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ABSTRACT

Research on group learning has focused almost exclusively on interactions among individuals within groups; there has been little research on phenomena occurring between groups of learners in classrooms. This exploratory study identifies, describes, and categorizes events occurring between members of different learning groups in three ninth-grade physical science classrooms. This study also investigates how the characteristics of learning tasks enable or constrain different kinds of inter-group interactions, and, in turn, how they affect opportunities for learning. Evidence gathered during the study supports four assertions about inter-group interactions in collaborative contexts: (1) inter-group dynamics are qualitatively different from intra-group dynamics; (2) the products of student work and the constructive processes leading to such products are significantly influenced by inter-group dynamics; (3) different types of tasks stimulate and constrain different types of inter-group interactions; and (4) within collaborative contexts, students are capable of engaging in complex activities and creating authentic products with minimal intervention from the teacher. (Contains 49 references.) (Author/YDS)

The Diffusion and Appropriation of Ideas in The Science Classroom: Developing a Taxonomy of Events Occurring *Between* Groups of Learners

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Abstract

Research on group learning has focused almost exclusively on interactions among individuals *within* groups; there has been little research on phenomena occurring *between* groups of learners in classrooms. This exploratory study identifies, describes, and categorizes events occurring between members of different learning groups in three ninth-grade physical science classrooms. This study also investigates how the characteristics of learning tasks enable or constrain different kinds of inter-group interactions, and, in turn, how they affect opportunities for learning. Evidence gathered during the study supports four assertions about inter-group interactions in collaborative contexts: 1) inter-group dynamics are qualitatively different from intra-group dynamics, 2) the products of student work and the constructive processes leading to such products are significantly influenced by inter-group dynamics, 3) different types of tasks stimulate and constrain different types of inter-group interactions, and, 4) within collaborative contexts, students are capable of engaging in complex activities and creating authentic products with minimal intervention from the teacher.

Introduction

Collaborative learning environments which involve complex problem-solving (Savery & Duffy, 1996) or design (Blumenfeld et al., 1991) engage students in highly-contextualized tasks with the aims of cultivating deep understanding of subject matter, fostering learner persistence, creativity, and self-organization, and, developing the ability to work productively with others (Duckworth, 1978). In such environments, information and ideas often flow between formally assigned clusters of learners in unpredictable, and, as yet unstudied ways. Not only do learners interact with members of their own groups, they inevitably overhear the conversations of other groups, visit each other's groups, share material and intellectual resources with other groups, and witness the triumphs and failures of their classmates.

Research on group learning has focused almost exclusively on interactions among individuals *within* groups; there has been little research on phenomena occurring *between* groups of learners in classrooms. Studies of how students learn from others in group situations have generally considered interactions occurring outside the assigned group as "noise", mentioning them only parenthetically or ignoring these effects altogether. However, as teachers and researchers will attest, classrooms are fluid social environments in which the universe of influences on what an individual learns is not circumscribed by the small number of classmates to whom one is assigned. As more science teachers consider collaborative learning activities for their students, it becomes increasingly important for the research community to develop theoretical frameworks that reflect the ecological complexity of the classroom.

For such a theory to be suggested, it must describe phenomena that are not addressed in a systematic way by other explanatory frameworks. Interactions *between* groups of learners can be, for example, qualitatively different that those occurring *within* groups of learners. Even though assigned student groups in a classroom can be presented with similar problems to solve, these groups can construct the problem differently, invoke different intellectual resources, materials, and tools, use different conceptual language to develop ideas surrounding these tasks, embark on completely different solution paths, and construe success in unique ways. As opposed to transactions that occur within groups which serve to focus ideas, narrow down options, and generate consensus, transactions can occur between groups in which learners have constant access to alternative ideas, even after their own group has committed to a certain trajectory of thought and action. In collaborative classrooms, these alternative ideas are an evolving "public property", kept accessible to everyone throughout the duration of the project, not simply unveiled to the rest of the class during final show and tell.

Unfortunately, descriptions of how members of different learning groups interact with one another remain largely anecdotal. Empirical studies are necessary to confirm whether arguments such as the one above have any basis in fact, and if so, how they are manifested in specific classroom situations. This exploratory study is a first step in understanding inter-group interactions; it seeks to identify, describe, and categorize events occurring between members of different learning groups in three ninth-grade physical science classrooms. Because the diffusion and appropriation of ideas in classrooms is an organizing concept in this study and because the inter-group phenomena observed in this study was powerfully mediated by available tools, information resources, raw materials, and drawn representations, distributed cognition is used as a framework for describing how student interactions served to diffuse ideas throughout the collective and how these interactions influenced the products of students' work. This study also investigates how the characteristics of learning tasks enable or constrain different kinds of inter-group interactions, and, in turn, how these tasks affect opportunities for learning.

Theoretical Background

The notion of learning with and from other students has been reinforced by documents such as *The National Science Standards* which states, as a foundational assumption of teaching, that "student understanding is actively constructed through individual and social processes" (National Research Council, 1996, p. 28.) and *Science For All Americans* (AAAS, 1990) which encourages group work in classrooms because "it is the norm in science" (p. 206). In response to widespread calls for group work, an increasing number of science teachers are implementing constructivist models of instruction which feature collaboration and increased opportunities for between-student dialogue (Windschitl, 1999).

Science education research has contributed much to our understanding of how learners work in collaborative settings, including how learning is influenced by the composition of student groups (Bennett, 1991; Slavin, 1989-1990; Webb, 1992), discourse among group members (Alexopoulou & Driver, 1996; Cazden, 1986; Richmond & Striley, 1996), epistemological frameworks of individuals working in groups (Hogan, 1999), tools as mediators of group activity (Carter, Westbrook, & Thompkins, 1999), metacognitive activity within groups (Artzt & Armour-Thomas, 1992), and a host of other aspects related to collaborative/cooperative learning.

In collaborative learning environments, students work in small groups, negotiating goals, tasks, and meanings with peers (Blumenfeld et al., 1991; Nastasi & Clements, 1991); they often support one another's developing understandings through joint construction of artifacts such as functional models, symbolic representations, or special tools (Barab, Hay, & Duffy, 1998; Papert, 1991). In designing such environments, teachers must establish an atmosphere that encourages the exchange of ideas, nurtures reflection, and supports students in carrying out practices that are personally meaningful and that result in conceptually functional products (Barab, Hay, & Duffy, 1998; Hannafin, Hall, Land, & Hill, 1994; Jonassen, 1991).

When studying collaborative work, conceptualizing learning as an individual performance is not realistic in terms of the ways intelligent activities are organized and accomplished. Just as in the real world, these activities depend on resources beyond a person's long-term memory, and require the sharing of tools, materials, and representations (Pea, 1985). In the world outside school, part of learning how to learn and solving complex problems involves knowing how to create social networks, interrogating and exploiting the special expertise of others, and using the features of the physical environments to one's advantage. Socially scaffolded and artifact-supported cognition is so predominant in the world, that its disavowal in the classroom is detrimental to the transfer of learning beyond the classroom (Pea, 1993; Resnick, 1987).

