 and 1/2]. Basically it's the same thing. Let's say they give you a choice of answers, but if they don't give you a choice of answers, sometimes you might *not* get the right answer.
Alicia:	Then you feel stupid.
Mrs. Mar:	Well, oh no. [i.e., you shouldn't feel stupid]. It's also part of programming. If we had learned about lists [in Logo] when you were doing your projects . . . see, you had the same problem coming up the way. Do you see what I am saying?

This discussion demonstrates how fraction representations and programming problems can become intertwined. In Logo, there are several ways to write a procedure which accepts more than one answer as the correct one (e.g., by using lists). The students did not know about lists, which would have allowed them to accept different "right" answers at the same time for their instructional quizzes. After this issue was raised, we realized that the students lacked an important programming skill that could facilitate their design and teaching strategies as well as their fractions knowledge (e.g., of fractions equality). Here we find an ideal context in which Logo programming knowledge could have supported particular aspects in the fractions knowledge, and vice versa. It reemphasizes the idea that learning in integration can be easier than learning things in separation (Harel & Papert, 1990).

Activating Knowledge of Logo Programming

Episode 3. How Jeannine finds out what Caroline needs to know in Logo. While working as consultants and in follow-up discussions, much of the students' work referred to Logo programming problems. Their accounts covered a range of problems—from simple syntax errors to Logo Page arrangements and program control. Furthermore, the consultants often introduced the younger students to "new Logo programming tricks" and discussed in the classroom how to go about teaching Logo. For example, in the follow-up discussion of the first session, Jeannine (fifth grader) remarked that Caroline (fourth grader) "did not know about procedures."

During the first consulting session, Jeannine was sitting next to Caroline and simply watching her. Since Jeannine did not know Caroline very well, it did not occur to her that knowing about procedures was far out of reach for Caroline, who was still using Logo in the direct mode (i.e., writing the code at the Logo Command Center only). Although Jeannine was quite astonished to find out that one can program "such long programs without using procedures," she was not sure whether Caroline was ready for learning about procedures. During the second consulting session, Jeannine copied Caroline's code from the Command Center to the Flip Side, wrote a procedure, and then searched for something to teach Caroline at her level. Jeannine chose to teach Caroline how to use SETPOS (the Logo command for placing the Turtle on the screen by specifying two numbers, the Cartesian coordinate positions).

Idit [to Caroline]:	Was she helpful, was Jeannine helpful?
Caroline:	Ahem.
Idit:	What did she help you with?
Caroline:	SETPOS.
Idit:	With SETPOS. Did you ever use SETPOS before?
Caroline:	[nods 'yes' with her head].
Idit:	But she explained it to you. I see . . . she put it in certain places . . .
Idit [to Jeannine]:	What was her problem with SETPOS, Jeannine?
Jeannine:	She really didn't use it.
Idit:	Oh, she really didn't use it. So you put it . . . where did you put it in the program?
Jeannine:	On the Flip Side.
Idit:	On the Flip Side. Where do you think she needed it?
Jeannine:	Whenever she "function-9!"
Idit:	Function-9. Great!

Shortly after Jeannine taught SETPOS to Caroline, and they went through Caroline's code and implemented it at various places, we asked Caroline, "Did you ever use SETPOS before?" She nodded and smiled. Jeannine smiled too,

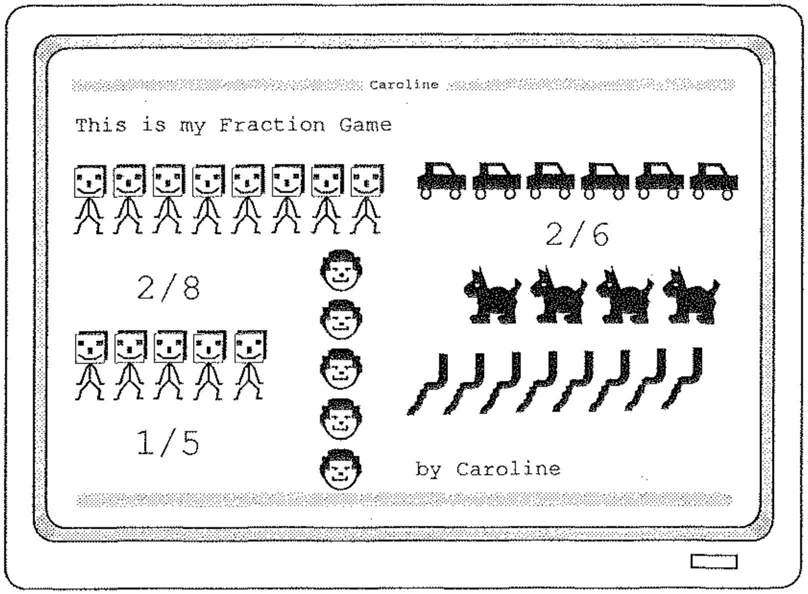

Figure 4. Caroline's screen showing 6 different fractions.

and said that was not true. We interpret this as Caroline's appropriation of the new skill (see Figure 4).

