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Managing Uncertainty in Collaborative Robotics Engineering Projects: The Influence of Task Structure and Peer Interaction

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Managing Uncertainty in Collaborative Robotics Engineering Projects: The Influence of Task Structure and Peer Interaction

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Uncertainty is ubiquitous in life, and learning is an activity particularly likely to be fraught with uncertainty. Previous research suggests that students and teachers struggle in their attempts to manage the psychological experience of uncertainty and that students often fail to experience uncertainty when uncertainty may be warranted. Yet, few educational researchers have explicitly and systematically observed what students do, their behaviors and strategies, as they attempt to manage the uncertainty they experience during academic tasks.

In this study I investigated how students in one fifth grade class managed uncertainty they experienced while engaged in collaborative robotics engineering projects, focusing particularly on how uncertainty management was influenced by task structure and students' interactions with their peer collaborators. The study was initiated at the beginning of instruction related to robotics engineering and preceded through the completion of several long-term collaborative robotics projects, one of which was a design project. I relied primarily on naturalistic observation of group sessions, semi-structured interviews, and collection of artifacts. My data analysis was inductive and interpretive, using qualitative discourse analysis techniques and methods of grounded theory. Three theoretical frameworks influenced the conception and design of this study: community of practice, distributed cognition, and complex adaptive systems theory.

Uncertainty was a pervasive experience for the students collaborating in this instructional context. Students experienced uncertainty related to the project activity and uncertainty related to the social system as they collaborated to fulfill the requirements of their robotics engineering projects. They managed their uncertainty through a diverse set of tactics for reducing, ignoring, maintaining, and increasing uncertainty. Students experienced uncertainty from more different sources and used more and different types of uncertainty management strategies in the less structured task setting than in the more structured task setting. Peer interaction was influential because students relied on supportive social response to enact most of their uncertainty management strategies. When students could not garner socially supportive response from their peers, their options for managing uncertainty were greatly reduced.

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CHAPTER 1

INTRODUCTION

"Doubt is not a pleasant state, but certainty is a ridiculous one."
-Voltaire

This research addresses learning in the academic context of instruction in robotics engineering that occurred in a fifth grade classroom. Among other things, academic contexts consist of tasks structured in particular ways and of interactions among individuals who each come with particular histories and practices. I argue that learning in academic contexts necessarily involves experiencing psychological uncertainty and that the ways students manage the uncertainty they experience while engaging in academic tasks influences their learning from those tasks. Although undoubtedly many interdependent factors influence students' experience of uncertainty and management of uncertainty in different academic contexts, in this study I focused on the structure of academic tasks and interaction with group members as potentially important variables influencing students' uncertainty management as they collaborated to reach academic goals.

As of yet, the psychological experience of uncertainty and how students respond to and manage that experience have received little attention in the educational literature. The small body of empirical research that has explicitly addressed uncertainty management in academic contexts has largely done so using survey approaches and focused on between-person differences in what are assumed to be fairly stable orientations to uncertainty (Sorrentino & Roney, 2000) or tolerance for particular forms of uncertainty such as ambiguity (Levitt, 1953). Few researchers have directly observed what students do, their behaviors and strategies, as they attempt to manage the psychological uncertainty they experience during academic tasks, although there are some notable exceptions (see for example Metz, 2004; Rowland; 2000; Sieber, 1974).

No cohesive body of literature exists on specific strategies students use to manage the uncertainty they experience during academic tasks. However, we do know from previous research that academic tasks vary in how much uncertainty they are likely to induce in students (Doyle & Carter, 1984). I elected to conduct this study in a robotics engineering instructional context because the projects assigned in this context had many of the qualities that have been identified as tending to elicit uncertainty from students. We also know that children as young as second grade can recognize their own uncertainty (Metz, 2004). Students across ages have been observed to reduce uncertainty as quickly as possible (Doyle & Carter, 1984) or to fail to become uncertain when uncertainty would likely facilitate their learning (Sieber, 1969).

Why Uncertainty

It seems important to increase our understanding of how students manage uncertainty during academic tasks for at least two reasons: (1) uncertainty is endemic to learning, and (2) uncertainty is ubiquitous in life.

Uncertainty is Endemic to Learning

Learning tasks are fraught with uncertainty associated with encountering new semiotic systems and complex practices in contexts ranging from learning to read and write a first language, to acquiring a second language, to understanding math and science concepts, to manipulating technological and digital literacies. So too, academic settings are places where uncertainty is likely to stem from social issues as students encounter unfamiliar sociocultural practices and as individuals with diverse histories, beliefs, motivations, expectations, and values attempt to share the small space of a classroom. Students may be especially likely to experience uncertainty when they are expected to collaborate with peers to accomplish an academic task.

We often think of learning as an equilibrium-seeking endeavor, a process of going from a state of not knowing to a state of knowing as quickly as possible or from uncertainty to certainty. However, a model of learning as a process of moving between two dichotomous states does not match descriptions students often give of their own learning as a clearing of the fog, or a fuzzy picture coming slowly into focus. I argue that students likely spend much of their time in many learning situations in between not knowing and knowing, experiencing varying degrees of uncertainty. If uncertainty is a pervasive experience in learning contexts, then it behooves us to try to understand learners' responses to this experience.

Although learning is often portrayed as a process of reducing uncertainty, researchers have long recognized that learning requires not only the cultivation of knowledge or skills, but also the cultivation of uncertainty (Bereiter & Scardamalia, 1993a; Piaget, 1972; Sieber, 1969). Piaget (1972) described learning as resulting from a process of disequilibration. In this trajectory, learning proceeds by a learner moving from one state of clarity to a new state of clarity; the move is catalyzed by disequilibrium. It is this experience of uncertainty that pushes us towards scheme reorganization, or in other words, prompts us to learn.

Beyond an initial disruption needed to get students to loosen up their hold on old ideas and accept a new idea, the benefits of increasing uncertainty are seldom considered, nor the potential benefits of *conserving uncertainty*, of remaining in a state of disequilibrium. I argue that increasing uncertainty may at times be an appropriate academic end-goal rather than complete understanding and certainty. Thus, learning may take the form of moving a learner from a sense of clarity, coherence, and closure, to a state of confusion, wonderment, and uncertainty. For instance, expertise can be seen as a process of investing in progressive problem solving, and experts as individuals always seeking the edge of their knowledge, where uncertainty resides, rather than resting in full knowledge (Bereiter & Scardamalia, 1993a). Furthermore, expertise in fields such as architectural and engineering design and academic research require the ability continually to live with or even seek out uncertainty in order to learn and innovate.

That uncertainty is endemic to learning is no small thing, as uncertainty is often a difficult and stressful cognitive feeling to manage. Although uncertainty can induce a host of positive emotions and cognitive benefits, uncertainty is often accompanied by negative affective responses, and individuals often find it difficult to manage uncertainty effectively. For this reason, and because uncertainty is likely to be pervasive in learning contexts, the ways students manage their uncertainty will likely affect their ability to engage successfully in academic tasks.

Uncertainty is Ubiquitous

The 20th century brought new understandings of the meaning of uncertainty in the world and in the lives of individuals. Scientists have increasingly come to recognize sources of uncertainty that arise due to fundamental unknowability in many of the systems of which we are a part and in which we live. For example, the discovery of chaotic dynamics in systems such as weather patterns, population levels, and cardiac rhythms has led us to realize that even completely deterministic systems can have inherently uncertain dynamics over long timescales (Liebovitch, 1998). Quantum physicists have come to appreciate the impossibility of complete and accurate knowledge about all aspects of a particle; increasing measurement precision of momentum causes one to become less certain of position (Bohm, 2002). These new understandings of the natural world crushed the hope of completely eradicating uncertainty in predictions of an unfolding future (Prigogine & Stengers, 1997). Furthermore, postmodernist philosophers have called into question the certainty of any one "totalizing" theory being the correct and final interpretation of an ambiguous world, claiming that we live in an increasingly fragmentary, complex, and hypertextual world requiring interpenetrated and imbricated thought processes and interactions (Giddens, 1991).