The perspective of cognition as distributed across individuals and their environments suggests that human activity is heavily influenced by the local affordances of available artifacts, tools, and other people. Lave and Wenger (1991) extend this idea by describing the relationship between thought, action, and the environment as so tightly interwoven that the mind cannot be studied independently of the culturally organized settings within which people function. In any learning situation, the tools, rules, values, and actors constitute a complex, highly interacting system (Greeno, 1991; Lave, 1988). For classroom learning, this means that textbooks, computers, classrooms norms, grouping of learners, and even the organization of desks all serve to enable or constrain intellectual activity (Pea, 1993).

Distributed cognition recognizes both non-social factors (e.g. tools, materials, symbols, created artifacts) as well as social factors in learning (e.g. co-constructing ideas with others, creating and exploiting social networks). The influence of non-social factors, however, makes sense only in light of how they are used within a social context. Tools, materials, symbols, and created artifacts are frequently the focus of attention in classrooms in much the same way that design drawings or computer models are for teams of engineers. These material objects serve as a common locus of intellectual effort and have important functions in the problem-solving activities of groups (Bond, 1989; Henderson, 1991; Latour, 1992; Suchman & Trigg, 1993). They serve not only as the topic of participants' conversations but also as a reference against which participants make sense of each others' talk. As such, these material objects structure interactions and stimulate social thinking. In the development of the focal artifact, which is witnessed by participants in the design process, the artifact embodies the history of the participants so that they can refer to specific instances in past conversations and project future changes by indexing relevant features of the artifact (Roth, 1998).

In contrast to the emphasis on the non-social (tools, artifacts, and other material influences), members of the sociohistorical school (e.g. Vygotsky, Luria, Leont'ev) have emphasized the effects of scaffolding and other human interactions on learning (Moll, 1990; Wertsch, 1985). This school of thought suggests that knowledge exists in the way that groups communicate and organize their belief systems, as well as in how they make use of symbols and tools. Knowledge and action are fundamentally social in origin, organization, and use, and are situated in particular social and material ecologies (Jordan & Henderson, 1995). Understanding is not a process of coming to know the entities and attributes that exist in the world, but of successfully negotiating the meaning of these objects with others (Brown, Collins, & Duguid, 1989).

Science classrooms, like many other types of communities, can be characterized by the material, social, and conceptual resources available to the activities of members working alone or collaboratively. By investigating how these different types of knowledge (e.g. simple facts, concepts, tool-related practices, problem-solving strategies) diffuse throughout a classroom and come to be recognized as shared by the students, one can provide empirical evidence for the distributed and situated nature of learning in school settings. Unfortunately, only a few classrooms have been successfully conceptualized in this way (e.g. Cobb, 1991; Roth & Bowen, 1995; Scardemalia & Bereiter, 1994). We also know little about how and why communal artifacts are developed, and more investigations are needed to understand the inventive processes that give rise to the social and material distributions in classrooms (Hewitt & Scardemalia, 1998).

In one of the few studies that addresses these distributions, Roth (1995) examined an elementary school civil engineering class in which students shared ideas, materials, and tools to build wooden towers. Roth suggested that it was not only important for students to share resources, but also to set up the social and physical conditions that could promote the distribution of knowledge and resources. One of these conditions was that students be allowed to move freely throughout the room:

> ...moving about the classroom, talking to other students, or seeing different structures became important aspects of this classroom culture. Students moved freely throughout the classroom to pick up new materials, returned to their seats to pick up something from their desks, or crossed the classroom for a glue gun job. This movement brought them in contact with new ideas, problems, and solutions, or tool-related discourse practices. When they returned to their workstations, they often constructed solutions to problems that seemed intractable previously. Students did not necessarily intend to copy specific solutions, but to receive inspirations for new perspectives on their own problems (p. 499).

The study described in this article takes place in one of the most increasingly common classroom learning situations -- students in small-groups engaged in complex projects -- and examines the diffusion and appropriation of ideas between groups of learners. It foregrounds the social distribution of facts, concepts, ideas, and strategies across groups of learners and casts the non-social elements (materials, tools, artifacts) as objects to highlight interactions among learners.

Context of Study

Participants and Classroom Context

Ridgeview (pseudonym) is a public, suburban high school in the northwest United States, with an ethnic distribution of approximately 71% White, 20% Asian-American, and 9% African-American students. This study involved three ninth-grade physical science classes at Ridgeview. Each of these classes had 32 students; there are no honors sections at the ninth-grade level and all classes include special needs students. Each science class meets twice a week for 110 minutes and once a week for an additional 50 minutes.

The classrooms themselves are furnished with eight lab stations, located around the periphery of the room, and eight tables, also placed around the outside of the room for group work. For most activities, tools and materials were located on a table in the center of the room, and expensive instruments (e.g. gram scales) were kept on the teachers' bench in the front of the room. Students worked in groups of two or four, depending on the nature of the activity. Because the ninth-grade curriculum is entirely designed around group work, activity within the classrooms is highly decentralized. Students are free to move about the room at any time to get materials, visit with other groups, or talk with the teacher. The atmosphere in these classrooms is informal and open; students from other classes, teachers, and administrators routinely move through the rooms during classtime and converse with students as they work on projects.

The Science Program and the Teachers

This study of interactions among groups of learners was made possible, in part, by the unique combination of a design-based curriculum and a set of classroom norms that encouraged collaboration, inquisitiveness, persistence, and a spirit of discovery in the students. It is important, then, to describe the local origins of this curriculum and the motivations of the teachers involved.

The science program at Ridgeview High School is recognized by the school's administration and by the local community as being intellectually stimulating and highly effective. Students are also enthusiastic about science and subscribe in large numbers to all of the advanced classes offered in the program. The program, however, had not always enjoyed this level of widespread appeal. Ridgeview's science program underwent a significant metamorphosis four years previous to the study. Prior to that time, the program was highly traditional in that all courses emphasized the learning of factual knowledge through lectures and daily worksheets; this regimen was supplemented by a meager number of laboratory experiences that were largely confirmatory exercises for basic principles covered in lecture. Veterans of the current science faculty recalled that students were disengaged from science and retained little of what they learned.

When several science teachers left the school, those who remained, together with a group of newly hired science faculty, took the opportunity to reconceptualize the science program. Two new teachers, Allen and Robert (pseudonyms), were hired during this time and were instrumental in transforming the curriculum to its current state. Robert is a Ph.D. in biochemistry and had worked in a variety of settings including as a scientist for the Atomic Energy Commission, a college teacher, and a junior high school teacher. Allen had just graduated with a teaching certificate and also holds a wildlife management degree. He had been hired as a long-term substitute teacher at Ridgeview and had witnessed first-hand the shortcomings of the previous science program, remarking during an interview that: "it was basically worksheet after worksheet." The third teacher in this study, Hugh, worked as an engineer for several years before becoming a teacher. He was a 30-year veteran of education and was part of Ridgeview's science program before its transition. He, too, was discouraged by the previous science curriculum and methods of instruction, and commented on the instructional approach that dominated the program: "...the 'stand and deliver' method tends to bypass the brain, essentially going from the oral presentation through the student into the notebook...but not through the activity of learning what these ideas mean." A year previous to the development of the new science curriculum, Hugh attended a BSCS summer workshop where he had a chance to explore constructivist methods of teaching. This experience, together with the hiring of Allen and Robert, were the critical stimuli that began the transformation of the ninth-grade introductory physical science course at Ridgeview High School.

