

Designs for collaborative learning environments: Can specialization encourage knowledge integration?

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Abstract: In this paper, I develop strategies for designing and assessing collaborative learning environments from a knowledge integration perspective. I identify strengths and weaknesses associated with collaborative learning, linking them to the instructional approaches used in an eighth-grade science curriculum where students design a desert house. The house design activity provides a context for connecting instructional goals and technical innovations. Focusing on how students specializing in different areas can share ideas and provide feedback for each other, I show how social and technical supports can work to achieve common goals. I examine two assumptions about how an expanded repertoire of models contributes to knowledge integration. First, I provide evidence that considering more alternatives leads to improved designs only if students have a framework for organizing those alternatives and selecting between them. Then, I provide evidence that encouraging students to iteratively refine their ideas contributes to knowledge integration. Finally, I show how these cognitive goals can be pursued through social and technical innovations which seek to encourage knowledge integration by making thinking visible for students.

Keywords: assessment of learning, cognitive analysis, design framework, discussion forum, learning through design, project based learning, scaffolding, shared knowledge, web

Introduction

The knowledge integration perspective conceives of learning not simply as the memorization of facts or as an incidental effect of experience. The goal in knowledge integration activities is to help students develop a repertoire of models (Linn, 1995). Differentiating between these models involves not only recognizing their different characteristics but the situations where they can be applied. Collaboration can facilitate this process of identification and differentiation. Learning becomes a process of reorganization and integration involving the restructuring of relations between ideas instead of a simple process of replacement. Rather than focusing on isolated facts, knowledge integration defines a flexible and dynamic type of understanding, incorporating social and situational factors which help queue explanatory models for different contexts.

What types of activities and supports can help students understand the relationships between different perspectives? And how can we improve these activities and supports? In this paper, I present the methods used to design and analyze the technical and social

supports for a Web-based, eighth-grade house design activity. I begin with an overview of the advantages and disadvantages of collaborative learning. Then I relate the design of the learning environment and the desert houses activity to the cognitive goals of the curriculum.

The purpose of this study was to investigate the organizational strategies afforded by specializing in different areas of a house design task (e.g., analyzing heating and cooling concepts, comparing construction materials, or critiquing coherent designs). In addition, six goals were articulated for the activity. These goals, derived from previous research on collaborative learning, guided the design of the activity by using technology to structure the co-generation and evaluation of ideas within and between the groups of specialists.

In analyzing the success of this curriculum, I examine two assumptions about how an expanded repertoire of models contributes to knowledge integration. First, I provide evidence that encouraging students to iteratively refine their ideas contributes to knowledge integration. Second, I provide an explanation for why considering more alternatives does not necessarily lead to improved designs. The overall approach, using cognitive goals to guide technical innovations, recognizes the rich variety of ways in which knowledge integration occurs and thus the need to support a diverse set of approaches to collaborative learning.

Strengths and weaknesses of collaborative learning

Recent research indicates that collaborative learning has the potential to help students generate ideas and identify alternatives (see Linn & Burbules, 1993). Technical innovations in collaborative learning make it possible to represent these alternatives in a more equitable manner than is afforded by verbal discourse. In addition, CSCL research has investigated a range of potential benefits from intentional learning and the construction of shared knowledge bases (Gomez, Pea, Edelson, et. al., 1995; Scardemalia & Bereiter, 1991) to providing a conceptual and linguistic basis for metacognitive reflection (Frederikson & White, 1997; Brown & Palincsar, 1989). Activities capitalizing on the strengths of collaborative learning include developing shared criteria, negotiating alternatives, and differentiating between perspectives (Linn & Burbules, 1993). Collaborative learning can help break "design fixation" where students cling to original and often unelaborated ideas (Cuthbert, 1996). From a knowledge integration perspective, this breaking of fixation happens because collaboration encourages reflection, promotes critique, and introduces new approaches to a problem.

Prominent among the disadvantages of collaborative learning is "group think". Group think is the tendency to converge on a solution path without analysis of the alternatives. In online and classroom discussions, students frequently make decisions based on social status rather than on evaluation of the issues (Hoadley, 1998). The finding that students lack effective discourse strategies works against unmoderated and unstructured discussions, a dominant form of collaborative learning. Similarly, planning is difficult for groups of students, though this drawback can be addressed through the use of checklists, activity maps, and learning cycles (Bell, Davis, & Linn, 1995).