In short, the 20th century ended with the conclusion that the only thing we can be certain about in the 21st century is that we are stuck with uncertainty. The issue is not simply that we do not know completely; it is that sometimes we cannot know completely. Because our world unfolds unpredictably, we are likely to experience uncertainty about what events will occur, why events occur, how we should respond, or even what are our response options. At least some of the psychological uncertainty we experience cannot simply be reduced but must be responded to, or managed, in a variety of ways.

Learning to Manage Uncertainty: A Role for Schools

If we accept that the personal, subjective, psychological experience of uncertainty in human life is ubiquitous, multi-faceted, and inescapable and that uncertainty is endemic to learning, then the ability of individuals to manage the psychological experience of uncertainty becomes important. I submit that few psychological experiences are more prevalent during academic tasks than that of uncertainty and that few skills are more needed in 21st century societies than the ability to manage uncertainty in a wide range of circumstances and contexts. Several programs of research have examined implicitly or explicitly the role of momentary "cognitive feelings" of uncertainty as cues for deciding how well one understands something and as important input to various judgment and decision making (see Clore, 1992) and sensemaking processes (Weick, 1995). The way individuals manage uncertainty will in part delimit the decisions they make and the sense they make of their world, of their lives, and of their academic experiences. Yet, research has revealed that uncertainty can be a difficult experience to manage. For these reasons, it seems critical that educators and educational researchers increase their understanding of how students manage uncertainty in academic contexts.

One of the purposes of schooling should be to enable participation in a complex world where uncertainty and ambiguity are the norm and where change is common. Uncertainty is likely an especially frequent experience in academic settings as students struggle to learn new knowledge and skills and come to new understandings. Some researchers have asserted that schools do not adequately teach students how to manage uncertainty or only teach them to approach uncertainty in limited ways (Beyth-marom & Dekel, 1983; Beyth-marom, Novik, & Sloan, 1987; Langer, 1997; Metz, 2004; Verhoeven, 1967). Students are usually taught to “regard problems as having clear and determinate solutions and to look to others for the answers” (Sieber, Clark, Smith & Sanders, 1978, p. 2). Teachers fall into routines of asking known-answer questions and rewarding specific right answers. Students engage in a guessing game about what the teacher expects (Kennedy, 2005). Students themselves ask few questions (Nystrand, Wu, & Gamoran, 2003). As Sieber et al. (1978) noted, “The result of this regimen is as one might expect: when questioned about problematic matters, students usually give simple, dogmatic answers” (p. 2).

Schools primarily afford students learning opportunities through the creation and implementation of academic tasks. Academic tasks vary in the opportunities they present to help students learn to manage different amounts and types of uncertainty stemming from various sources (Doyle & Carter, 1984). Academic tasks that are rich in terms of affording students opportunities to experience multiple forms of uncertainty and to learn to manage uncertainty may also be the hardest to implement in classrooms (Doyle, 1988). Previous research suggests that teachers and students struggle in their efforts to manage uncertainty in classroom settings (Doyle & Carter, 1984; Baker-Sennett, Matusov, & Rogoff, 2008; Rohrkemper & Corno, 1988). Teachers’ propensity to reduce uncertainty may impede students’ attempts to make sense of school environments and of the open and confusing contexts in which they live (Graff, 2003). If most academic tasks with which students are asked to engage induce only low levels of uncertainty, then students may not be getting the practice necessary to learn to manage uncertainty successfully in the ill-defined and less structured tasks they are likely to encounter throughout life.

The collaborative robotics engineering projects observed in this study were purposefully selected as academic tasks likely to induce uncertainty in students. The partial knowledge and understanding students have about new content, the intractable ambiguity associated with creative endeavors, and the negotiation of social roles, responsibilities, and positions all require uncertainty management during engineering design tasks. Examples of such uncertainty include “Is this a good design?” “What do my group members think of my idea” “What grade am I likely to get?” “How well do I understand this?” “How good am I at building robots?” Also, robotics engineering tasks are made up of several subtasks, and students’ strategies for managing uncertainty may change across time. Moreover, complications abound in such academic contexts because these multiple contingencies are interdependent (e.g., knowledge of content constrains creative options; uncertainty about interpersonal relationships within a group inhibits creativity). Thus, this seemed an opportune context in which to observe students managing uncertainty in conjunction with their peers.

Defining Uncertainty and Uncertainty Management

For the purposes of this research, I define uncertainty as a personal, psychological, subjective experience of doubting, being unsure, or wondering about how the future will unfold, what the present means, or how to interpret the past. Individuals can be uncertain about themselves, other people, the possible consequences of actions, along with a host of other aspects of their environment. Uncertainty exists when…

Individuals are unsure about their knowledge.

Individuals are unsure about their understanding.

Individuals are ambivalent about their choices, preferences, or values.

Individuals perceive that they have incomplete, contradictory, or ambiguous information. Individuals perceive that they cannot predict the outcomes of their behaviors.

Individuals mistrust the information and/or knowledge they have.

Individuals can experience multiple uncertainties simultaneously, and these uncertainties can interact with one another.

Human experience of uncertainty can stem from the limitations of our perceptual and cognitive systems (Lorenzi, 1980; Weick, 1979). Unfamiliarity, novelty, time constraints, and complexity can all quickly overpower our limited cognitive capacity and lead us to experience uncertainty (Jones & Christianson, 1999; McDaniel, Waddill, Finstad, & Bourg, 2000). Uncertainty can also stem from the human ability to prefer, to value, to make choices, and to make sense. It is these sources of uncertainty that lead us to create and appreciate art, to theorize about the natural world, to innovate and design. Our capacities to wonder about what is not in front of us, to create and contemplate hypothetical situations, to imagine possibilities, and to hope, allow us the opportunity to be uncertain.

However, we may fail to experience uncertainty when experiencing uncertainty is warranted. Our heuristics for comprehending environmental uncertainties are systematically biased and prejudiced (Kahneman, Slovic, & Tversky, 1982). In our efforts to make sense of our experiences, we frequently attribute patterns and predictability to random outcomes and occurrences (Taleb, 2001). We find it difficult to apply probabilistic information consistently, "especially when the probabilities are small and the risks are unfamiliar" (Johnson & Covello, 1987 p. ix). Although we live in a probabilistic world, we tend to err on the side of determinism (e.g., Gilovich, Vallone & Tversky, 1985). We mistakenly attribute single and simple causality to decentralized nonlinear systems (Hmelo-silver & Pfeffer, 2003; Jacobson, 2001; Wilensky & Resnick, 1999). Individuals are often overconfident in their judgments and wrong when they feel totally certain (Fischhoff, 1977; Langer, 1975). Failure to respond to uncertainty appropriately, and to recognize when it is warranted to be uncertain, can lead to individuals holding very simple views of the world (Sieber et al., 1978).