The revitalized science faculty focused their curriculum revision efforts on the ninth-grade introductory physical science course, reasoning that they could reach all students through this required course, that a positive science experience might encourage more students to enroll in advanced courses, and, that a more meaningful involvement with the study of science would better prepare students to participate in society as science-literate citizens. They decided to create a curriculum that would motivate students, engage them in authentic science and technology activities, encourage collaborative learning, and cultivate persistence in problem-solving.[1] They produced a set of twenty physical science activities, some of which emphasized design, such as creating a novel musical instrument and explaining the scientific principles behind it. Other activities were problem-based without conspicuous design components such as tracking down the source of pollutants in a stream. All activities were intended to last between one and four class periods (of 110 minutes each) and involved either designing a functional artifact that incorporated some principle of physical science or solving a complex problem (as in the world outside school, activities often involve both design and problem-solving; in many cases, the design of the artifact is the problem, such as creating a calorimeter or a weighing device).

Although the general goals of each of the activities were outlined by the teachers, students often had to re-frame the problem for themselves and deal with emerging layers of sub-problems. Students had to organize themselves, develop some shared conception of the activity, coordinate different components of the overall task among themselves, and monitor their progress on the way to achieving their goals. The five activities observed during this study were:

1) *Traffic Jam*, in which students designed and built a functional two-way traffic light that was operable using a single switch.

2) *Apollo*, in which students designed and used a set of tools that could retrieve a series of objects from successively challenging enclosures.

3) *Calorimeter*, in which students designed and built a functional calorimeter. They then used the calorimeter to test the energy value of food samples.

4) *Survey*, in which students created three hand-made tools and used them to survey a plot of land. Students then constructed a topographic map from their survey readings.

5) *Catapult*, in which students designed and built a catapult from a limited range of materials. The catapult had to incorporate two simple machines and accurately launch a projectile over a three-meter distance.

Figure 1 shows samples of student design drawings that were used to create products for each activity.

Because all activities in the curriculum required collaboration, inventiveness and persistence, the teachers encouraged four classroom norms.

1) Students were allowed, even invited, to move out of their assigned groups and interact with others in the room.

2) There were no sanctions against adapting ideas developed by others.

3) Unless specified, materials and tools brought from home could be applied to any problem.

4) Creativity in design and problem-solving was encouraged.

Teacher interactions with students were generally restricted to telling them where certain materials could be found or clarifying requirements of the task. Typically, students' questions were answered by return questions from the teacher, or, teachers would scaffold students' efforts by directing their attention to overlooked, key elements of the tasks.

Methodology

Data Collection

Because of this study's focus on distributed cognition during authentic design activities in classrooms, it was modeled on studies of cognition in everyday activities and studies in cognitive anthropology (e.g. Hutchins, 1995; Lave, 1988; Lynch, 1985). Five activities were observed over a period of five months. The system of activity was the focus of the investigation (Pea, 1993); this system included persons, environment, materials, tools, and student-created artifacts. Data collection procedures were directed at capturing events occurring between assigned groups of students. I based this decision on the assumption that reasoning as a socially structured and embodied activity is observable (Suchman & Trigg, 1993).

Because I did not know ahead of time what ideas, materials, etc., might be shared outside of the assigned groups or how this might occur, I had to make decisions for data collection as the activity occurred, collecting first-hand data rather than depending on retrospective accounts (Patton, 1987). Also, because it was impossible to observe an entire class, I selected for observation two groups of four students in each class, who sat at adjacent tables. In addition to noting within-group activities, every instance in which a member left their group to interact with other students was recorded, as well as instances in which members of other groups came to one of the two observed groups to interact. I followed up significant observations with informal interviews during class time. In this way, I constructed additional understandings that could not be derived on the basis of observations alone. In addition to the primary data sources of direct observations and informal interviews with students, other data sources included videotapes of design activity, interviews with teachers, class handouts, and student-created artifacts and tools.

To ensure credibility, certain research criteria were followed that are widely recognized by anthropologists, sociologists, and others who engage in fieldwork; these include prolonged engagement, persistent observation, peer debriefing, negative case analysis, and member checking (Guba & Lincoln, 1989). Debriefings with teachers were periodically held after classes or during their common lunch period to check my interpretations of the classtime experiences against theirs. Informal interviews were conducted *in situ* with students to allow me to test developing notions of how the students might be constructing their experiences. Because all sections of these ninth-grade classes used identical lesson plans, handouts, and materials, no systematic differences were expected between the classes. This assumption was borne out in the succeeding months of observation.

Data Analysis

Data analysis adhered to recommendations by theorists in the domains of interpretive research (Erickson, 1986). The goal of this analysis was to identify regularities in the way that participants utilized resources of the complex social and material world within which they operated (Jordan & Henderson, 1995). Because of the scarcity of classroom research in this area and the lack of existing theoretical frameworks for making sense of inter-group activity, I employed inductive analysis in searching for patterns rather than imposing pre-determined patterns on the data (Patton, 1987; 1990).

From the first month of class activity, case records of inter-group interactions were constructed from the field notes, interviews, and student-created artifacts. From the initial review of this data, patterns of social interactions and actions within the groups were developed. During the second review of the data, the emerging patterns were revised, and, after a third review, these interactions were placed into broad categories, referred to as *situations*, these included: 1) learners witnessing public events outside the scope of their own group's activity, 2) learners interacting while visiting each other's groups, and, 3) learners interacting while congregating in public spaces. Each of these situations served as backdrops for specific *events*. To clarify the organization of the developing taxonomy, I identified a *situation* as a set of relationships between students, peer, and place that represents the setting for the diffusion, appropriation, and/or adaptation of ideas. I identified an *event* as a specific interpersonal phenomenon that mediated the diffusion, appropriation, and/or adaptation of ideas by learners. All examples of events in this taxonomy occurred between students working in different groups.

During the next four months of class activities, I used the situation and event categories that emerged from the initial data to frame subsequent observations as well as develop a more elaborate taxonomy of inter-group events. In addition to developing this taxonomy, four working hypotheses about the nature of the inter-group activity in this particular environment were developed during the data collection. Evidence was sought on a continual basis to support or disconfirm these hypotheses. These hypotheses are stated in the form of assertions in the

Findings section and corroborating evidence for these assertions is offered from multiple data sources and instances of class activity (Denzin, 1978).

Findings

Using the Traffic Jam Activity to Develop an Inter-group Interaction Taxonomy

I begin this section with a detailed account of the first class activity by relating several specific inter-group phenomena that occurred. I further describe the emerging patterns that characterized these phenomena and framed observations of subsequent classroom action. Accounts from all five activities are then used to develop a taxonomy of inter-group interactions, complete with a variety of examples. Finally, I make four assertions about the nature of inter-group interactions in these classroom environments and the influence of the types of class projects on these interactions. These assertions include evidence gathered from all five activities.

The first project observed was called "Traffic Jam"-- it was the sixth activity of the year for the students. For a passing grade, students had to use a small assortment of materials (strings of holiday lights, cardboard, brass paper fasteners, paper clips, a nine-volt battery, tape, and wire) to design one parallel and one series circuit. For a higher grade, students had to complete the requirements for the passing grade and then design a system of three lights that would operate like a traffic signal, using a single switch to operate. For the highest grade, students were to build and operate a system of six lights: red, green, and yellow bulbs embedded on one face of an angled piece of cardboard, and another three lights embedded on a face at a 90-degree angle to the first side. This system had to model the operation of a two-way street light: when one side had the green light illuminated the other side would have red, then successive combinations of yellow/red, red/green, red/yellow, and finally back to green/red. This system also would have to be operated by the movement of a single switch.