Recognizing the differences between related perspectives, let alone connecting them in a systematic manner, has proved to be particularly challenging for students (Cuthbert & Hoadley, 1998a). How can we help students distinguish between different perspectives? Designers of cooperative learning environments often take the path of creating multiple representations to help students see the connections between different perspectives (see Conklin, 1988)(1). For example, an online discussion may be viewed in terms of the number of new or total comments, links to specific contributors, or sequentially, based on the dates and times when comments were entered.

A complementary, though less frequently seen, approach is to orchestrate social arrangements which encourage the productive exchanges and patterns of interaction that the software seeks to support (Scardemalia & Bereiter, 1991). One such arrangement, investigated in this study, involves specialization. The claim is that specialization affords students different organizational strategies and different paths for approaching design problems. This arrangement, in turn, creates opportunities for students to share different perspectives and develop an expanded repertoire of models.

Specialization and cooperation

Many problems today require cooperation and coordination between groups of specialists. The research presented here is based on the hypothesis that specialization has the potential to help students integrate multiple perspectives, make connections between ideas, and differentiate between context specific and more general elements. Unlike expertise, which forms over a period of many years, specialization is used here to refer to focused learning or inquiry in a specific area. For example, students investigating different dimensions of water quality (e.g., biological versus chemical) would be considered specialists even though their individual research activity lasted only a few days. Designers of CSCL environments seek to elicit these perspectives, making thinking visible for students and helping them develop a broader problem definition. The challenge for designers of CSCL environments is to create situations where specialization leads to collaboration instead of isolation.

Research indicates that specialization can create opportunities for collaboration between students if completion of the task requires integration of all the areas of specialization (Brown & Palincsar, 1989). The house design problem meets this criteria by requiring students to design a complete house, making decisions about all the component areas (e.g., walls, windows, roofs). In addition, students need to explain heat flow in terms of related scientific concepts (e.g., equilibrium and heat exchange).

The WISE Houses In The Desert Activity

To facilitate the sharing of perspectives and use of evidence to support decisions, we created technology supports in our Web-based Integrated Science Environment (WISE) to help students locate relevant Internet sites as well as annotate and search through them. WISE is a structured learning environment that guides student inquiry, eliciting their

ideas, and helping them to make connections between scientific content and their previous experiences.

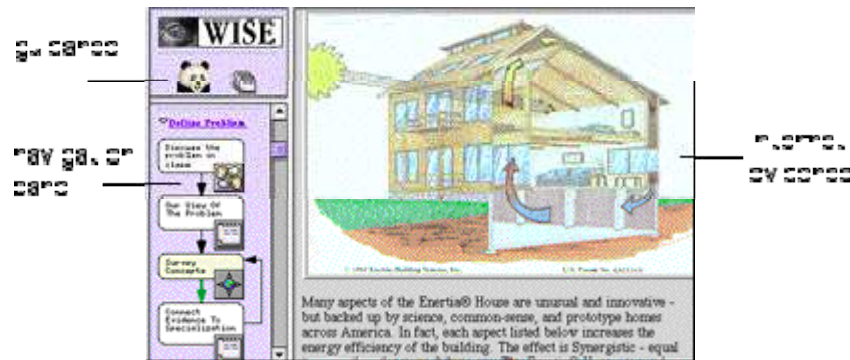


Figure 1. The Web-based Integrated Science Environment (WISE)

WISE views Internet sites as "evidence" which can be critiqued, used to support different theories, or invoked to justify design decisions. In the house design activity, six related goals helped guide the design of the social organization (i.e., having students specialize in different areas) as well as the technical innovations (e.g., a collaborative search page and online discussions).

Goal one: Elicit students' ideas

In some situations, such as brainstorming, the goal is to generate as many ideas as possible before evaluating them. For example, students created their initial designs as homework on the first day of the project to increase the probability that pairs of students would have stable representations of different ideas. In the online discussions, having contributors' pictures or names associated with ideas increases the likelihood that ideas will be evaluated based on the social cues. To reduce this possibility, students entered the alternatives they were considering for their house designs before they were given access to other students initial ideas.