Episode 4. Alicia and Tracy working on debugging Tracy's Logo code together. We have already described one episode from the first consulting session when Alicia (fifth grader) was working with Tracy (fourth grader) and had problems understanding one of her representations. In the second consulting session, Alicia worked with Tracy again, this time on a debugging problem related to variables and conditionals. Alicia's description of this situation in the follow-up discussion demonstrates that she understands the Logo syntax for conditionals and variables very well (i.e., at what places the quotes and colons have to appear when dealing with variables in a program).

Interestingly, Alicia herself had many difficulties with this aspect of programming when she was previously working on her own software. (Recall that the fifth graders were involved in ISDP during the fall semester.) Here is an example from Alicia's Logo code from the fall. The procedure "half.circle" draws on the computer screen a fraction representation of a circle divided vertically into halves. At the top of the screen a question appears, asking, "What is this fraction?" The question is printed, but Alicia did not write the appropriate code for accepting the user's input (answer). The following is a code fragment from Alicia's fractions project from November 28, 1989:


```
. . . .
to half.circle
rg ct
pu setpos [-45 0]
rt 90 setc 5
fd 45 fd 45 fd 23 fd i
pu setpos [14 10]
setc 5 pd fill
pr [What is this fraction?]
pr [4/5 or 3/4 or 1/2]
end
. . . .
```

The procedure "half.circle" is one of three such examples in Alicia's program. In fact, Alicia was one of the very few students who did not immediately implement the appropriate code for a "quiz procedure" after it was discussed in the classroom. She waited a few weeks before implementing it in her program (see Kafai & Harel, 1990). One day she came to Kafai and asked for her help (with the implementation of the quiz procedure within the pre-prepared program segments). More than 3 months later, in the consulting session, Alicia approached this problem very professionally:

> Alicia in the Spring (in classroom followup discussion): Tracy has, had problems with her . . . her, ahm, you know, the stuff you use with answers [taking user's input], the two dots, she kepts on putting the dots in the wrong places. She didn't know what was the matter. And she also doesn't know how to use SHOWPOS and SETPOS. But she wanted her, ahm, letters to go all over the screen and come back to their places, and then to leave them alone. That's it. I helped her.

We captured on videotape the beginning of this particular consulting session when Alicia and Tracy were working at debugging Tracy's quizzes. The video segment starts with the two girls running Tracy's program and realizing that something is wrong. They move back and forth between running the program and debugging the code on the Flip Side. What is remarkable in this consulting situation is the way these two girls share the access to the computer keyboard. The video gives a nice example for how both girls closely interact as they work on quite a complex debugging problem.

Consulting on Spelling and Writing

Episode 5. What did Gerald discover in his consulting session with Brian: spelling and writing problems. In the following excerpt from the discussion, Gerald (fifth grader) raises the problem of Brian's (fourth grader) misspellings. The teacher puts it in the context of what she had seen in her own students'

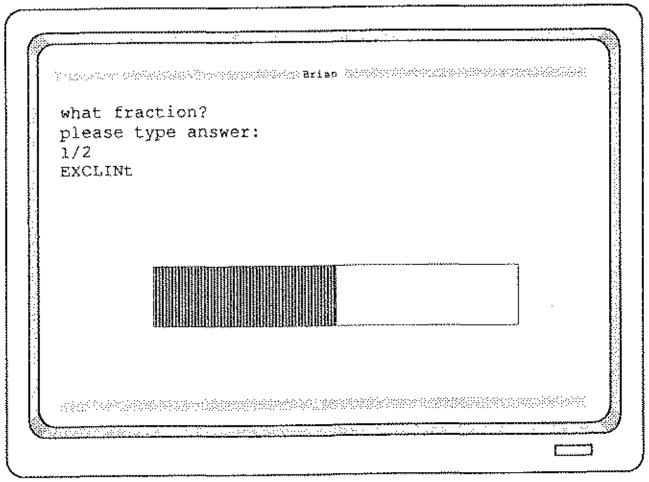

Figure 5. Brian's screen representing 1/2 (note his spelling mistake).

programs while they were working on their projects in the Fall. This is the screen to which Gerald, Eugene, and Matt are referring in this episode (see Figure 5):

Gerald: I was working with Howard. He, Howard, he was good, but then Brian's, he was good too, but he prints [the word] excellent and he didn't spell it right like 'e' then 'x' . . .
Mrs. Mar: Did you tell him that his 'excellent' was spelled wrong?
Gerald: Yes, and he said 'Oh' and then he just went along.
Mrs. Mar: Did he fix it?
Gerald: No [looks a bit upset].
Mrs. Mar: Maybe, well, it will be very interesting to see if he fixes it later on. Maybe, he just wanted you to look at his program. [Looking at Eugene who raises his hand, saying] Eugene?
Eugene: I did this too with him, and I saw this 'excellent' thing too.
Mrs. Mar: Ah, so you noticed what I have noticed in a lot of your projects. Because one of the first things which catches my eyes is when [you print] 'what fractions' and that 'w' was not capitalized. Or, I was looking to see where was your question mark?
Gerald: Yeah, he didn't have that either, [a question mark].
Mrs. Mar: But those are the kind of things that you can tell them. [Looking at Matt who raises his hand, saying] Matt?
Matt: I went over to look at Brian's software. And when I looked at it, he spelled excellent all in huge letters and then he had this small "t" and I said, 'What is this: excellennnnn t?'
Mrs. Mar: Maybe with that one, he wanted that. I don't know.
Alicia: Tracy, she put the two little dots at the end of her question. Like, 'What fraction is this:' [shows the two dots with her fingers in the air] What does that mean, the two dots? You know, the two dots?