Uncertainty involves motivation to know (Budner, 1962; Polanyi, 1958) and the recognition that one does not fully know (Sieber, 1969), and so is differentiable from "not knowing" (Smithson, 1989). *Ignorance* refers to complete lack of information; uncertainty refers to partial knowledge (Smithson, 1989), understanding, or ability to make meaning. This is important from a learning perspective because knowing does not spring full-blown from a state of total ignorance, as shown by research on the role of prior knowledge in learning (Walker, 1987). Thus, students cannot be said to be uncertain when they do not know; only when they become aware that they do not know how to come to know what they do not know. Managing in the face of ignorance requires different skills and strategies than managing in the face of uncertainty. Rather than addressing situations in which students are unable to engage effectively in tasks because of ignorance, this study was focused on uncertainty management.

Managing Uncertainty

By *managing uncertainty*, I am referring to behaviors students engage in to enable action in the face of uncertainty. The term *uncertainty management* may come with some "baggage" for many readers. For educational psychologists, it might seem to echo academic discourse about managing anxiety. I am referring to something that is closer to managing change than it is to managing anxiety. Anxiety is predominantly seen as negative and therefore is generally managed in order to reduce it. Change, on the other hand, has both positive and negative aspects, and therefore must be managed in order to benefit from positive aspects and reduce the costs of negative ones. The same is true of uncertainty. In this work, I avoided making the assumption that uncertainty would necessarily produce negative emotions and concentrated instead on understanding the experience and meaning of uncertainty to my participants (Brashers, 2001).

Some readers may equate the term *manage* with *reduce*. That is not what I mean. Throughout this dissertation, I use the term *manage uncertainty* in a fashion like that of communication researchers who differentiate between *uncertainty reduction* and *uncertainty management* (see, for example, Babrow & Matthias, 2009). Individuals manage uncertainty in a variety of ways; there are several alternatives to reducing uncertainty. Individuals often attempt to manage uncertainty by reducing it, but they may also ignore, maintain, or even increase uncertainty as they attempt to enable action and reach a goal (Babrow, Kasch, & Ford, 1998).

Although I have elected to adopt the term *uncertainty management*, I too am concerned with its association with control and negative appraisals of uncertainty and the potential for management to be interpreted as *reducing* (Babrow & Matthias, 2009). However, for now, I still land on the term *managing uncertainty* because I interpret the term *management* to mean "taking action in the face of" a feeling of being uncertain. Before settling on this term, I toyed with the phrase *responses to uncertainty*, but this term implies a passivity and/or reactive quality that does not seem to represent well the relationships individuals have with their uncertainty experiences and the situations from which those experiences arise. For some individuals, *managing* may hearken to intentional self-regulation of learning. I take the viewpoint that uncertainty management is a goal-directed behavior, and that individuals are in fact intentional in their responses to uncertainty even when their attempts to manage uncertainty are unconscious.

Uncertainty Management as a Collaborative Process

Managing uncertainty is a social task. Like learning, it requires the development of relationship systems that enable individuals to implement the strategies they have and to leverage the strategies other people have (Gill & Babrow, 2007). Throughout their lives, individuals must make decisions and take actions under circumstances in which they are not certain, and they must manage the uncertainty they experience; often they must act under these conditions in conjunction with others in families, communities, and organizations. A majority of activities students are likely to face as adults are collaborative tasks, and most of the learning they do will be of a social nature (Bruner, 1981). For most individuals most of the time, the primary resource they have for managing uncertainty is each other, whether in face-to-face or virtual interaction, thus, becoming skilled at "using" a group to help one manage uncertainty is important. Given the central position of relationships in determining how social systems emerge and unfold (Arrow, McGrath, & Berdahl, 2000; Vygotsky, 1978), it is likely that the nature of interdependencies and interactions within a collaborative group will influence the ways individuals in that group manage uncertainty. Reciprocally, chronic feelings of uncertainty influence social cognitive processes (Weary, Marsh, Gleicher, & Edwards, 1993). This reciprocal relationship between uncertainty and peer interaction will likely influence students' abilities to navigate academic tasks successfully.

Statement of the Problem

In this dissertation, I present findings from a year of research I conducted that relied primarily on observations and interviews with students in a fifth grade class who were studying robotics engineering. I was interested in how students managed the uncertainty they experienced as they worked with their peers on three small-group collaborative projects across the school year. The first two projects were closed-ended or well-structured tasks; students were introduced to the materials and practices of robotics, and they re-produced largely pre-designed robots. The object was to meet a pre-specified goal assigned by the teacher. The final project was a less structured task – what Spiro, Feltovich, Jacobson, and Coulson (1991) called an *ill-structured task*; the objective was not pre-determined; students had to decide what they were doing to create and then plan how to create it, and they had to justify how well their robot met the objective of solving an environmental problem.

I used an inductive and interpretive framework to analyze data coming from naturalistic observations and interviews to address the following questions:

- How do students manage psychological uncertainty as they engage in collaborative robotics engineering projects?
- How do task characteristics influence students' responses to uncertainty as they engage in collaborative robotics engineering projects?
- How does interaction with peer collaborators influence students' responses to uncertainty as they engage in collaborative robotics engineering projects?

I developed a grounded theory model using a combination of constant comparison (Corbin & Strauss, 2008) and sociolinguistic microanalysis of discourse (Erickson, 1992; Wells, 2000). Following Hiebert and Wearne (1993) who identified academic tasks and classroom discourse as essential and interdependent variables affecting learning, I relied on discourse analysis as my main methodological tool, examining the conversations among peers collaborating to fulfill task requirements.

The robotics engineering projects observed in this study offer students complex multimodal literacy experiences in which print literacies interact with hands-on activity.

Robotics engineering is a field heavily reliant on computer science to create mechanical structures guided by computer or electronic programming to move these structures autonomously through their environments and respond to sensory input as they complete a specified objective. In general, a robot is composed of a mechanical structure, a central computer, motors and sensors, and a power source. Robotics are used in everyday aspects of our lives from the automated doorways allowing easy entry into public buildings to tools used in the exploration of space and the ocean floor, healthcare and warfare applications, and the assembly of automobiles and airplanes.

The instructional setting observed in this study was selected for several reasons. While engaged in robotics engineering projects, students must manage uncertainty as they struggle to acquire understanding of new sign systems and learn to participate in robotics engineering practices. Because the nature of these academic tasks is likely to induce multiple uncertainties, they provide opportunities to learn not only about technology and science, but also critical skills of how to deal with the uncertainty students are very likely to experience while collaborating on open-ended tasks. Additionally, educators are increasingly interested in engineering education in elementary grades as they consider skills students need to live well in the 21st century. Collaborative problem solving around engineering design issues are especially important because they represent the ways professional engineers often work. I hypothesized that the talk that goes on between peers may be especially important as students work together on engineering design tasks. My intent was to identify aspects of peer discourse that might make a difference in the quality of students' learning and the design products they created. I expected that successful engagement in these types of tasks would entail successful management of uncertainty, especially management that utilizes peer discourse.

Bounds of the Study

The study of uncertainty and uncertainty management as defined and operationalized in this dissertation research needs to be differentiated from two related lines of study. I was not studying heuristics and biases, a line of study dedicated to understanding how people respond to well-defined probabilities, most well-known through the work of Kahneman, Slovic, and Tversky (1992). Additionally, I differentiate my work from that of researchers studying the effect of environmental uncertainty (see for example, Lipshitz & Strauss, 1997; Luhmann, 1993; Milliken, 1987). Although environmental uncertainty is related to individuals' psychological experiences, feelings, or sense of uncertainty (e.g., one is more likely to feel uncertain in a situation that is inherently unpredictable, volatile), research suggests that environmental uncertainty and the psychological experience of uncertainty are not as strongly correlated as one might think (Kilduff, Angelmar, & Mehra, 2000; Thomas & McDaniel, 1990). This study is differentiated from other studies of uncertainty and uncertainty management in learning contexts in that it addressed uncertainty management through direct observation of individuals as they experienced uncertainty. Although it is likely that students strategies' for managing uncertainty are tied to what has been called their stances or orientations toward uncertainty (Budner, 1962; Kruglanski & Webster, 1996; Sorrentino & Roney, 2000) and also to their ontological and epistemological beliefs about uncertainty (Hofer & Pintrich, 1997; Kitchener & King, 1994), it was not my intention in this study to address either of these issues directly.