I observed Hugh's class first. Hugh gave an introductory explanation that lasted only 10-15 minutes (as did the other two teachers), and it was the only time he formally addressed the entire class about the subject matter during the two-week activity. He also distributed a one-page handout, describing what tasks students would have to accomplish and how they would be assessed. Students could use textbooks in the back of the room, assorted materials on a table in the center of the room, and any materials they wanted to bring from home in order to complete the project. The groups of four students were required to draw out any circuits they wished to build. Before beginning, each student was required to answer seven questions from their textbooks on principles of electricity and circuits.

When Hugh finished describing the goals of the activity, students went into action immediately; some retrieved texts from the back of the room and began to answer the required questions while other members of their groups visited the table in the middle of the room and surveyed what materials were available to work with. After about 30 minutes, at least one member of each of the groups had answered the questions, and most groups were busy designing and assembling their series and parallel circuits. Some group members set to work stripping wire from holiday tree lights while others were drawing out designs and still others were assembling materials ahead of the design process. At this point, the classroom norms of informality and interaction became evident, and several inter-group interactions began to unfold.

Two girls and a boy, all from different groups, gathered around the materials table in the center of the room. As they worked together to disentangle the lights, they found many lights had wires that were too short to be spliced together to build circuits. One of the girls suggested that, rather than discarding the short-wire bulbs, they use them to test batteries to see if they held a charge. The other two students expressed surprise that batteries might need testing and observed the first student as she tested the bulb using a nine-volt battery. The practice of battery testing with short-wire bulbs was then transported back to three different tables. At one of the three tables, the practice later evolved into testing bulbs as well as batteries using a cross-checking system.

After about 30 minutes, all students at the two observed tables had left their seats at least once to either check out the materials table, ask the teacher a question, or interact with students at other tables. At one table, students were discussing how wires should be connected to bulbs when one of the group members, David, left to ask the teacher a question. As he stood behind another student waiting for his turn to speak to the teacher, he listened to the student ask the teacher if a paper clip could act as the switch for the circuits. David stepped in to join the teacher and the student in the conversation about the switch. After a few minutes in this conversation, David moved to the materials table to pick up a paper clip and a brass paper fastener. He returned to his table and announced: "We have the switch here." Up to this point, the subject of discussion and the object of intellectual effort in David's group had been the configuration of the wires and how they could be connected to the bulbs. The word "switch" had been used in the group, but how the switch was supposed to work and the implications of placing a switch somewhere in the network of wires had not been addressed. As David held out his hand with the paper clip and brass fastener, his gesture attracted the attention of a girl at an adjacent table. This girl approached David's table and asked, "What are these brass things for? What are you using the tape for?" David replied, "They're for the switches." At both David's table and the table adjacent to his, the task of fashioning switches out of paper clips and brass fasteners quickly became interdependent with the task of configuring the wires into circuits.

Later, as the teacher circulated around the room, two members of David's group overheard another remark by the teacher to students working in an adjacent group. Examining their circuit set-up the teacher commented, "Yup, you got it, one switch that controls all the combinations." The conversation at David's table immediately turned to the task of developing a single switch (rather than multiple switches) that could control the different light combinations throughout the steps in the traffic light sequence. After about 20 minutes, they had developed such a switch themselves.

This representative series of episodes encompasses only about 45 minutes of class activity, yet provides examples of three kinds of situations in which ideas and resources diffused between groups of students (Figure 2). In *Situation 1*, learners could witness public events outside their own group's conversation space (as David overheard a discussion about switches between the teacher and a student from another group). In this case, the teacher dialogue with a member of another group served to refocus the object of David's group's work (from wire configurations to switches). This was not a direct exchange between members of different groups, but rather an opportunity to learn by overhearing (witnessing) relevant conversations. After observing of all five student activities, *Situation 1*, represented the setting for not only (1a) overhearing dialogue between the teacher and members of other groups, but also for (1b) students seeing how materials were being used by other groups, (1c) students watching the developing practices of other groups, and, (1d) students seeing the successes and failures of "trial runs" by other groups (described later).

Another major setting for events that recurred in all the classes was that of students migrating to and interacting with other groups (*Situation 2*), as did the girl who visited David's table to learn about what materials were being used for switches. This situation was the setting for nine types of events including students (2a) bringing design drawings to another group to engage in dialogue about it, (2b) transforming the design plans or drawn representations of another group, (2c) borrowing tools and materials from another group, (2d) testing another group's tool or model, (2e) listening to deliberations of entire groups that have come to ask questions, (2f) asking for explanations and re-focusing another group's attention to overlooked aspects of their project, (2g) going to other groups and sharing specific problems they have encountered, (2h) introducing essential concepts into the working dialogue of another group, and, (2i) generating dialogue in other groups about how their activities relate to task goals.

In *Situation 3*, learners interacted while congregating in public spaces. This was exemplified by the students who met over the materials table in the center of the room. This interaction resulted in the diffusion of an "idea" resource (the notion that batteries might have to be tested for charge) as well as a practice (using the short-wire bulbs to test batteries and the use of tested batteries to then test bulbs). Over many observations, this situation was found to be the setting for three kinds of more specific events: (3a) students meeting in a materials area to discuss how different materials might be used, (3b) students meeting in areas where projects would be tested and discussing the challenges of the test, and, (3c) students gathering in areas where essential tools were stationed and discussing the affordances of these tools.

Over the course of the Traffic Jam project, I witnessed the same situations and their respective events in all three classrooms. Later observations of the other four activities in the ninth-grade curriculum confirmed the comprehensiveness of the event taxonomy outlined during the Traffic Jam activity. Observations of the Apollo, Calorimeter, Survey, and Catapult activities also added a rich array of examples for each of the event categories and revealed that some activities offered unique affordances and constraints on the type of knowledge diffusion that could take place in the classroom. I now offer four assertions that were developed during the study and substantiated by evidence collected from all five activities.

Assertion #1: Inter-group interactions were qualitatively different from interactions occurring within groups. At the outset of an activity, each observed student group embarked on a course of dialogue that included a unique mixture of conceptual vocabulary, attention to particular aspects of the problem, and the invocation of background knowledge of participants. These intra-group conversations eventually committed members of each group to a particular trajectory of action, driven by their consensual perception of the problem and range of possible solutions. In contrast to the increasing homogeneity of thought within groups, profoundly different approaches to problem-solving evolved between groups. The diversity of approaches adopted by different groups was the key underlying condition for interactions between groups that were not possible as intra-group phenomena. Four specific kinds of such inter-group interaction are described in the following paragraphs.