Mrs. Mar: Colons. She did go on, may be. Was there a question mark?
Alicia: But it is a question. Why does she have to put dots in there?

Interestingly, the student, Gerald, who brought up this question in the first place, had a similar language problem while designing his own piece of software. Here is an excerpt of a discussion from October 1989 that Gerald had with Matt, while they were working together on their software projects. At one point, Matt indicated to Gerald:

Matt: You have to write "What fraction is *this?*" and not "What fraction is *it?*"
Gerald: Why *this?*
Matt: Because *that's* what you are asking your users, about this one (points to the representation Gerald created on the computer screen).

It was interesting for us to observe that the consulting did not only deal with the core issues such as the correctness of fraction representations, but also with little details such as correct spelling and grammar. This seemingly little detail caught our attention, since the fifth-grade teacher repeatedly indicated her concerns about writing and spelling to her students during the previous term. However, most students ignored this type of comments. As consultants, the students shifted perspectives, and became more concerned with this aspect of the software.

Episode 6. Instructional and pedagogical concerns. An example of the children's awareness of the instructional or pedagogical quality of the software can be found in the second consulting session, particularly when Gerald (fifth grader) was working with Howard (fourth grader) on the feedback he gives his users about their answers. The following is the code of Howard's program before the consulting session 1:

```
to fract
. . .
{first screen shows a rectangle divided into halves, both colored in}
. . .
print [what is this fraction?] print [please type your answer!]
name readlist "answer
ifelse: answer=[1/1]
[print[good answer]] [print[go ahead]]
wait 15 ct rg cc
. . .
end
```

Howard included all his screens in one procedure. The only distinction between the feedback he gave to correct vs. incorrect answers is the printed message on the screen: either "good answer" or "go ahead"—but in both cases the program continues ahead. After that first session, Gerald told his classmates:

Gerald: I was working with Howard and . . . everything was good, except one thing he put 'Go ahead and correct.' He did this everytime. Instead of printing 'try again,' he put 'go ahead' and he goes to the next problem! And I had to fix all of that.

Gerald's sensitivity to this issue surprised us. He proposed a solution to Howard: to include "try again" as a reply for a wrong answer, and to have users go back to the beginning of the project. Howard implemented Gerald's suggestions.

Consulting on Design

Episode 7. Eugene, Matt, and Marion: Fixing the look of shapes and symbols. In the second session, for example, Eugene and Matt (fifth graders) and Marion (fourth grader) worked together. This episode provided us with an example of consulting on a nearly finished piece of software. Since there seemed to be no fraction or programming problems, the three students focused on correcting minor design problems related to the symbolic representation of 3/4 which Marion had designed using the Logo Shapes-Page.

In the following scene, Marion had the keyboard on his lap. Matt discussed in detail with Eugene how to improve the look of the 3/4, in particular the look of the number 4 in the 3/4 representation:

Matt [to Eugene]: I showed you that shape here . . . look. [They are looking at the Shapes Page. Matt moves his hands on the screen and points to the Shape showing a symbolic representation of 3/4.]
Marion: Yeah. I am gonna change that.
Matt: [His finger touches the computer screen, pointing on the fraction denominator '4.' He doesn't like the way the number 4 looks on the screen; he looks at Marion, and says:] Make this one over one, and move this block, too.
Marion: [flips back to the Shapes page, points to Shape number 4, and says:] That's what it's got to look like. [He then moves back to the Shapes building area. One can see the cursor moving on the screen, for adding blocks to the number 4 to make it look more like a 4. The three boys say:] There.

Episode 8. Leslie and Sara: "How many fractions do you need for your software to be really good?" A recurring discussion theme in all the ISDP projects is related to how many fraction representations would qualify a project to be finished and good. In the beginning, students were asking us frequently "How many fractions [representations or screens] do I need to make for this project?" It was difficult to convince them that the number of screens was not a decisive point.

While Leslie (fifth grader) was looking at Sara's (fourth grader) software, she was a bit disturbed by the fact that Sara had included only four representations and was already working on her software's title page:

Leslie: I was working with Sara. She didn't have any problems [she means screens showing a representation of a fraction and a related problem to solve]. She didn't have any problems. She had about *only* four problems, she was working on another one. She asked me to help her on the front page and I didn't know . . .
Yasmin: Why do you think she didn't have enough problems?
Leslie: Because she was [already] working on her front page!
Idit: Is it good or bad, or, it doesn't matter?
Leslie: I don't know. I guess it's good . . .