Because I saw uncertainty management as a fundamentally social act, the unit of analysis for this study was “the individual-in-group context” (Hogan & Fisherkeller, 1999; Vygotsky, 1978), as I examined individual cognition primarily as it occurs in interpersonal interactions. Recognizing that students are nested in multiple system levels, one needs to be careful about the level at which one conducts analysis (Kauffman, 1995; Lemke, 2000a; Wilensky & Resnick, 1999). In this study, I defined as my systems of interest small groups of students interacting in a collaborative academic setting, conceiving of each of these groups as a complex adaptive system (Arrow et al., 2001). I defined the agents in these systems as being comprised of the group members. As for the classroom; students in other groups and the teacher, I defined these as part of the environment in which collaborative groups were embedded.

Although the ways that students managed uncertainty as they attempted to successfully complete their robotics projects were undoubtedly influenced by many outside factors (e.g., teacher, students in other groups, family members), I primarily analyzed how students managed their uncertainty in conjunction with their group members without evaluating the multiple influences impacting group interaction. The teacher’s influence is backgrounded in this study, as is the influence of class members who were not members of the same collaborative group and members of the larger community outside the classroom. This is not to say that interactions with these interlocutors did not strongly mediate students’ management of uncertainty. Those analyses are important and relevant, but outside the scope of this investigation.

Although an analysis like the one I conducted does not represent a full sociocultural analysis (Wertsch, 1991), it does forefront the essential place of relationships and interactions in learning. I am cognizant that cognition occurs at the level of the group (Salomon, 1993) as well as at the level of the individual. For this project, I focused on the psychological experience and processes of individuals while engaged in discourse with peers, examining the inter-psychological plane insofar as it helps us to understand individuals' responses to and management of uncertainty. Although this study focused on uncertainty management of individuals, I tried to remain sensitive to group-level phenomena as analysis progressed. I limited my discussion to students' management of their own individual experiences of uncertainty; even though it became clear that students also helped their group members manage uncertainty and that students also managed uncertainty at the level of a collaborative group.

In the second chapter of this dissertation, I provide an integrative analysis of relevant research. After laying out the theoretical frameworks underlying my research, I focus on the literature pertaining to responses to uncertainty and managing uncertainty, educational and learning issues related to students' uncertainty management during academic tasks, and language and discourse as they pertain to expressing and managing uncertainty. In Chapter 3, I detail my research design, describing the research methodology I chose to address my research questions and laying out a research protocol. Chapter 4 outlines my findings. In Chapter 5, I present a model of uncertainty management I developed based on my investigation. I identify limitations of the study. Finally, I suggest implications of the study for educational practice and for theory and further research.

CHAPTER 2

LITERATURE REVIEW

"Education is man's going forward from cocksure ignorance to thoughtful uncertainty."
-Kenneth G. Johnson

In the first section of this chapter I describe three theoretical frameworks that influenced the conception and design of this study: community of practice, distributed cognition, and complex adaptive systems theory. In Sections 2, 3, and 4, I review literature from three strands of topics related to my research questions. In Section 2, I briefly review literature on how individuals respond to the psychological experience of uncertainty and how individuals influence one another's responses to uncertainty across a range of contexts. My purpose in this section is to develop a broad sense of the topic of this study: "What do we know about how individuals manage uncertainty?" In Section 3, I examine literature related to how uncertainty and uncertainty management have been conceptualized and studied in academic contexts. Finally, in Section 4, I explore literature on discourse as it relates to managing uncertainty, focusing on peer discourse as it occurs in collaborative academic settings.

Collaboration in Learning: Theoretical Frameworks

Believing that "theoretical pluralism is essential for a complex, applied discipline such as education" (Hogan, Nastasi, & Pressley, 2000, p. 380, see also, Giere, 1999), I drew from three theoretical traditions in conceptualizing and designing this study: communities of practice, social cognition, and complex adaptive systems theory. Each of these systems theories facilitates our thinking about small groups of learners collaborating to accomplish an academic goal.

Communities of Practice

With the advent of sociocultural conceptions of learning came increased interest in how is it that individuals learn from the environments in which they reside. Building off the ideas of Vygotsky (1978) and other sociocultural theorists, Lave and Wenger (1991) defined learning as a process of becoming a member of a *community of practice* through initially peripheral participation in goal-directed group activity. Taking trade apprenticeships as a metaphor, these authors described how newcomers gradually come to appropriate the shared practices of a community through *legitimate peripheral participation* in the activities and discourses of that community. Rather than emphasizing *learning about* abstract and decontextualized subject matter, a communities of practice framework emphasizes *learning to become.* Transfer of learning is a problematic concept from a community of practice perspective in that this theory emphasizes how learning is situated in specific contexts. What one knows cannot be separated from what one does. Understanding learning requires paying attention to the conditions of learning such as social relations and physical surroundings (Brown & Duguid, 1991).

Community of practice theorists concentrate on how individuals are influenced in their goal-directed behavior by the cultural goals, values, and practices of the cultures in which they are embedded. It emphasizes how individuals come to learn, share and shape goals, values, and practices of a particular group. In particular, it focuses on how newcomers (e.g., students) are influenced by an existing community engaged in fulfilling particular goals and on how individuals develop an *identity of mastery* within particular groups of which they are members (Lave & Wenger, 1991).

Although community of practice theory focuses on how newcomers are enculturated into community practices (Brown, Collins, & Duguid, 1989), it also asserts that knowledge is co-constructed as community members participate in and contribute to communal activity. “Learning, thinking, and knowing are relations among people in activity in, with, and arising from the social and culturally structured world” (Lave & Wenger, 1991, p. 51). Innovation and change are possible as newcomers replace old timers and as the demands of practice force the community to modify its practice (Brown & Duguid, 1991). Community of practice theorists have recently turned more attention to the reciprocity between individual and collective development, examining the ways that a community is shaped by its members (Greeno, 2006).

The concept of communities of practice has been used extensively to describe a range of educational issues; however, criticisms have been leveled against this theoretical framework. For instance, Gee (2005) argued that *membership* and *belonging* mean different things in different contexts and may be inappropriate to apply to classroom collectives. Also, educational researchers have questioned the image of lengthy apprenticeship within established, stable social formations. This picture may not represent well the social practices in many classroom communities (Duff, 2007; Thorne, 2009).

Distributed Cognition

While community of practice theory helps us consider how goals and identities are shaped by participation in socially valued activities, theories of distributed cognition reflect on how collectives enable things individuals cannot do. Prior to the late 20th century, cognition was assumed to be an individual level phenomenon. Thus, the history of research in human cognition was a story of insights gained by creating models of cognition that take the individual cognizer as the unit of analysis (Goldstone & Janssen, 2005). However, theorists championing *distributed* or *social cognition* have more recently attended to how the outcomes of many human endeavors are not determined entirely by the information processing properties of individuals, nor can they be inferred from the properties of individual agents alone ((Hutchins, 1995a). Rather, the expertise needed to accomplish many goals is distributed among individuals, artifacts, and environments (Hutchins, 1995a; Salomon, 1993; Arias et al., 2000).