Goal two: Reduce planning problems

Planning is one of the perennial problems students have as evidenced by the number of hands which are routinely raised to ask "What should we do next?" To address this problem, WISE projects consist of activities and steps (figure 1).

Students join project teams, typically composed of pairs of students, and proceed through the activities and steps by clicking on the navigational panel in the left hand frame. These steps guide the students through the project.

1	2	3	4	5	6	7	8
Define Problem	Create Initial Design	Identify Design Issues	Search For Evidence	Present Special-ization	Merge Designs	Analyze Support	Detail Final Report

Figure 2. Activity sequence for Houses In The Desert

Figure 2 illustrates the activity sequence and steps for the house design project. When students first log in, they are provided with a link to the last activity on which they were working. The activity sequence provides structure for students while giving them the flexibility to move back and forth between different types of resources. This approach reduces problems with planning, freeing teachers to circulate through the classroom and interact with small groups of students.

Goal three: Represent ideas equitably

Online discussions, embedded seamlessly into WISE (figure 3), helped students negotiate criteria for making design decisions about their specific houses. Students posted questions for other student specialists and answered questions about their own areas of research.:

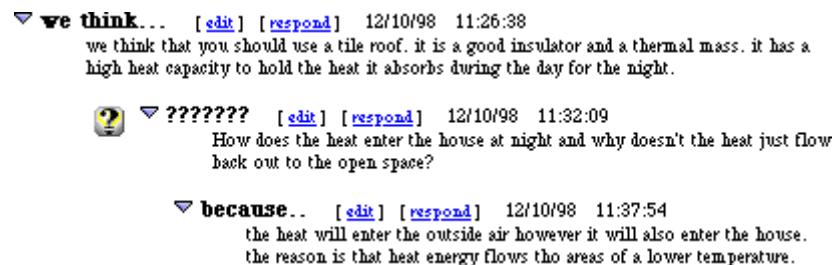


Figure 3. Structured discussions in WISE use graphical icons to represent comment types, and optionally, student photos to provide social cues (not shown).

To counter the possibility that decisions about reliability are frequently based on the social status of the contributor, students were allowed to enter comments anonymously. Hsi & Hoadley (1997) found that anonymity lead to more equitable levels of contribution across genders.

Goal four: Encourage sharing of resources

One advantage of collaborative learning is that students can share resources since they are working on a common problem. The challenge is to provide ways for students to locate and use resources effectively. Differences in how students approach the problem complicate this goal. One solution is to have multiple ways of accessing the information contributed to the shared pool of resources (e.g., through contributor, area of specialization, or by searching the comments for specific phrases). Annotating Internet sites can make the sites easier for students to interpret, and, perhaps more importantly,

encourages them to reflect upon the utility, understandability, and validity of the material they are submitting.

For the house design activity, students searched the Internet for sites to use as evidence to support their design decisions. Useful sites were added to a classroom-wide database which other students could search. Earlier research indicated that students having difficulty searching the Internet benefited from having access to a collection of relevant sites (Cuthbert & Hoadley, 1998b). Still, students are inconsistent in the methods they use for evaluating those sites.

Goal five: Develop shared criteria

Developing shared criteria can help students evaluate evidence. Shared criteria refers to a set of requirements or guidelines for interpreting ideas and making decisions. Criteria operate at different levels, from determining the adequacy of a piece of evidence to the coherence of a design. From a knowledge integration perspective, criteria should help students make informed decisions using scientific principles. Unfortunately, students have little idea what the word "criteria" means and even less about how to use criteria to make decisions. Modeling for students is necessary (we had some success getting students to think about the criteria they would use to buy a pair of shoes: What criteria could be used by both boys and girls?) In this particular study, students used the same criteria: Is the site understandable? Does it have supporting evidence? Does it compare alternatives? Our current research compares students who develop shared criteria with those who employ their own implicit criteria (see Cuthbert, in press).

Goal six: Differentiate between perspectives

One of the most important dimensions of collaborative learning is the potential for students to recognize views that are distinct from their own. From a knowledge integration perspective, identifying and differentiating between different models is a central part of learning. In the house design activity, this learning involved distinguishing between different strategies for temperature regulation, specifically insulating the house versus storing and releasing heat energy. Previously, we modeled the negotiation process by having students contribute to an online discussion between two experts representing these perspectives. Having students specialize in different areas of the house design problem continues this line of research to determine effective strategies for making thinking visible for students.