Leslie's insecurity pointed to a particular concern of the designers regarding the size of the fractions software (or the number of screens), which we had discussed during the fall with the designers and their teacher. In the midst of the fifth graders' project in the fall, the students started talking about *"how many screens are actually needed in order to say I am done."* Very frequently one could hear students asking each other when talking about their own projects "How many screens do you have?" On the other hand, when giving presentations in our fall "show and tell" session, you could hear one student say to the presenter (Antonio): "And this is all?" referring to the four fractions screens of Antonio's project.

Leslie's insecurity about taking a clear position on this case reflected her ambivalence and that of the other class members on this issue. However, an interesting discussion emerged about whether one way to evaluate whether a piece of software is good or not is related to how many problems/representations are presented in the software. The question of whether this is a criteria, or a category, for judging a piece of software is related to both design and pedagogy.

Social and Moral Issues Involved in Consulting

Episode 9. Using other students' ideas. A special situation occurred when Nora (fifth grader) and Wanda (fourth grader) were working together. Quite often, Wanda had problems in 'adjusting' her design ideas to her Logo-programming skills. One of her very first ideas was to design a fractions game in the spirit of Nintendo's Mario Brothers. She spent an enormous amount of time designing screens for the different "worlds" (i.e., a Nintendo metaphor) both in her Designer's Notebook and in Logo. However, making her ideas work as an interactive fractions game (like Mario Brothers) required sophisticated Logo-programming skills she did not have. After a while, Wanda became frustrated and decided to do something else more closely related to what other students were doing. Therefore, she was one of the few students who did not have much to show in terms of an implemented project, yet she had a great deal to share in terms of her imagination and ideas.

When Nora came to consult Wanda, they talked for a while about Wanda's ideas. When Nora realized that Wanda did not have much of a program to show, she decided to show her the software she had designed 3 months before. Wanda liked Nora's project very much and asked Nora if she could copy her programming code as is, and add some of her ideas to it. Here is what Nora told her classmates after this session:

Nora: I was working with Wanda. From her whole game, she had only her front page! She didn't save anything. And then I decided to show her my game, and then she said she wants to do exactly like my game. I said, she couldn't have it just like that. And I showed her my front page with the music on it. And she wanted it like that, and I said: 'You can't.' And then she started acting like she was crying and she was mad. She wanted it like Mario Brothers at first, and then she saw my game, and she wanted it different. Like mine. So she kept on changing her ideas back and forth.

Idit: How did you solve it?

Nora: I just asked her which one she is going to do. And she said, I want to do my game just like yours.

Idit: And your cover page too? [Nora loved her opening page with the music.]

Nora: Yeah.

Idit: Why didn't you want her to have it just like yours?

Nora: Because.

Alicia: [answers for Nora] It's mine!

Nora: Yeah. It's mine, not hers.

This was an issue which was of particular importance for the consultants: "Who owns an idea?" Or, "Can one copy someone else's program? Why or why not?" In the Fall, we had a long animated discussion on this topic (e.g., Kafai & Harel, 1990), and the fifth-grade students came to the conclusion that it was "o.k. to share Logo programming tricks but not to pick up screen ideas from other students." The following short excerpt from the *classroom discussion on "software rights and confidentiality" of November 3, 1989* illustrates the students' concerns about ownership and the sharing of ideas:

Amy: If we have an idea and we share it with a couple of people, is this fair?

Mrs. Mar: Do you think it is fair? To learn something new? If it is *their* idea and you want to share it with one or two people . . . An idea or procedure or something new. Well. Do I have to share everything I know with you all?

Students: No.

Mrs. Mar: Do you get mad if you think I don't? [Idit laughs] It's a personal thing. You share something with whom you want to share it. It's a personal thing. [Talking to Nora] Nora?

Nora: I don't think that's fair because, say, like Antonio said, right, if he got something new, he will only tell a boy and he will leave us [the girls] without knowing it.

Mrs. Mar: Do you think if you have something new you're gonna walk over to Antonio, Eugene, Gerald and Matt and tell them?

Students: No you won't.

Nora: No. I tell girls first.

Mrs. Mar: What makes you think . . . what's the difference between that? [telling boys or telling girls]

Nora: Because, see, they always tell boys first and I just tell girls first.

Idit: Let me tell you something, in a software company, there is a policy. Do you know the word confidential?
[Several students at the same time: No, no, yes, yes no . . .]
Could you explain it?

Mrs. Mar: Confidential. It means like if I have this folder on my desk and the word confidential was written on it, that means that *no one* has the right to open up that folder. Just like nobody has the right to go into my copy book. Like nobody has the right to go into your personal journal. It's confidential. It's for certain people who have certain permissions to do it.

Idit: O.K. So what usually happens in software companies, and if we agree we are like a software company here, we can say: the information we are producing here, the products we are producing here are confidential to the outside world. And it will be sort of o.k. to say: Ok we do not want other people to see what we are doing. But, it is pretty common in a company to work together and share information within the company. Because, on one day you might not want to share your invention. That's fine. But always remember that other people have great ideas and inventions too, and that we can a learn a lot from those. See, you always have to remember the other side of the coin. You can decide to make your project confidential if you want too, that's fine. But then it will not be fair for you to walk around and see what's going on [on other people's computers]. So always remember that. The minute you say 'my project is confidential,' or 'I am only sharing information with my teacher, with Yasmin and with two other children,' then, remember it is not fair to walk around and look at other people' ideas.