Distributed cognition is a construct embodying the claim that cognition is often dispersed among or "stretched over" individuals and objects (e.g., artifacts, tools, nature) across space and through time (Greeno, Collins, & Resnick, 1996; Lave, 1991). Authors taking a distributed cognition stance differ widely in their conception of the relationship between individuals and groups (see Moore & Rocklin, 1998 for a review). Some theorists take an individual-plus-environment stance, conceptualizing cognition at the individual level, though divided among an individual, other individuals, and sometimes objects and activities (Derry, DuRussel, & O'Donnell, 1998). The individual exists squarely as the driver in this framework and is of primary concern. The interest is in how environmental factors such as the relationship between group activity, group processes, and the use of artifacts, tools, and activities effect the development of individual cognition (Derry et al., 1998; Lebeau, 1998).

Whereas the individual-plus view is that *some* cognition is distributed, the social-only camp believes that *all* cognition is distributed, thus distinction between individual and group cognition is meaningless (e.g., Derry et al., 1998; Resnick, 1991). These researchers treat groups as cognitive entities that construct knowledge (Hewitt & Scadamalia, 1998), believing that "Learning, thinking, and knowing are relations among people in activity in, with, and arising from the social and culturally structured world" (Moore & Rocklin, 1998, p. 104). Still others argue that individual cognitions and group cognitions can interact. I side with Salomon (1993) in distinguishing *shared cognition* in which individuals jointly engage in cognitive activity from the *division of cognitive labor* in which an individual shifts responsibility onto a tool or person.

Distributed cognition has been applied to a wide range of human endeavors. In Hutchin's (1995b) description of the cognitive activities involved in deciding and manipulating the speed of an airplane as it descends for landing, he took the airplane cockpit as a cognitive system, viewing the redundant and multimedia interactions between tools, activities, and individual who monitored them as the creator of an external representation. Brown (1993) described pairs of children working out a mathematical problem as shared cognition; students collaborate to set up the problem, discuss and perform procedures, and work out partial answers on paper. In recent years, distributed cognition has been applied frequently to human interaction around technological tools and environments. In educational research, it has been especially used to explicate and improve the process of interaction between individuals and technologies, such as in computer-supported-learning (CSCL) environments (e.g., Dror & Harnad, 2008; Hewitt & Scadamalia; 1998) look at classroom practices as "knowledge building communities" in which a Computer Supported Intentional Learning Environment (CSILE) facilitates the distribution of knowledge by providing a storehouse of information that students can access and to which they can contribute.

Complex Adaptive Systems Theory

Unlike communities of practice and distributed cognition, which both grew out of cognitive and social sciences and have often been applied to educational contexts, complex adaptive systems theory has its roots in the natural sciences. Begun in the 1980s, its birth is detailed in the book "*Complexity*" by Waldrop (1992). Complex adaptive systems theory has since been used to model a wide range of phenomena in the natural and social sciences including the formation of ant trails, the aggregation of slime molds, the development of organizational cultures, and the propagation of fads, disease, and chemical reactions. It has been increasingly applied to systems related to human education, learning, and development. Researchers have conceptualized educational institutions (O'Day, 2002), small groups of learners (Davis & Sumara, 2006; Jordan et al., 2008, Kapur & Kinzer, 2008) and even individual learners (Barab et al., 1999; Thelen & Smith, 1994) as complex adaptive systems.

Complex adaptive systems are learning systems, with learning defined as the ability of agents in the system (which might be students in a group, see Arrow et al., 2000) to change their behavior based on information they receive during interactions with each other and with their environment. Multiple nonlinear interdependencies among interacting agents can lead to unpredictable system dynamics (Capra, 1996). Thus complex adaptive systems theory supports philosophical and pragmatic observations that uncertainty is unavoidable and sometimes fundamentally irreducible; and therefore it must be lived with and tolerated. Moreover, sources of uncertainty are potential catalysts for order and creativity (Kauffman, 1995; Prigogine & Stengers, 1997). Rather than being completely controlled by hierarchical plans or leaders, decentralized agents self-organize themselves primarily through local interactions; selecting, iterating, and magnifying small perturbations, fluctuations, and variations to create emergent patterns and system order (Holland, 1998). Although they can be stable, self-organized patterns of interaction are not static but are instead dynamic forms that maintain their coherence through ongoing adaptation in response to positive and negative feedback (Goldstone & Janessen, 2005; Granic & Lamey, 2000).

Complex adaptive systems theory describes the relationship between individual cognition and social cognition in several ways. For one**,** cognition is self organizing at the level of the individual and at the collective level. As Lesh (2003) argued, “Regardless of whether we focus on the development of individuals or groups, their ways of thinking are characterized by communities of complex and interacting conceptual systems” (p. 222). Also, social cognition can be said to emerge from the local interactions of individuals. Individuals at lower system levels interact with each other and through those interactions create *emergent properties* at higher system levels that are not reducible to a summation of the properties of the individual agents (Goldstone & Janessen, 2005). Finally, the cognition of individuals and the cognition of collectives can be said to be *co-evolving*. Organized behavior occurs at multiple nested levels. As Goldstone and Janessen (2005) noted, “[O]ur thoughts both depend upon and determine the social structures that contain us as elements within those structures” (p. 22). At the same time that collective cognition emerges from the cognition of individuals, collective cognition feeds back down to influence those same individuals. As Seitz (2003) noted, “The communities and environments with which an individual interacts act as cultural amplifiers (Bruner, 1996), augmenting certain cultural practices…and not others” (p. 247).

Summary of Theoretical Frameworks

Being systems theories, all three of the frameworks discussed above have much in common. Yet each adds something unique to our understanding of human learning and cognition, especially of how individuals and collectives influence one another. Of the three theories, a community of practice lens focuses the most attention on individual cognition as it is influenced by social interaction. Theories of distributed cognition speak to various ways representations can take place beyond the human mind but offer little in advancing our understanding of the mechanisms or structures that enable these external representations. Complex adaptive systems theory describes how groups composed of interacting individuals who are distributed across a system and have differing views of that system and differing representations of their environment can jointly construct a representation of that environment that is not reducible to the representations of the agents and that surpasses the capacity of any one of them (Weick, 2005). It suggests that cognition at the group level and at the individual level are nested systems, reciprocally interdependent and having different properties. I find this theory least helpful in terms of defining learning, but most helpful in articulating the role of interdependencies among individuals in groups and the relationship between individuals and systems, and for considering the meaning of uncertainty in academic learning contexts.

Experiencing Uncertainty: What We Know about Responding to and Managing Uncertainty

To understand how students manage uncertainty during collaborative tasks, one must examine how individuals vary in their emotional and cognitive responses to uncertainty because these are interdependent with actions (Thomas & McDaniel, 1990).

Individuals' cognitive and affective responses to the experience of uncertainty constrain the behaviors in which they engage to manage uncertainty. Furthermore, individuals' responses to uncertainty are socially influenced. In this section, I draw most directly from the psychological and organizational management literatures to explain responses to uncertainty, and then from the psychological and educational literatures to address individual orientations toward uncertainty. My discussion of uncertainty management draws most extensively from the literature in communication theory.