Methodology

The research took place in an eighth grade science classroom where students used WISE to design passive solar houses for the desert. The project served as the capstone activity for a semester on heat and temperature. Students worked in pairs to generate and refine sketches of their house. They annotated and added relevant sites to a digital library while collecting evidence to support their ideas. Online notes, class presentations, and worksheets provided opportunities for students to refine explanations about the factors affecting heat flow over the course of a day. For approximately two weeks, fifty minutes

per day, students used the Web-based Integrated Science Environment (WISE) to help scaffold their work in the activity. Student grades were based on the coherence of the explanations, the normative use of scientific principles, and how well the ideas were supported with evidence.

Design

In this experiment, students were placed in one of three conditions:

Table 1. Areas of specialization for different groups of students.

Concept Specialists	Component Specialists	Complete Design Specialists
analyzed heating and cooling concepts like heat capacity and equilibrium	compared construction materials for windows, walls, or roofs	critiqued coherent designs (e.g., a rammed earth house)

Two class periods were assigned to each condition. Students had several opportunities to interact, first within their area of specialization (figure 2, step 3), and then across areas of specialization (figure 2, step 6).

Individually, students developed initial design sketches as homework. Then they compared their designs with their partner, entering what they thought were the most important differences into a Web form. These comments were used to seed the initial online discussions which took place within the areas of specialization, thus avoiding the polling problem (see Koschman et. al., 1994, p. 243) where students reformulate other students' initial statements.

The pairs of students worked to merge their two designs into a single final design. Near the end of the project, students were able to consult other specialists, even those in other conditions in a second online discussion. The final design report asked for explanations of the factors affecting heat flow at different times of day. Annotations of Web sites and notes were recorded online, while worksheets were used for analyzing heat flow and generating design sketches.

The areas of specialization were selected because of the distinct organizational strategies afforded by the different areas. The prediction was that component specialists would have an easier time structuring the problem and would be more likely to focus on trade-offs between alternatives. They would be able to decompose the problem, generate more alternatives, and use evidence to support specific decisions about components of the house. Students specializing in complete designs would be more likely to experience

design fixation since they were introduced to a possible solution early in the project. In addition, complete design specialists were expected to consider the least number of alternatives, focusing on a single solution path linked to the house design they researched. Concept specialists would have a hard time comparing alternatives but would be more likely to explain heat flow in terms of day-night cycles and equilibrium as opposed to heat flow through an object such as a wall or window at a specific time of day. Concept specialists would consider the least number of alternatives since they would be focused on refining their understanding of scientific principles as opposed to comparing specific alternatives about which wall, window, or roof to use.

Measures

A wide range of outcome measures were used in this experiment drawn from previous research on ill-structured design problems (see Goel & Pirolli, 1992; Guindon, 1990; Simon, 1973) and peer learning processes (see O'Donnell, DuRussel, & Derry, 1997; Saxe, Gearhart, Note, & Paduano, 1993). In addition to the number of alternatives considered, the outcome measure focused on in this paper is the **design method index**. The design method index was constructed by comparing the two initial designs (created independently by each student in a dyad) with the pair's merged drawing and the associated final report. Noting the possible confounding effect of the cross-specialization discussions (the second online discussion), when categorizing students' design methods I relied primarily on design revisions prior to the cross-specialization discussions. For triangulation, I examined the Internet search worksheet (recording their goals, queries, and overall results of searching for evidence) as well as the note students took about how the designs were merged.

The categorical ratings used for the design method index were: (1) design fixation (maintained the same initial design of one student), (2) copy-delete strategy (replacement of entire design with little justification at various points throughout the project), (3) refinement or aggregation, (4) refinement citing principles or trade-offs as justification for refinement. While coded as a categorical, dependent variable, there was an hypothesized increase in performance for the higher ranking categories.

Results & Discussion

All 79 groups of students completed the complex two-week project. Surprisingly, the overall performance, as reflected by the final project grades, indicated that the concept (N=28) and complete design specialists (N=28) significantly out-performed the component specialists (N=23) (concept-component $F(50)=4.578$, $p<.05$; design-component $F(50)=4.006$, $p<.05$).