Antonio: You mean, if we mind only our own business, and if we do have a secret, we don't have to tell anybody?

Mrs. Mar: You don't have to tell anybody; but don't expect that somebody else who learns something new is going tell you about it.

Antonio: But they won't know if it is, if I already ahm . . .

Mrs. Mar: They might find something different that could be beneficial to you. But if you are going to act like Mr. Snootie or Mr. Stinky and not share your ideas, why should they share it with you?! That's basically what we are saying here. So you learn something, and you will feel good enough about sharing it then somebody will share something new with you. [Looking at Leslie, saying:] You'll be the last one [to talk] and we have to go to the library.

Nora's initial reaction has to be understood in this context. Furthermore, it put her in a difficult social situation because Wanda was having a hard time accepting that she could not copy Nora's game: *''And then she started acting like she was crying and she was mad.''*

In Wanda's fourth-grade class, students did copy Logo tricks and design ideas from each other. In fact, 1 week before this consulting session, Kafai helped Wanda to copy several shapes from Caroline's (fifth grader) computer, because she liked them so much. She only wanted to have them, not use them. Caroline did not mind. Through this consulting session Nora worked through this issue as well, and managed to solve it:

Idit: But I saw you working on something. So what did you work on?

Nora: It's the same, but it sounds different and it looks different.

Idit: So you decided to do almost the same but a slightly different music and slightly different colors. Right?

Nora: Yes.

Idit: But the same concept and the same idea. Did she agree to this at the end?

Nora: Yes.

Idit: So, now she is happy?

Nora: Yes. [smiling].

Idit: O.K. Now, how did you deal with it at that moment, when she was acting out. What did you do?

Nora: I just was looking to her, and then, she stopped and looked at me. I said to her 'What's wrong with you?' and she said: 'I want my game like yours.' And I said: 'So?' and she said: 'Hey, let's forget it then.' And I said: 'No. Then do it. That's okay, you can do it.'

DISCUSSION: WHY CONSULTING FOR LEARNING?

In this chapter, we continued to examine the interplay between social and individual processes in ISDP. We followed and observed a class of students over a period of one school year. This allowed us to situate their thinking and activities in a larger context. During our research, we chose to investigate and describe two features of social interaction that are quite contrary in terms of their openness: one feature we described was the flexible nature of collaborative processes in ISDP (Kafai & Harel, Chapter 5 in this volume), whereas this chapter focused on the function of the consulting process. From the outside, learning through consulting might project a more contrived picture. However, we found that interactions and themes chosen by the consultant-consultee pairs were rich and diverse. In that sense, even learning through consulting left the definition of goals up to the students. Special importance was given to the fact that conceptual models were generated by the students in their processes of interaction. In several instances, we were even able to trace how the consultants' questions and observations were related to their own past work and interviews.

Originally, we generated and implemented the idea of ''consulting'' with some reluctance. Our reluctance stemmed from the fact that we did not know what to expect from the students-consultants, who three months before the consulting sessions were quite happy to finish their projects and move on to a new project. Taking into consideration students' typical attitudes in relation to schoolwork and its routines, we were not sure whether they would be enthusiastic about revisiting an ''old'' finished project three months after its completion. And as much as we strongly believed in the intrinsic importance of the ''consulting pedagogy'' and thought of it as an important constructionist activity to experiment with in the context of ISDP, we were also ready to cancel the consulting sessions in the case of students' rejections or negative attitudes.

However, the students' attitudes surprised us. There was not one objection about becoming software-design consultants to the fourth graders. Observing and interacting with the students during the consulting sessions and the follow-up discussions did not lead to any misunderstanding: The students were engaged and enthusiastic about the consulting activities. Moreover, it seemed that the students were excited about helping the fourth graders, showing their own finished pieces of software, and revisiting and discussing (once again!) their own knowledge of fractions and Logo.

Our hypothesis is that, above all, students liked discussing their mathematical and design ideas within this playful context. On one hand, helping the younger children was familiar to most of the students who are used to help their young siblings at home. On the other hand, consulting was like a game to these students with roles and rules they usually don't play in school. It provided students with a different audience from the one they usually have. In regular school-like situations—by facing a teacher, who by definition seems to know everything—students might feel intimidated to announce their ideas or problems, discuss their theories and raise hypotheses. We found this not to be the case in this study.

The collection of nine episodes from the two consulting sessions shows an extensive range of questions the consultants were engaged in: about fractions, Logo programming, design, pedagogy, writing, and so on. They were free to choose what they wanted to work on. The observations and analyses of these two sessions provided multiple examples supporting the hypotheses that consulting can be a rich context for learning. We saw Alicia and Karen expressing their confusions about equality of fractions and the different frames of references used to understand fraction representations. We also saw Gerald, Matt, and Alicia learning about spelling, punctuation mistakes, and question phrasing.[2] In fact,

[2] The topics under discussion ranged from concerns regarding deep issues (e.g., representation of fractions or fractions equality) to concerns regarding surface issues (e.g., spelling and punctuations).

there were many more episodes during the two consulting sessions, as well as in the follow-up discussions, where students had a chance to make explicit their knowledge and understanding about Logo programming, software design, fractions knowledge, or teaching strategies. It is beyond the scope of this chapter to describe all of them here. Our point is that many questions and reflections were raised during this context *by the children*, in forms which made them learn a great deal, without perhaps, them noticing they were actually doing so.