Responding to Uncertainty

Uncertainty is associated with affective, cognitive, and behavioral responses, and these are interdependent. Rather than a coldly cognitive phenomenon, uncertainty can be thought of as a *cognitive feeling* (Clore, 1992) that can be more or less conscious and more or less tied to emotions. Emotionally, uncertainty has often been found to induce a negative response experience (van den Boss, 2001) and tends to be associated with anxiety, worry, and fear of failure or loss of control (Roseman, 1984; Smith & Ellsworth, 1985). However, uncertainty also creates "the freedom to discover meaning" (Langer, 1997, p. 130), and has been linked with hope (Smith & Ellsworth, 1985; Tiedens & Linton, 2001), pleasure (Wilson et al., 2005), and excitement. Cognitively, uncertainty can sharpen or dull cognitive functioning (Tiedens & Linton, 2001). Uncertainty affects one's ability to make meaning (Folkman, Schafer & Lazarus, 1979), to reason, and to adapt (Kagan, 1972). "[Un]certainty can both empower and incapacitate" (Ford, Babrow & Stahl, 1996, p. 191). Uncertainty is a source of possibility and potential action (Hatch, 1999), but it can also prohibit action (Anderson, 2003).

Individuals respond cognitively to uncertainty by making causal attributions of the source of their uncertainty. Novices may be especially limited in the range of attributions they make about their uncertainty. For example, Lingard, Garwood, Schryer, and Spafford (2003), in an observational/interview study that took place in the context of a medical school, found that beginning medical students tended to attribute uncertainty primarily to their own ignorance, whereas more expert practitioners attributed uncertainty to multiple origins including limits of evidence, limits of professional agreement, and limits of scientific knowledge. Additionally, uncertainty can be appraised as an opportunity or threat (Lazarus, 1983; Mishel & Braden, 1988; Taylor, 1983; Thomas & McDaniel, 1990). Negative affect responses signal a troubled appraisal whereas positive emotional responses result from a positive appraisal (Brashers, 2001).

Measuring Responses to Uncertainty: Normative Scales

What makes us uncertain and how we respond to our uncertainty varies between people as a function of individual level factors such as ontological and epistemological beliefs or stances toward knowledge (Hofer & Pintrich, 1997; Kitchner & King, 1994). Psychological studies of uncertainty have been particularly focused on between-person differences in individuals' stable tendencies to respond to uncertainty or their tolerance for particular forms of uncertainty (e.g., ambiguity), sometimes naming these tendencies *uncertainty orientations*. Self-report scales, projective measures, and experimental methods to measure individual orientations to various forms of uncertainty, often used in educational contexts, can be traced back from the mid-20th century through the present (e.g., Adorno, Frenkel-Brunswik, Levinson, & Sanford, 1950; Budner, 1962; Cacioppo, Petty, & Kao, 1984; Debacker & Crowson, 2006; Huber, Sorrentino, Davidson, Epplier,

& Roth, 1992; Kruglanski & Webster, 1996, 1990; Levitt, 1953; Neuberg & Newsom, 1993; Rokeach, 1960; Salomon & Sieber, 1970).

In terms of this dissertation study, the assumptions inherent in the literature on individual differences in uncertainty orientations are problematic on several counts. The philosophical underpinnings of this work tend to reflect "outdated, naive realism" (Smithson, 1989). These studies are largely driven by a normative orientation that may lead to biased interpretations and results. Most troubling in terms of my research is the assumption that one's uncertainty orientation is context independent, "an unconscious screening device for all situations" (Sorrentino, 1999, p. 420). Empirical research indicates that contextual factors such as danger, slack, and assimilation of resources account for more variation in risk-taking behavior than do stable individual traits (March, 1991). Even researchers with a decidedly individual-level orientation have moved to take a more contextualized perspective**,** allowing that a *need for closure* of uncertainty can be situationally evoked (Kruglanski & Webster, 1996) and that *uncertainty orientations* tend not to hold in situations in which individuals are afraid of failure or social rejection (Sorrentino & Roney, 2000).

Managing Uncertainty: Conceptions and Contexts

The affective responses, appraisals, and attributions individuals make about the source of their uncertainty will affect what they think they can do about it – their management of uncertainty. The literature discussed above suggests that students' management of uncertainty during collaborative academic tasks will be influenced by individual and contextual factors that influence responses to the experience of uncertainty. The issues about which students are most threatened may be the uncertainties they try hardest to manage. In the social context of an academic collaborative group, students may be especially concerned with how they appear to their peers and so put forth much effort to manage that uncertainty. If a student is confident of his/her place in a group, uncertainty about how his/her peers will respond to his/her ideas will probably elicit curiosity rather than anxiety. If students attribute their experience of uncertainty during academic design tasks to fundamental unknowability in the environment, then they are likely to manage that uncertainty differently than if they attribute it to their own lack of obtainable knowledge (Kahneman & Tversky, l982; McDaniel, Jordan, & Fleeman, 2003).

Specific categories of strategies for managing uncertainty have been distinguished in various ways by researchers in psychology (Lazarus, 1983; Wildavsky, 1988), organizational management and decision making (Haslam & McGarty, 2001; Lipshitz & Strauss, 1997), and communication theory (Babrow, Kasch, & Ford, 1998; Brashers, 2001; Goldsmith, 2001). In a review of the literature on health communication, Babrow et al. (1998) surmised that individuals learn to adapt to uncertainty by reducing, maintaining, and creating or increasing it at various times. Other researchers have further differentiated between reducing and ignoring uncertainty (Lipshitz & Strauss, 1997). Because uncertainty management is the key interest of this research proposal, I review this literature in a bit more detail than the previous sections of this chapter. I outline strategies and tactics for managing uncertainty that have been identified in various disciplines. I then consider social issues in uncertainty management.

Reducing uncertainty. The most commonly cited and commonly used strategy for managing uncertainty is to attempt to reduce it (Smithson, 1989). Researchers have identified a wide variety of tactics for reducing uncertainty in different contexts. One such tactic is to gather information through direct inquiry or by placing one's self in situations in which one is likely to encounter information (Brashers, 2001; Mishel, 1988). Students might seek information from teachers, texts, or peers by talking, listening, or acting. Another tactic for reducing uncertainty is to appeal to experts (Giddens, 1990). Teachers often act in ways that legitimate this tactic by placing themselves in the position of expert. Although this tactic may be appropriate under some conditions, Kahneman et al. (1982) warned that experts often overestimate their own ability to predict outcomes of actions.

***Ignoring uncertainty*.** In a study of teacher uncertainty, Munthe (2003) pointed out that "doing nothing is a decision" (p. 26). Doing nothing is one tactic for utilizing the management strategy of ignoring uncertainty (Einhorn & Hogarth, 1986). Some researchers have asserted that when people minimize their uncertainty or its importance, they may inappropriately simplify uncertainties (Sheer & Cline, 1995; Stacey, 1992). For example, individuals frequently diminish ambiguities to problems of defining probabilities rather than seeing them as problems of evaluating irreducible competing interpretations (Kahneman & Tversky, 1982). However, others have called attention to how ignoring uncertainty can be beneficial when it allows one to act without being paralyzed in the face of unknowable or incalculable uncertainties (Anderson, 2003; Einhorn & Hogarth, 1986; Taylor, 1989).