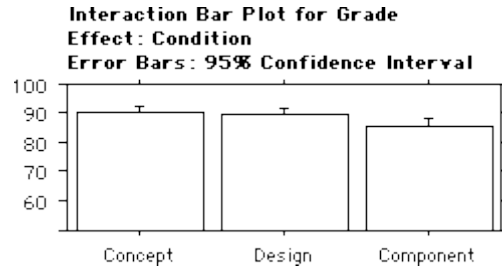


Figure 4. Grade differences by specialization.

The final grades reflect knowledge integration (e.g., coordination of intuitive ideas, scientific terms, laboratory work, and "everyday" experiences (2)) as well as the use of principles and evidence to support design decisions. Why were concept and complete design specialists able to make better use of the alternatives they considered? Closer analysis of students' notes on why they considered and rejected different alternatives suggests that specializing in concepts or complete designs provided an organizational framework for students to approach the problem. Specifically, complete design specialists tended to consider alternatives in relation to their existing complete design while concept specialists tended to consider alternatives related to the concept in which they were specializing. For example, concepts specialists researching reflection and scattering tended to consider the trade-offs between white tile roofs and metal roofs. Students specializing in a rammed earth house tended to consider the trade-offs between earth and styrofoam as insulating materials.

Surprisingly, the concept specialists considered more alternatives than the component and the complete design specialists (figure 5). While not a significant difference or a large difference in mean value, it is interesting that the prediction that concept specialists would consider significantly fewer alternatives was incorrect.

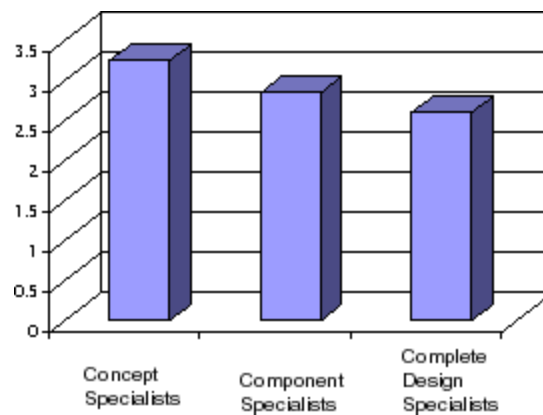


Figure 5. Alternatives considered by specialization

The question remains of why specializing in components didn't provide a framework for students to organize their ideas and consider alternatives more effectively?

Why component specialists were able to identify alternatives but not make connections

One possibility why component specialists were able to generate alternatives but not make connections is that these students were unable to identify similarities between components. The activity encouraged students to differentiate between alternatives (e.g., between using a metal roof and a wood roof) but was not as effective at helping students identify similarities across the components of the house. For example, deciding that a double-paned window would be effective because of the increased insulation did not necessarily help students decide what type of wall to use. One explanation is that students did not realize that the same principles could be used to make decisions about the different components of the house. Identifying similarities phrased in terms of scientific principles requires a more advanced structure of conceptualization and generalization (see Vygotsky, p. 164), one that was provided by specializing in concepts but not in components.

In many of the interviews I conducted, students began by identifying linkages between structural components; only later did they reformulate or justify their decisions in terms of scientific principles or systems. This pattern suggests that specialization provides a starting point for knowledge integration but connections, which occur when students revisit ideas, reformulate their explanations, and compare alternatives, happens through a convergent process involving self-explanation, discussion, and negotiation (see Roschelle, 1992). It seems likely that students specializing in components had the potential to invoke scientific principles to explain the trade-offs between using different components, but that analysis based on scientific principles did not come earlier enough in the activity to benefit the selection process for these students.

Finally, a component-based view may make the house design project seem more like a selection task (e.g., choose a window, a wall, a roof) as opposed to a task involving understanding and regulating heat flow. Analyzing the between-specialist discussions, we can gain insights into students' conceptualization of the problem and their emergent goals supporting this hypothesis. Analysis of the online discussions indicates that students in the component condition tended to ask for recommendations for specific components while students in the concept condition asked for explanations about how those components worked. These differences suggest that the areas of specialization influenced students' conceptualization of the problem in distinct, though not always productive, ways.

Did students' design process determine their success in the project?