Our questions of whether learning through consulting actually works and why have been touched upon at several points in this chapter. We will use these two consulting sessions as a springboard to tie our reflections to the social aspects of the ISDP environment.

Learning with Multiple Perspectives

The idea of learning through consulting has been created to provide learners with multiple ways of building knowledge in several contexts simultaneously. Our assumption is that, some times, learning takes place in a deeper and richer way when a child has the opportunity to approach a problem or explore a domain of knowledge from different angles (e.g., Perkins, 1986). ISDP builds on this very point of how the process of designing a piece of software about fractions can become an "object" with which to think about fractions—the "object" is conceived and seen from various perspectives: the perspective of the designer, the programmer, the child as a teacher, and the further target user (e.g., Harel, 1988, 1990).

Later, when students become software-design consultants, they gain an additional perspective. As consultants, they advise students on software design and fraction representations and deepen their own understanding. This is done by trying to understand the other designers' problems, debugging their programs, and improving their software's functionality. In particular, consulting fosters a different epistemological style of interaction with software in that the students can have a much greater *cognitive distance* to the piece of software than when they are engaged directly in their own production process. Like Collins, Brown, and Newman (1990), we think that an important part of building understanding is to have that distance. It gives another opportunity to reflect upon what one has done and what one knows. This "cognitive distance" first takes place during the software design process, when students think about teaching others or play with each other's pieces of software. But the social context of learning, as expressed in the consulting sessions, provided a motivational rationale for the students to make their thinking even more transparent to the consultees in order to be helpful, communicative, and productive—together. The process of making their implicit knowledge "explicit" for the consultees allows them to compare their own ideas/knowledge with that of the consultees.

To summarize, in the consulting situation the student consultants have a cognitive distance to the product which they are evaluating. This cognitive

distance has a reflexive character, because it allows the consultant to see the fraction representations of others—which they could have constructed on their own. The consulting situation has a mirror-like character which can reflect both solutions and misunderstandings.

Often, this process generates "cognitive conflicts." The student-consultants are engaged in the process of comparing their own understandings (and conceptual framework) to what they see in the consultees' products of learning. Possible differences become clearer and allow the consultants to express their conflicts clearly (as, for example, Alicia and Karen did in the followup discussions). Therefore, through the effort of searching for and modeling solutions to the consultees, the consultants confront many cognitive conflicts. Thus, as much as they reactivate and apply "old" knowledge, they also gain "new" understandings about concepts they could not fully explore and acquire previously.

We propose the following model (Figure 6) as one that illustrates this context for learning that provides students with multiple perspectives on the same problems or domains of knowledge.

At the center of the model (the area of the overlap of the three small circles) we can see the product of ISDP—a piece of software. The piece of software itself is a product of an interdisciplinary, multifaceted process of learning (i.e., the integration of Logo programming with the developing of fraction representa-

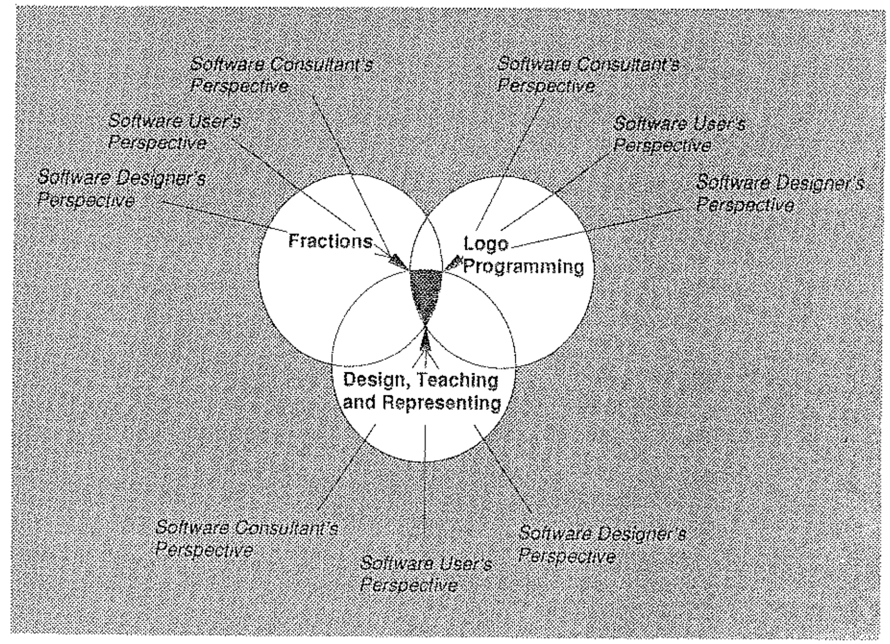

Figure 6. An interdisciplinary and multifaceted process of learning and knowing in ISDP in general, and in consulting activities in particular.