Maintaining uncertainty. The strategy of acknowledging, absorbing (Boiset & Child, 1999), or maintaining (Babrow et al., 1998) uncertainty includes the tactic of taking small steps and observing the effects of one's actions. Advocated by Brian Arthur

(1999), an economist with a complexity science orientation, this tactic maximizes learning and one's potential to use that learning at the next step of coupled decisions, minimizes potential disruption of unforeseeable wrong turns, and allows a range of options to be maintained. Karl Weick (1995), a social psychologist, suggested sensemaking as an alternative to decision making under uncertainty. By focusing on making sense of a situation, the propensity to defend one's decision and to seek only information consistent with the decision can be avoided, and decisions can be delayed. Delaying decisions necessitates the ability to maintain uncertainty, at least for a while. Delaying decisions has been identified as a particularly important possible step during the problem scoping phase of a design task (Glanville, 2007; Kilduff, Angelmar, & Mehra, 2000).

***Increasing uncertainty*.** Related to acknowledging uncertainty is the strategy of creating, welcoming (McDaniel et al., 2003), or seeking (Haslam & McGarty, 2001) uncertainty through tactics such as problem seeking or progressive problem solving (Bereiter & Scardamalia, 1993a). Similar tactics have been advocated by education researchers arguing for a questioning and an open-minded stance in learning (Barnes, 1975; Bruner, 1986; Covino, 1988; Dewey, 1929). Wondering can also be considered a tactic for creating uncertainty, a way to "experience abundant possibilities" (Noica 1987; p. 148). Individuals may be more inclined to seek uncertainty under particular conditions as when they know the uncertainty will eventually be removed as when reading a mystery novel (Wilson, 2007) or when they feel psychologically safe (Dewey, 1910). Welcoming uncertainty has been associated with creativity (Koestler, 1964) and so might be a key strategy for engineering design tasks.

Effective uncertainty management sometimes requires reducing uncertainty and at other times ignoring, maintaining, or increasing it (Babrow et al.1998). The adaptiveness of any given strategy is dependent upon the set of conditions in which it is used; the nature of the uncertainty: its magnitude (Thompson, 1967), its importance (Doyle, 1988), its duration (Ford et al., 1996), and the thing about which one is uncertain (Milliken, 1987). In this study I am especially interested in social factors that influence uncertainty management.

Social issues that affect uncertainty management. Gill and Babrow (2007) defined uncertainty as "a fundamentally communicative phenomenon spread and shared by identification, sympathy, empathy, and interdependence" and maintained that "communication is the primary medium, source, and resource in uncertainty experiences" (p. 136). Babrow called for multilevel analyses of uncertainty management including of individuals and sociocultural context (1992).

Goldsmith (2001) took a normative approach to social issues in uncertainty management by examining "the larger set of beliefs about persons, relationships, and communication within which uncertainty is meaningful" (p. 524). Goldstein emphasized that the need to manage uncertainty occurs simultaneously with other goals and desires. Behaviors associated with managing uncertainty must often serve multiple functions (e.g., preserving social harmony while granting status to the speaker). To be judged appropriate and effective within a particular context, one's strategies for managing uncertainty must adapt to potentially conflicting values. There are socially accepted ways of managing and talking about uncertainty – and these vary between cultural contexts. For example, academics tend to hold one another accountable for the ways they manage and talk about uncertainty (Highland, 1996; Hymes, 1974). Teachers, as well, vary in how they talk about uncertainty with their students versus how they talk about uncertainty with each other (Feldman & Wertsch, 1976).

Managing Uncertainty in Classrooms: How Educational Researchers Talk about Uncertainty

In educational theory and practice, uncertainty has been addressed most directly by John Dewey (1925/1981) who recognized that life consists of "the stable and precarious, the fixed and unpredictably novel, the assured and the uncertain" (p. 55). Dewey (1929) noticed that individuals are often tempted to jump to conclusions too quickly in order to escape uncertainty, but that a disciplined, inquiring mind "takes delight in the problematic" and enjoys the doubtful (p. 228). Bruner (1986) expressed concern that teachers often represent to students a world that is settled and non-negotiatory and that they "close down the process of wondering by flat declarations of fixed factuality" (p. 126). He was emphatic that education should bestow "some sense of the hypothetical nature of knowledge, its uncertainty, its invitation to further thought" (p. 126). He saw students as knowledge makers, potential contributors to "the negotiatory process by which facts are created and interpreted" (p. 127).

Many other researchers and educators recognize that math and science related disciplines are replete with irreducible uncertainty. Gray and Tall (1994) claimed that successful mathematical thinking requires one to manage ambiguity flexibly in interpreting symbolism. Rowland (2000) asserted that "tentative belief, as opposed to certain knowledge, is an essential component of mathematical thought" (p. 48). Some science education theorists have maintained that the practice of science is an open and creative process that may generate better, but never final, answers (Bereiter, 1994), and therefore might be more usefully taught from a design perspective than from a belief perspective (Bereiter & Scardamalia, 2003).

How Young Students Comprehend and Manage Uncertainty

Few researchers have directly focused on children's uncertainty associated with authentic learning situations. Two exceptions are Joan Sieber's work on warranted uncertainty and Kathleen Metz's study of elementary students' identification of their uncertainty during science inquiry. Both of these lines of research are described in some detail below.

Warranted uncertainty. In the 1960s and 1970s, Sieber and her colleagues conducted a series of studies on students' abilities to recognize when it is warranted to be uncertain (e.g., Sieber, 1969; Sieber, Epstein, & Petty, 1970; Sieber et al., 1978). Across a wide range of ages including elementary, secondary, and post-secondary students, study participants overwhelmingly expressed great confidence in their responses to math, spelling, and logic questions. Often their confidence was not closely related to the correctness of their answers. These researchers found that *secondary ignorance*, the inability to recognize that one should be uncertain, was related to being able to improve performance and to overall level of ability.

Sieber et al. (1970) developed and implemented an instructional unit aimed at teaching middle-grade students to distinguish among five types of questions: (1) questions to which the individual knows the answer, (2) questions to which the answer is known by someone, (3) questions for which the answer is not known but can be found using existing tools and/or methods, (4) questions that cannot be answered because events they pertain to have not occurred yet, and (5) questions for which no way of obtaining the answer presently exists. In a longitudinal experimental study using matched participants from fourth, fifth, and sixth grades, students trained in warranted uncertainty significantly outperformed a control group on questionnaires developed to assess their ability to recognize when it is warranted to be uncertain, to categorize questions, and to transfer their knowledge. Differences between groups had significantly diminished three years later in follow-up assessment but were still greater for students who had received the training.

The work of Sieber and her colleagues is important in that it demonstrated that students can change how they manage uncertainty in ways that make a difference in their performance on academic tasks. A limitation of this work is that it examined students' responses to subjective uncertainty primarily in close-ended, highly structured problems. The five question types the authors identified pertain only to questions that have one specific, knowable answer. Students may have different ways of thinking about uncertainty in less structured problems, such as the collaborative robotics engineering projects assigned to the students I observed in this study.

Uncertainty in science inquiry**.** Metz (2004) was interested in students' abilities to pursue their own inquiry in science and the metaknowledge needed to participate in such inquiry. In a study of second, fourth, and fifth grade students, dyads designed and conducted experiments about crickets as one activity in a curricular unit on animals. In videotaped structured interviews, Metz asked students how confident they were in their findings and how they could increase their level of confidence. She identified every episode of the interviews in which a student identified her/himself as being uncertain and marked whether or not the student had identified a source of the uncertainty and/or voiced a strategy to reduce his/her uncertainty. Students expressed uncertainty about five areas: (a) how a desired outcome could be consistently produced; (b) whether the data were reliable or trustworthy; (c) their interpretation of their data; (d) the generalizabilty of their findings; and (e) the theory that best accounted for the data. The majority of students in both the older and younger grades expressed uncertainty about at least one of these areas and a majority of students came up with at least one strategy to try to reduce their uncertainty (80% in second grade, 97% of the fourth/fifth graders).