The first of these interactions involves members of a group being exposed to elements of problem solutions that were outside the bounds of the current thinking of the group. For example, students in Allen's class were asked to create a catapult from wood scraps, rubber bands, metal rods, other assorted items, and any materials they wished to bring from home. One group of students focused on the rubber bands as the propulsive force for one end of the catapult lever. As they developed and tested their prototype, they were dismayed at the lack of force it generated. One of the students in this group noticed a classmate at another table who had brought a large lead weight from home and was using it as a counterweight on one end of the catapult lever. This prototype had fewer working parts than the catapults designed with rubber bands, and this model proved to be both powerful and consistent in launching projectiles. The group using the rubber band model then made plans to adapt the idea of "counterweight as propulsive force" to their own prototype. Up to this point, the students in this group had focused their conversation on how to tighten the rubber band to generate more force and how to release the rubber band with greater consistency. The stimulus of the novel idea of "counterweight as force" altered their conversation, and, rather than copying the design of the students who had originated the counterweight idea, they successfully adapted the counterweight element into their design while keeping the rubber band as an additional propulsive force.

A note about imitation is necessary here. Students rarely copied the designs of others; they found the notion boring and unimaginative. They would, however, incorporate ideas from other groups into their own design or adapt novel ideas to suit their needs. The notion of diffusion and appropriation of ideas in these classrooms did not suggest imitation, but rather the processes of interpretation, adaptation, and evolution.

A second type of inter-group interaction that could not have taken place as intra-group phenomena involved witnessing public trials of products. Because groups were working at their own pace, some were ready to test their designs early, and these tests were often public events that drew the attention of classmates. Occasionally classmates witnessed "what worked", or at least saw that success was possible given the materials and information available. One example of this was the testing of calorimeters. Students were given access to a range of materials, including two soda cans, from which they were to build a calorimeter. After building their calorimeter, they were then to burn small samples of low-fat and regular potato chips in the lower half of the bottom can and measure the heat energy produced. Students in two groups designed and assembled theirs well in advance of the other groups and were ready to test. As they attempted to ignite their food samples, the rest of the class watched. Neither group could sustain combustion in their calorimeters and students in one of the observing groups, who were only in the initial stages of their design, surmised that the fuel was not getting enough oxygen. These students found a nail and used it to punch holes along the bottom of their own calorimeter. This strategy eventually proved successful and the hole-punching strategy spread rapidly throughout the room.

Public trials of students' designs, however, could not always be unambiguously interpreted as examples of success or failure. In Robert's class, members of one group were perplexed at the notion of "burning food". Their discussion indicated that they did not believe that food samples would bum, or what the purpose of burning food was. Later in the class period, a shout went up from across the room: "Dude! Bonfire!" All eyes turned toward a boy who was tending to a growing fire inside his calorimeter as smoke spewed out into the room. Although the object of the activity was to weigh out small fragments of chips, burn them in the calorimeter, and carefully measure the temperature increase in a water reservoir at the top of the device, this group of students had filled their calorimeter with dozens of chips and continued to dutifully stoke the fire. One boy from across the room shouted: "What'd you *do* man?" To which another boy replied: "He put in all the chips-- the regulars, not the diet." A third boy added: "It's the fat, man, we started fires in scouts with a bag of chips."

Burning all the chips at once was not a success in terms of measuring the energy value of different samples of food, but it was a dramatic demonstration that food is combustible and that high fat foods have comparatively high amounts of stored energy. After this public trial, the group of students who were originally unsure about whether one could burn food began conversations about food energy and what they could bring from home that might burn even more readily than the chips.

In addition to witnessing such public trials there was another circumstance that arose from student groups progressing at different rates-- students who were done early with their projects could circulate freely throughout the room. Some, although not all, of those students who finished ahead of others had picked up specific skills and strategies that they could apply or adapt to the efforts of other student groups. A boy and girl who were done early with their Traffic Jam project left their group and circulated around the room, explicitly tutoring other groups. The boy, Jared, carefully scaffolded another group's work by directing their attention to the switch and asking them to think about how it could conceivably control all of the red/yellow/green light combinations. He remarked "You get the switch to do that and then I'll come back", leaving them with a comprehensible piece of the larger task as he moved on to help another group of students. The girl, Alexa, moved to a group of three students who had jointly constructed a complex diagram of a six-light set-up. However, one member of the group, Deanne, commented that they had confused themselves by penciling in too many wires and that they could not make sense of what they had drawn.

> Alexa: Is that what you're working from? [pointing to the diagram]
>
> Deanne: Yea, we're lost. We got too many wires here.
>
> Alexa: Where's your first set of wires...[inaudible]...the ones that give you the first red and green?
>
> Deanne: [Attempts to locate wires in the center of the diagram] Ahhhh...they're here, no...these? [turns to look at one of her partners]
>
> Alexa: [After a few moments] Here, no, I see. [picks up a highlighter] I start at the battery [directs attention away from center of diagram by gesturing to the battery at the bottom of the diagram]...and go here. [traces the path of electricity from battery to the red bulb] So, where does the electricity go from here?...it has to have a continuing circuit, somehow, all the way back to the battery again.
>
> Deanne: We...it's connected to the next bulb, oh they'll both go on because the circuit is continuous...I see, we can't do that.

In this interaction, Alexa scaffolds Deanne's understanding by directing her attention to the battery as a place to start thinking about current flow, using the highlighter to focus on relevant aspects of the diagram and verbally reinforcing the notion that electricity must flow in an unbroken path to and from the battery.

Not all students who were done early with their projects were willing or able to share what they had learned with other groups and not all were as skillful as Alexa, but during the Traffic Jam project, three of the six groups observed had some positive interactions with individuals who were done early and offered to help others. These interventions were generally well-received by the groups getting assistance.

The fourth kind of event that was unique as an inter-group interaction was a group member being asked to explain a design by a visitor from another group. This happened frequently as curious students visited each other's groups and wanted to know how a design was intended to work. These interactions were particularly valuable to the host group because members were then compelled to make explicit the unstated assumptions used by the group to create their artifact. They often had to put in their own words the purpose of the design and then connect their work to the goals of the activity. Frequently a group would complete a project and show it off proudly to classmates, only to have members of other groups point out that they had not completed the full set of requirements for the task. This resulted in lively discussions between groups about what the goals of the project were and whether or not the artifact in question met those goals.

Assertion #2: The products of student work and the constructive processes leading to such products were significantly influenced by inter-group dynamics. From the observations described in the previous section, this notion seems well-supported. Throughout the observations of the six groups of students working through five different projects, there was not a single case where a group worked as intellectual isolates from the other students in the room. Although not every kind of interaction between members of different groups was qualitatively different from interactions that took place within groups, inter-group phenomena produced a far greater volume of ideas for diffusion than could have been the case within a single group. Conceivably, every group in a room could have benefited from any other group that constructed a problem in a unique way, demonstrated what solution paths were not feasible, or used a tool, material, or concept in a novel way.

Not all group interactions, however, were positive influences on student work; there were at least two negative case examples. For the calorimeter activity, each group was given an assortment of materials which included (among other items) two soft drink cans and a small steel container (the size of a tuna can) in which to dispose of burnt matches. One group of students in Hugh's class thought that the steel container was supposed to be part of the calorimeter itself. They discarded the second soft drink can and attempted with great difficulty to cut through the smaller can with a tin shears. This practice occurred in only one of three classrooms, but, in that classroom, the practice spread rapidly and prevented any progress from occurring for about an hour. The smaller can was too thick to be cut easily with the tin shears, and, when joined with the soft drink can, it formed a chamber that was too small to burn food samples. I took this opportunity to ask the teacher (Hugh) what he did in cases where there was widespread diffusion of an idea that created an intractable problem. He replied:

> I let them flounder, this happens a lot. Somebody will figure it out sooner or later, I just don't want to tell 'em. You know, when one of them gets it, it's like a crystal dropped into a supercooled liquid--Whoooomp! [gestures outward with arms] Everything crystallizes.