tions, designing, teaching, explaining, etc.). Whether it is the learner's own piece of software or another pupil's piece of software, the learner has multiple routes for evaluating the piece of software, which reflects his or her process and product of learning and knowing.[3]

The consulting situation in particular, and the social interactions in general, in the ISDP learning environment provide ground for this model. As the student software designers look to their neighbors' screens, and as they walk around in the computer pods and try out each others projects, they encounter multiple models of what other designers want to incorporate in their projects. In that sense we argue that both sides—allowing students to find their own perspective and giving them multiple opportunities and routes for learning and knowing—are essential.[4]

Wrestling with Ideas Through Play and Without Feeling at Risk

We believe that the time spent wrestling with different perspectives and ideas in the Incubation Phase is the place when students start to build their conceptual models of what their instructional piece of software will be and what they want to communicate about fractions. We described these different processes in three case studies (of Gerald, Amy and Stacy, and Jeannine). The consulting activity provided a similar place in which these students were allowed to revisit their knowledge of fractions and programming through play, without feeling at risk.

One characteristic of children's play is the ability to experiment with and transform reality. Through this process, children can assume control over given situations and select the important issues they want to deal with (e.g., Bruner, Jolly, & Sylva, 1976). We were interested in using this aspect of play in the context of consulting. By inviting learners to play the role of expert software designers and consultants, we encouraged deep thinking about fractions, programming, and design.

However, we draw a fine line between play situations and the playfulness of consulting: On one hand, the students were able to grasp the situation of "playing consultants" because it resembled other familiar play situations, such as playing doctor, lawyer, or secretary. On the other hand, in contrast to the imaginary aspects involved in playing doctor, consulting in the context of the present study required the principle of truthfulness: the students were actually asked to become consultants because of their real expertise gained by participating in a similar project in the fall. This is in contrast to typical play situations, where students use the imaginary and not realistic quality of the situation to create adventure in their plots.

[3] We must take into account in this model that learning takes place over *a long period of time* and that students use *different styles* to accomplish this integration and to apply their multiple perspectives meaningfully (i.e., Harel, 1988, 1990).

[4] Some aspects of learning through multiple perspectives have also been applied to other learning activities, such as writing (e.g., Daiute & Dalton, 1989). Students can learn how to write by acting as readers, writers, editors, book designers, and publishers of their own or other students' writing.

Learning While Playing Experts

Certain episodes in our current study lead us to believe that novices can successfully establish themselves in the role of an expert and greatly benefit from that role. Our observations closely follow the results of a recent study conducted by Daiute (1989), where she explores the interactions among fourth graders as they collaboratively work on writing text. Daiute found evidence that novices can also demonstrate or acquire expertise in summarizing, questioning, rephrasing, and so on, during their interactions with each other.

We used a nontraditional lens in our study: We did not ask what the novice learned from the interaction with the expert, but rather what the educational benefits were for the expert. We found that students in the role of experts can gain insights not previously available to them. Our claim is based on the idea that our nonexpert experts themselves developed their expert conceptual models; whereas in the "cognitive apprenticeship" approach (Collins, Brown, & Newman, 1990) this model is provided to the apprentice/learner by someone else—the expert/teacher. Our episodes showed us how students interact with their consultees on the basis of their own notions of what was appropriate and correct. Gerald (fifth grader), in his interaction with Howard (fourth grader), for example, had a clear model in his mind for what was an acceptable way of phrasing the feedback the software should provide its target users. In Alicia (fifth grader) reaction to Tracy's (fourth grader) screen we saw that Alicia definitely had a set of expectations for how a particular fraction representation had to look and how to phrase the instructional questions and explanations of the representations. When Alicia was confronted with a screen she found difficult to understand, there was a conflict in her mind. But since she was playing expert, she had to find ways to understand what was going on in her consultee's project. She had a responsibility. Her conceptual model (which was developed in her own software design process) needed to be expanded or transformed. Her role as a consultant or teacher required her to reflect upon the problem, express it in the classroom, and find ways to accomodate the situation.

One can ask, however, in what way these personal models constitute expert models in the traditional sense? We would agree that the student-consultants' models themselves are not like the real domain expert models in the formal sense; nevertheless, the students' *processes of searching for and constructing* these models are very similar to those of real experts. Also, these models are quite sophisticated in relation to the fourth graders' models. Our argument is that the students' benefit lies first and foremost in their own process of constructing these models. This process is the one that later allows them to speak with confidence about difficult matters. One example we saw was Alicia, who herself had problems dealing with the variables in her fractions software programming code, and who could, in the context of consulting, apply this knowledge and refer to the case as "*She* [the consultee] didn't know what the matter was!"

A Rich Role for the Teacher

In the follow-up discussions (after the consulting sessions), the student-consultants could replay their consulting experiences while trying to explicitly explain to others how they had made sense of the consulting situation.

In a further step, these follow-up discussions could provide a springboard for mathematical discourse not traditionally known in the school context. A student-consultant could raise many fascinating questions about what he or she did not understand. Then, as others joined in, they could describe similar experiences and raise new questions. We observed that students used the classroom as a place to brainstorm about mathematics and software design as experts would do in their domain. We can see these follow-up discussions in our consulting context as an example of how these discipline-like discussions can be initiated in the classroom by the students as well as by the teacher.