There were no significant differences in design method between the three conditions. However, students specializing in complete designs were the least likely to use principles to select between design alternatives, with their design methods reflecting a copy-delete approach more than the other groups. Earlier research (Cuthbert, 1997) showed that design methods and search behavior were highly correlated suggesting that student problem-solving strategies were tied closely to student dispositions. This research provides additional evidence showing that students' methods for approaching open-ended

problems are dissociated from the imposed framework for structuring the problem, at least for these areas of specialization.

Examining group performance based on design methodology, there were significant differences in overall performance (figure 6), as measured by the final grade, between the first two categories (fixity and copy-delete) and the second two categories (refinement and refinement with trade-offs): fixity versus refinement $F(50)=3.478$, $p<.005$; fixity versus refinement w/ principles $F(29)=4.314$, $p<.005$; copy-delete versus refinement $F(48)=3.629$, $p<.05$; fixity versus refinement w/ principles $F(27)=3.818$, $p<.01$.

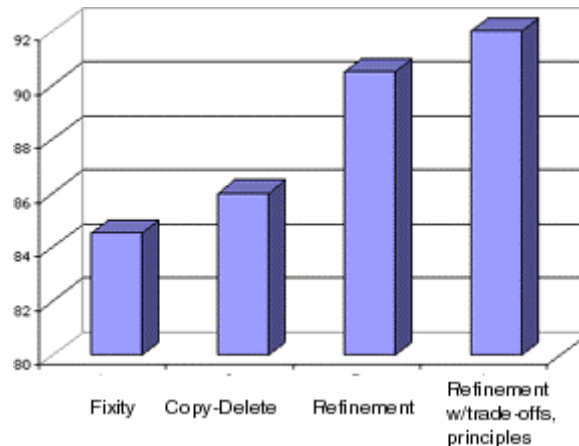


Figure 6. Final grade grouped by design method

This finding that refinement is better than design fixation or replacement is not surprising. The first two categories are characteristics of one hypothetical "type" of student, termed "consumers" (Linn, personal communication) while the second two categories reflect more principled, reflective characteristics. Since the activity itself is designed to encourage iterative refinement, evidence that this design methodology contributes to knowledge integration validates our general instructional approach.

However, it is important to note that some groups that did not refine their designs succeeded in the house design task. These students tended to reject information that they did not understand or that was too complicated, focusing on developing explanations using accessible scientific principles related to heat flow rather than more complex principles relating to heat capacity and thermal mass. This finding, that developing simple and constrained solutions can be a successful strategy for some students, goes against the hypothesis that an expanded problem definition leads to improved designs. The challenge for designers of CSCL environments is to create software supports that enable students to follow a range of paths for completing projects. This research points to two such paths: (a) iterative refinement and (b) developing a deeper understanding of pragmatic solutions.

Conclusions

One of the primary goals of the activity design was to have students refine their ideas in a variety of contexts including online discussions, worksheets, sketches, and in-class discussions. These methods for supporting specialization were validated by the finding that having students iteratively refine their ideas contributes to knowledge integration. In addition, this research provides evidence that specialization affords students different organizational strategies and different paths for approaching complex design tasks.

Interestingly, simply providing students with appropriate resources and encouraging them to consider more alternatives did not lead to better designs. Students need a framework for organizing their ideas and for selecting between alternatives. This framework was provided by specializing in concepts or complete designs, but not by specializing in components. Component specialists were not able to make better use of the alternatives they considered for a variety of reasons including lack of an organizational framework, a biased perception of the house design project as a selection task, and a need for principled analysis at an earlier stage of the design process.

Investigating the interaction between students' organizational strategies, peer interactions, design methods, and knowledge integration is a complex task. However, understanding these processes can inform the design of collaborative learning environments by providing a grounded perspective for connecting instructional goals and technical innovations.

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Footnotes

1. The distinction between "cooperative" and "collaborative" has been pointed out by Pea (1994) in much the same way that the difference between "common" and "shared" was highlighted by Bannon (1997). Collaborative learning refers to students working together on a group project with a shared product. Cooperative learning, on the other hand, involves sharing of resources but independent solutions. The learning environment and activity presented in this paper are

- examples of cooperative learning since each pair of students create unique solutions.
2. Everyday experiences are out-of-school experiences where instruction is not necessarily the focus of the activity. An example of an everyday experience would be noticing that the grass feels cooler than the sand on a hot day. See Vygotsky (1934/1986) for a more complete account of spontaneous ideas, scientific concepts, and everyday experiences.

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