Near the end of this class one group did experience a breakthrough (using the second can as the bottom of the calorimeter) and this practice was readily adopted by the other groups.

A second negative case example happened during the Traffic Jam activity. While conversing with a group of students, a visiting girl simply copied the circuit diagram of the host group without engaging in dialogue about what the diagram meant. She then returned to her own table with the diagram. Thirty minutes later her group called the teacher over to show their diagram and demonstrate their setup. The diagram and the lights on the front of the cardboard panel itself were configured exactly as the other group's had been but when the teacher tried to light the bulbs, nothing happened. Surprised, the teacher turned the cardboard facing over to find that, although the drawing was accurate, the model was mostly a facade-- there were only a couple of wires haphazardly connected to bulbs behind the cardboard panel.

There were, then, both significant positive and negative influences of inter-group interactions on the design and development of artifacts in these classrooms. The majority of interactions, however, did result in positive learning experiences.

Assertion #3: Different types of tasks afforded different types of interactions. Opportunities to learn from the ideas, successes, or failures of other groups was an emergent property of the learning tasks. The Traffic Jam task, for example, did not generate circumstances in which students could easily learn from witnessing public "trial runs." Students could see that set-ups of other groups worked (that the lights were activated in a particular sequence by a single switch) but the wiring behind the cardboard was hidden and provided few clues to the success of the set-up. Even when made visible, the wiring connections were too complex to be understood from a brief public display.

Other projects provided many more opportunities for students to learn from public trial runs of their peers (as in the previously described calorimeter example). In the Apollo activity, students were asked to create tools that could extract a series of small objects (e.g. a nut, ball bearing, ball bearing from inside a capped jar) from a box with a six-inch by six-inch opening cut in the top. This activity was preceded by the viewing of a videotape of the Apollo 13 space mission in which the astronauts had to fashion a carbon dioxide filter from a small assortment of materials on the ship. Likewise, the students were allowed only a small number of items (rubber band, clothespin, gumball, string, wood splints, straws, tape) to construct their extraction tools. Three boxes were placed on tables in the center of the room, each with different objects inside.

The particular set up of this activity afforded several specific inter-group events. Because there was a public space for testing the constructed artifacts (the extraction tools), and, the successful design of the tool was clearly indicated by its ability to extract the target objects, all groups could witness the success or failure of trials by other groups. One girl, whose group had succeeded very quickly at retrieving both the nut and the ball bearing simply by chewing their gumball and placing the gum on the end of a wood splint, tried the same technique with the glass jar. Several members from other groups gathered around to watch this group that had advanced quickly to the most difficult box. The girl tried to lift the jar with the gum, however the jar crashed to the bottom of the box several times in a row, confirming to the others that an alternative had to be found for lifting this ungainly object. Twelve different kinds of tools were eventually created in this particular classroom to extract objects from the boxes.

In contrast to the Apollo activity, the surveying activity provided the least opportunity for the public display of ideas-in-action. The task was not to build a functioning artifact, but rather, to engage in the practice of surveying and then create a symbolic representation (topographical map) of the area surveyed (the school grounds). Not only were there no public trials that could be observed, there were few opportunities for members of groups to visit other groups. During surveying, each of the three members of a group had to use a different surveying instrument in coordination with one another and the fourth member of the group acted as a recorder. One person looked out over a device with a built-in level and directed a second person with a pole marked in centimeter increments to move backwards until an index mark on the pole was 30 centimeters higher than the leveling instrument. A third group member then used a wheel to measure the distance between the two students. This procedure reduced the possibility for student migration between groups, and inter-group interaction was restricted to direct observation of the developing practices of other groups. However, the practices of other groups could not be ascertained as “correct” by mere observation-- there were no unambiguous indicators of successful practice to emulate.

Of the five activities observed, the surveying activity resulted in the least successful student products overall. Students had difficulty establishing systematic procedures to collect valid elevation data and had trouble making sense of how their data could be re-presented in a topographic map. One of the classes at the end of the project had only two completed maps from eight groups of students.

Assertion #4: Students are capable of engaging in complex activities and creating authentic products with little or no intervention from the teacher. The average amount of direct instruction from each of the three teachers was about fifteen minutes per activity (these activities lasted one to two weeks). The role of the teacher was rarely to tell, rather, it was to provide a challenge that would focus the efforts of the students and to furnish an environment in which there were few restrictions in exploring solutions to these challenges. Robert, Allen, and Hugh occasionally engaged in Socratic dialogue with students to focus their attention on important aspects of the task; when students asked them a question, they usually replied with their own question to refocus the student's attention on critical aspects of the task rather than giving out information or ideas.

Students exhibited remarkable initiative in locating information resources, materials, and tools, and discussing with each other their plan of attack on problems at hand. Teachers reported that it typically took the first six weeks of the school year for students to realize that they were entirely responsible for their own learning and that they had to gather their own background information to develop problem solutions. Throughout the year, students were quite successful in most of the projects. By the end of the Traffic Jam project, 14 of 24 student groups in the three classes had created functional, six-light traffic signals that were operated by a single switch. One student group produced a detailed, wooden scale model of a traffic intersection which included four separate two-way lights suspended from poles-- all operable with a single switch. In the calorimeter activity, all students in one classroom were able to construct a functioning calorimeter and measure the energy in a variety of food samples. In the catapult lab, all the observed groups created a functioning catapult; one group of students constructed a catapult out of wood scraps, screws, a rubber band, and a spoon, and calibrated it accurately enough to launch eight marshmallows in a row into an eight inch diameter bucket from a distance of three meters.

These activities took time, but they resulted in high degrees of participation as students produced complex functional models and other artifacts with almost no intervention by the teachers. Throughout the observation period, students showed high degrees of initiative, persistence and willingness to risk new approaches to solving problems. These findings are consistent with those from other constructivist learning environments (Duckworth, 1978).

Discussion

This study was made possible by the activity-oriented curriculum, the classroom norms of informality, and the reinforcement of the values of discovery, collaboration, and persistence. Such a wide variety of opportunities to learn from other students emerges only in the context of personal mobility and communication, and, even within this context, different types of tasks afforded different kinds of interactions among learners.

The taxonomy for inter-group interactions presented in Figure 2 is an effort to begin to understand the mechanisms of knowledge diffusion in a classroom by categorizing events in which members of a group are influenced by others outside the group. From the description of events in the taxonomy, one could say that certain entities were shared between groups such as tools, materials, strategies, and ideas. However, "diffusion" breaks down as metaphor when one notes that several events in the taxonomy do stimulate learning but do not involve any sense of the movement of ideas. For example, in some cases, individuals ask members of other groups provocative questions that these group members had never asked themselves, challenging these group members to make ideas explicit that had only existed as implicit or vague assumptions and had never been clearly articulated within the conversation of the group (events 2f and 2i in the taxonomy). These were transactions in which the student asking the initial question was receiving information in the form of a reply, but the group members being queried were not simply dispensing an answer. Rather, they were prompted to revisit their original plans, question their assumptions, and link decisions they made in designing their artifact with the goals of the task.