In our two consulting sessions, the students came back confused about what they had seen in the consultee's programs. By voicing that they do not understand the fraction representations, they offered "gates" for the teacher to discuss these problems in class. In consulting, the teacher's role is to provide room/space for discussion and to think about thinking with her students. As we have already described, the context of consulting confronts the student-consultant with an ill-defined mix of problems. Therefore, as a teacher and researcher, we could only speculate about the possible outcomes of the students' interaction in consulting. In the constructionist tradition, we believe that this is an appropriate model, with *students* bringing up the issues to discuss. The problems we raise here are, what can a teacher do with these issues? How can she or he facilitate the epistemological concerns that his or her students bring with them from their constructionist experiences? We are in the process of exploring these important questions.

CONCLUSIONS

We presented our explorations of the social and collaborative aspects of learning in ISDP to provide an example of how collaboration can be conceived in alternative ways. Our point is that ISDP can be seen as an exemplar environment for the social aspects of constructionist vision. ISDP facilitates the social processes supporting the individual construction of understanding in various domains. In this environment, which invites students in a multifaceted way to explore their own and other students' ideas, social interaction becomes a natural mode of being. Social skills involving giving and requesting help, about giving and receiving explanations and asking and answering questions, are tapped continuously.

This is in contrast to recent approaches in the collaborative literature (e.g., Johnson & Johnson, 1989; Sharon & Sharon, 1989) that request explicit training in collaborative skills. We do not train for collaboration. We do not teach consulting skills. We assume that the environment itself can create a context of a learning culture in which collaboration-though-the-air allows ideas to circulate and enter students' minds; an environment in which optional collaboration and flexible partnerships facilitate the students' construction of knowledge and of conceptual models; a culture in which brainstorming and consulting provide a context to travel through multiple perspectives while learning.

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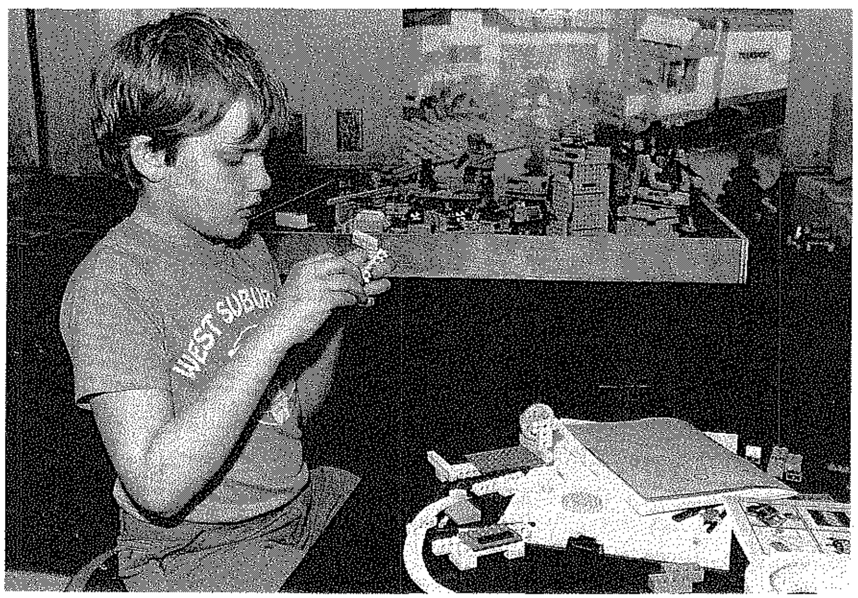

Stephen Ocko Photography

LEGO/Logo: Learning Through and About Design.
Design projects can give mathematical and scientific concepts a new relevance in the minds of children.

7

LEGO/Logo:
Learning Through and About Design

Mitchel Resnick and Stephen Ocko*

INTRODUCTION

Problem solving can be divided, very roughly, into two categories: analysis and design. Analysis involves decomposing problems into simpler subproblems, typically with the help of formalized rules. Design is different in several ways. In design, the problem goals are typically ill structured; defining the problem is part of the designer's job. Moreover, there is a somewhat fuzzy sense of what it means to "solve" a design task. Rather than seeking *optimal* solutions, designers typically seek *satisficing* solutions (Simon, 1969)—that is, solutions that roughly satisfy a given set of constraints.

Design is important in almost all fields of human activity. Of course, an architect uses design skills when preparing a blueprint. But so does a writer when writing a report, and a manager when restructuring an organization. Given the central role of design in human activity, one would expect design to play an important role in school classrooms. But it doesn't. In the minds of many educators, the ill-structured nature of design activities makes them ill suited for the classroom. Design activities, they complain, are difficult to "manage" and to evaluate. As a result, students rarely get the opportunity to design, to build, to create, to invent.

This chapter explores the role of design in the classroom. In particular, it focuses on the use of LEGO/Logo, a computer-based robotics system that supports a variety of design activities. The chapter examines how students using

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