Many of the transactions listed in the taxonomy represent activities known to foster learning. Among these kinds of transactions noted between groups were: students tutoring others, students receiving just-in-time help from other students who were willing to tutor, being asked to explain a model to someone else, comparing one's own model with another, and transferring design experience to the design practice of another group (Barnes & Todd, 1977; Cobb, 1991; Voight, 1985). These conditions do not merely represent "exposure" to or "acquisition" of a number of ideas passed around the room, they are transactions among learners in which ideas are co-constructed, defended, discarded, or adapted until they are reified as an artifact of value.

From Roth's studies of work among young learners in engineering classrooms (1998), he has suggested conditions "that favor the collective transformation of resources and practices", which may be the most appropriate way to interpret and apply findings from this study. Among Roth's conditions are: students interacting with others by moving about, students interacting with others by meeting with them in areas of high pupil-density, and students interacting over artifacts of their own design so that resources and practices are highly desirable in the pursuit of goals (p. 281). His suggestions were derived from observing classroom situations and interpersonal phenomena similar to those in the present study. He describes situations similar to those found in this study, for example, how areas of congregation in a classroom influenced student interaction patterns and the opportunities to learn from one another:

> ...high density areas are likely places where exchanges (the basis for knowledge transformation of the collective) are likely to occur. I observed a lot of shared knowledge around the grade 5 table, the material storage area, and around the electrical outlets where the glue guns accumulated. Other moments of high pupil density occurred when the whole class came together to talk about, celebrate, and praise specific projects. In all these situations, students had opportunities to engage with the processes and products of other students' work (p. 499).

The data from the present study substantiate that these conditions do encourage positive interactions among individuals and provide opportunities for unique learning transactions when members of different groups interact. The data from this study also warrants reframing

Roth's conditions, adding conditions that address the nature of the students' tasks and describing the climate of the classroom as well. Incorporating findings from the current study, these are the conditions that appear to favor the collective transformation of resources and practices:

1) The task involves the development of a complex physical artifact whose function can be appreciated and made apprehensible by the classroom public.
2) Student groups work on projects with similar goals so that the exchange of tools, materials, information and ideas is accommodated and groups can build on one another's ideas.
3) Student groups interact over artifacts of their own design so that resources and practices are highly desirable in the pursuit of goals.
4) Students have ample time to risk new ways of doing things, to engage in dialogue with others and to refine or reconceptualize their projects.
5) Students are allowed to test or display their artifacts whenever they are ready.
6) Students are allowed to interact with others while moving about the room or congregating in areas where tool, material, or information resources are located.

Note that these are framed as conditions rather than pedagogical prescriptions. They are not sufficient, in and of themselves, to design environments for learning science. However, data from this study do suggest that certain specific classroom activities may be appropriate, particularly within a design-oriented curriculum. For example, students should be required to periodically explain, using scientific principles, why an artifact is designed in a particular way. Student talk during the observed activities in this study often focused on "what worked" rather than on how scientific or mathematical principles could be invoked to accomplish a task. Students who were working on the circuit set-ups in the Traffic Jam activity generally operated on an intuitive basis to see if certain patterns of wiring would make the desired bulbs light. Many groups successfully identified patterns of wiring that "worked" and systematically reproduced these patterns to accomplish the three- or six-light set-up. However, few of these students mentioned the word "circuit", or used the concept of "complete circuit" to communicate with others about why certain set-ups worked and others did not.

In a related example with the catapult project, every group in one classroom built catapults which successfully incorporated simple machines in their design. When I asked students what class of lever was employed in their catapults and how they determined their answer, only four of eight groups in one classroom had sufficient explanations. When asked what would happen if the fulcrum were moved closer to the force and why, only one group of students had a cogent explanation. The teachers in these classes did require public exhibition of the students' artifacts and explanations to the class of how they functioned. Students, however, tended to use "what worked" as a way to build their artifact and then scrutinize the final version of it for its underlying scientific principles in order to prepare for the formal class presentation.

Conclusions

Educational theory helps us explain and predict phenomena of interest, but on a more practical level, it helps us to pay attention to certain things in our environment. This study draws our attention to some very common, yet overlooked events in classrooms-- interactions among groups of learners in a dynamic, activity-oriented curriculum. This kind of description is a necessary first step in developing explanatory frameworks for how groups interact, and for eventually regulating this type of activity for productive purposes in classrooms.

Unfortunately, a focus on the distributed nature of cognitive activity in classrooms is rare in educational research. The common assumption of solo intelligence as a central goal of education guides the investigation of learning, the cultivation of individuals' mental abilities, and the design of classroom instruction, with relative disregard for the social, physical, and artifactual surroundings in which these activities take place (Pea, 1993).

Despite this emphasis on individual thinking, many educators realize that students learn well in collaborative settings and that the most expedient, manageable way to organize collaborative work is to assign students to small groups and to have these groups work on complex projects with a similar focus but with multiple avenues to success. Although it takes a great deal of pedagogical skill to design an activity that is neither a cookbook exercise nor a conceptual free-for-all, many teachers like those at Ridgeview have met this challenge and have created activities that set the stage for intra- and inter-group interactions to increase opportunities for learning.

There were implications in this study for the roles of teachers as well as students. Interestingly, much of the impact of the curriculum described in this study came from what the teachers *did not do*. In the traditional classroom, it is the teacher who selects and organizes resource material, constructs explanations, answers questions and regulates how time is spent. In the classrooms at Ridgeview High School, the students were in charge of these intellectual activities and the teachers adopted roles as provocateurs and managers of opportunity-- not as the hubs of authoritative discourse.[2]

This study has not only provided a taxonomy for inter-group interactions but has provided evidence that inter-group dynamics are qualitatively different from intra-group dynamics, and, that the products of student work and the constructive processes leading to such products are significantly influenced by these inter-group dynamics. This study also provided examples of how different types of tasks stimulate and constrain different types of interactions. And finally, this study clearly demonstrates that students are capable of engaging in complex activities and creating authentic products with minimal intervention from the teacher.

These findings notwithstanding, it remains a challenge to find the particular alchemy of tasks, classroom conditions, and social norms that result in the optimal conditions for knowledge-building in collaborative settings.

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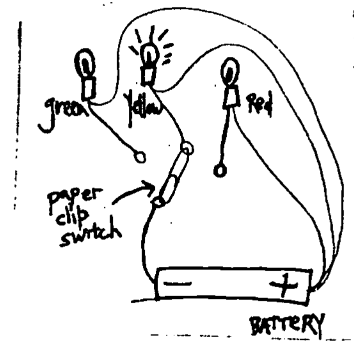
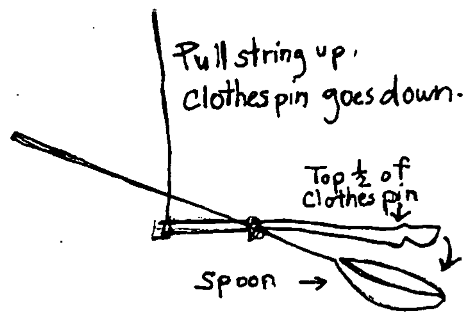
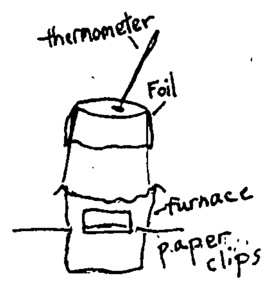
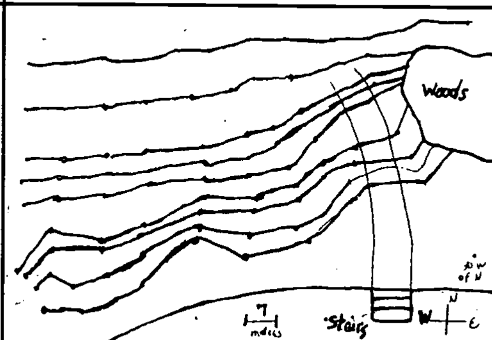
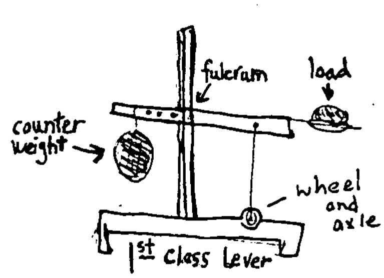
Footnotes

[1] Some of these projects were earmarked for end-of-quarter evaluation. These often combined two or more previous activities into week-long problem-solving tasks that students worked on in groups. One such assessment combined a previous activity in topography with another activity on detecting chemicals in water. Students were given a (fictional) report that toxic chemicals had been found in a local town's drinking water and that there were several suspect industries in another part of the state that may have leaked these chemicals into rivers. Students were given water samples from major streams in the area where each industry was located and asked to find the violator (s). Through a series of cross-checking tests (using multiple chemical reaction tests and combinatorial logic), students determined what chemicals were present in each water sample. They then had to use topographic maps to determine the drainage basin for each river and ascertain which industry could have contributed to the specific type of pollution at a site many miles away. Finally, students had to write a letter to the state commissioner of environmental health, asserting their claims of pollution, the methods by which they tested their claims, and the reasoning they used to identify the violators.

[2] Designing this kind of curriculum requires collaboration among teachers not unlike that expected of students. At Ridgeview, the seven science teachers agree on a list of activities for each semester. As the semester progresses, a sub-group of three teachers prepares the specifics of each upcoming activity, drawing on each other's expertise and the record of how the activity transpired the previous year. The teachers spend a great deal of time fine-tuning the task itself; they scrutinize the activity for its capacity to bring groups of students together over a complex problem, to present different levels of challenge within the activity, to elicit a variety of skills and talents from students, and to engage the students in the creation of some valuable artifact. This sub-group of three teachers then meets with the larger group of seven teachers and presents the activity structures, after which, the entire group offers refinements to the proposed activity. Because all the teachers use the same lesson plan, they can pool their intellectual and

experiential resources in developing a robust learning experience for students, they can use the same resources in their rooms, and, they can suggest alterations in the activity to their colleagues as early as mid-morning of the first day it is used with students. For example, in the Traffic Jam and Apollo projects, students were succeeding at the activities too quickly and new levels of challenges were added to the basic lesson plan by the middle of the first morning.

Also, the common practice of teachers moving freely through each other's rooms allow them to see first-hand how students are reacting to the activity that they have yet to present to their own students. In sum, the faculty were as collaborative in designing the curriculum as the students were in executing it.

Name of project	Description of project	Representative student designs
Traffic Jam	Design and build a functional, two-way traffic light, operable using a single switch.	
Apollo	Design, build, and use a set of tools that can retrieve a series of objects from successively more challenging enclosures.	
Calorimeter	Design and build a functional calorimeter; use it to measure energy in food samples.	
Survey	Build three measurement tools; use them to survey a plot of land; construct a topographic map from survey readings.	
Catapult	Design and build a catapult from a limited range of materials; incorporate two simple machines into the design.	

1. Learners witness public events outside the scope of their own group's activity	**Examples**
1a. Students overhear dialogue between teacher and other groups.	1a. Students re-focus efforts towards making a single switch after overhearing teacher's comment to other group: "Yup, you got it, one switch that controls all the light combinations." (Traffic Jam)
1b. Students see how materials are being used by other groups.	1b. Students see other groups of students using foil to form a reservoir for holding water above a calorimeter. (Calorimeter)
1c. Students watch developing practices other groups.	1c. Students observe members of another group coordinate their use of four different surveying tools. (Survey)
1d. Students see successes and failures of "trial runs" by other groups.	1d. Students see classmates who finished early transform topographical map into a 3-D cardboard model, but mistakenly translates horizontal measures from map into vertical features on 3-D model. (Survey)
2. Learners interact when visiting each others groups	**Examples**
2a. Students bring design drawings to another group; engage in dialogue about it.	2a. Student shares diagram with another group, shows how his counterweight rather than rubber bands provide force for his catapult. (Catapult)
2b. Students transform design plans or drawn representations of another group.	2b. Student comes to a group and traces over part of their circuit drawing to illustrate the possible path of electricity. (Traffic Jam)
2c. Students borrow tools and materials from one another.	2c. Students who created measuring wheel which was too small in diameter borrow another group's wheel. (Survey)
2d. Students test another group's tool or model.	2d. While one group is away from their table, another group examines their retrieval tool and practices using it. (Apollo)
2e. Students listen to deliberations of entire groups that have come to ask questions.	2e. One group visits another to ask how they incorporated two simple machines into their catapult. Visiting group deliberates about different classes of levers which is overheard by the visited group. (Catapult)
2f. Students visit other groups; they ask for explanations and re-focus group's attention to overlooked aspects of their project.	2f. Student sees group weighing out food samples before burning them in calorimeter and asks about this. Group members have not discussed this, require several minutes to jointly construct reason for weighing samples. (Calorimeter)
2g. Students go to other groups and share specific problems they have encountered.	2g. Excited about successfully trouble-shooting his traffic-light model, a student brings his set-up to another group to explain what the problem was and how he diagnosed it. (Traffic Jam)
2h. Students introduce essential concepts into the working dialogue of another group.	2h. On the school grounds a student approaches a group finishing their surveying, and asks what they used for a "benchmark". Discussion is generated about what a benchmark is and why one is necessary. (Survey)
2i. Students generate dialogue about how activities of other groups relate to task goals.	2i. Student observes a group celebrating success in getting measurable amount of heat from burning food samples. Student claims "You aren't done yet" and claims they need to measure heat per unit mass. This generates discussion about goals of the activity. (Calorimeter)
3. Learners interact while congregating in public spaces	**Examples**
3a. Students from different groups meet around materials table to discuss available resources and how they can be used.	3a. Students from different groups disentangle strings of lights, find some too short to be useful in circuits. Student suggests that rather than discarding, they can be used to test batteries to see if charged. (Traffic Jam)
3b. Students from different groups meet in areas where projects will be tested and discuss challenges.	3b. Students from different groups examine the boxes from which they must retrieve small objects. They share observations about the challenge, and suggest ideas for the design of retrieval tools. (Apollo)
3c. Students from different groups gather in areas where essential tools must remain. Conversation focuses on the affordances of these tools.	3c. Students gather as they wait to use the drill press; they share ideas about how the holes create the possibility of moveable "arms" for the catapult. (Catapult)

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