Metz's work demonstrated that students are "able to reflect on their research with a degree of skepticism, to conceptualize veridical sources of uncertainty" (Metz, 2001, p. 2) and that they can develop strategies to manage uncertainty. The students in Metz's study expressed more uncertainty than the students in the studies by Sieber et al. that were described above. It is possible that differences in research procedures explain the differences. The elaboration on ideas that Metz asked of her participants may have prompted students to express more uncertainty than the questions used in Sieber's studies. It may also be that differences in the task structure assigned to each group of students influenced their response to uncertainty. The assigned task in Metz's study was to design and carry out an experiment, a less structured and open-ended task whereas all the tasks in the studies conducted by Sieber and her colleagues were more structured and close-ended.

Limitations of Metz's work include that she assumed that students' strategies for managing uncertainty would be only to reduce it. She did not consider the possibility that they might at times intentionally ignore, maintain, or increase their uncertainty. Although

Metz identified the open-ended nature of the assigned task as important, she did not examine students' process in designing their own experiments. Although students expressed uncertainty about their theories to account for their data, Metz did not examine uncertainty associated with generating these theories. Finally, although students worked in dyads, how this affected uncertainty management was not explored. Interviews were conducted with dyads, and this was only discussed as a problem in attributing thoughts to individuals. Metz did not attempt to understand how students use peers to manage uncertainty or how peers may influence one another's uncertainty management.

The Nature of Academic Tasks and How They Influence Uncertainty Management

In some ways, my study builds most directly on Doyle's research from the 1980's in which he found that teachers and students alike struggle with uncertainty in academic tasks. In descriptions of educational settings, tasks as a unit of analysis became established as an important way of describing the school day with Doyle's seminal review of the literature (1983) and intensive case analysis of junior and senior high classes across disciplines (Doyle & Carter, 1984), followed closely by a special issue of the *Elementary School Journal* called *Schoolwork and Academic Tasks* (1988, January, vol. 88, no. 3).

According to Doyle and Carter (1984), the goals and content of an educational curriculum are in large measure delivered through academic tasks. How students think about subject matter is highly influenced by the assignments and activities they are given (Emmer, 1986). At least three elements define academic learning tasks: (1) a goal or product to be evaluated, (2) a set of available resources, and (3) operations and procedures through which students can utilize the resources to achieve the goal or generate the product (Doyle & Carter, 1984). Later, Doyle (1988) amended this list to include the evaluative “weight” of a given task in the accountability system of a class. Blumenfeld and Meece (1988) expanded this conception to include the social organization of the activity, whether it is whole class, various small group configurations, or individual work.

Most important in terms of my research study is Doyle and Carter’s (1984) claim that academic learning tasks necessarily elicit uncertainty in the form of ambiguity and risk. These authors attributed much of the uncertainty in academic tasks to the evaluative nature of schooling, defining *ambiguity* as the degree to which correct performance is clearly definable for learners in advance, and *risk* as the probability assigned to the possibility of failure to meet the evaluation criteria of a given stringency for a given task. Based on these criteria, memory tasks would be low ambiguity because the answer is known ahead of time and low risk because it is clear what actions are required to succeed, whereas comprehension tasks would be high on both ambiguity and risk because multiple answers must be weighed and justified, and because the definition of success is vague.

Researchers have identified several other characteristics of tasks that can affect the amount of uncertainty students experience while engaged in them. Lessons involving *novel tasks*, that is, those with which student were unfamiliar, move along “bumpily” as students negotiate with the teacher about ambiguity and risk, whereas the use of familiar tasks can lead to efficient production of work. Blumenfeld, Mergendoller, and Swarthout (1987) found that when the form of a product is *complicated* or *ambiguous*, students may focus more on the product than on its content, especially in group social settings. These authors noted that when task “procedures are *complex* students are likely to focus their attention and spend time on aspects of the task that interfere with their successfully achieving the cognitive goal" (Blumenfeld et al., 1987). It may be that students are engaging in these behaviors in order to avoid uncertainty associated with more rigorous or confusing aspects of complex academic tasks.

Although not argued explicitly in any literature of which I am aware, it seems likely that the structuredness of academic tasks would also influence the amount of uncertainty that students experience. Spiro, Feltovich, Jacobson, and Coulson (1991) argued that much educational instruction is flawed in that it offers students a representation of knowledge domains as simple and *well-structured*, when in fact; many knowledge domains are complex and *ill-structured*. In ill-structured domains, particular problems involve simultaneous interaction among multiple conceptual structures, interaction that is irregular, or varies, across cases of the same type. Spiro et al. (1991) presented engineering design as an example of an ill-structured domain. Even though engineering utilizes physical science principles that present well-structured problems (orderly and regular relationships), the application of those principles in real-world engineering differs from case to case, involving different patterns of scientific principles in each particular problem. Researchers have found that ill-structured tasks may increase some students' anxiety, resulting in withdrawal rather than constructive engagement. Other students may experience frustration with tasks that are too well-structured (Kapur & Kinzer, 2008; Lodewyk & Winne, 2005). Anxiety and frustration can both stem from uncertainty.

Strategies for managing uncertainty may be differentially appropriate for different tasks. Uncertainty due to lack of obtainable knowledge in an algorithmic task might be managed best by an information search to reduce uncertainty, whereas creative tasks undertaken under conditions of ambiguity may elicit or even require tactics for acknowledging or creating uncertainty. Engaging in simple or straightforward tasks may require only a few strategies for managing uncertainty, but solving complex problems such as engineering design, that takes place over a long period of time and have several phases requiring multiple iterations, "entails a complex interactional weave of multiform uncertainties" (Babrow et al., 1998, p. 3). In such problems, strategies will likely be used in conjunction with one another.

Tasks that are rich in terms of affording students opportunities to experience uncertainty of multiple forms and to learn to manage uncertainty may also be the hardest to implement in classrooms (Doyle, 1988). Previous research suggests that teachers struggle in their efforts to help students learn to deal with uncertainty. Herbst's (2003) analysis of a middle school geometry lesson suggested that teachers may experience ambivalence about conveying clear directions and constraints on the one hand and maintaining a productive ambiguity on the other hand. Teachers frequently soften accountability requirements to compensate for the added complexity of novel tasks (Doyle, 1988; Herbst, 2003). Teachers across disciplines overwhelmingly assign tasks low in both ambiguity and risk (Doyle, 1983, 1988). Tobin (1985) observed that laboratory activities in middle and high school science classes focused on following procedures to collect data, with very few opportunities to design investigations or interpret results. Burrill's (1998) quantitative review indicated the same thing, ten years later.

Teachers are not the only ones to be implicated with limiting opportunities for students to experience and learn to manage uncertainty during academic tasks. When teachers do attempt to create and implement more open-ended, generative tasks, students themselves often resist, seeking to reduce ambiguity and risk "by clarifying task requirements, obtaining feedback, and pressuring teachers to transform task demands" (Doyle & Carter, 1984, p. 145). Rohrkemper and Corno (1988) reported that students often "do not confront difficult tasks as much as they are confronted by them" (p. 302). In other words, students have difficulties managing or regulating their uncertainty by altering their approaches to a task or by transforming the task itself.

The uncertainty students experience in relation to academic tasks depends not only on the nature of the task itself, but also in the way the task is perceived by students (Doyle, 1983). Student perceptions may depend on the ways in which classroom cultures expect and *allow* students to think about tasks (Herbst, 2003) and on how tasks are framed by teachers (Engle & Conant, 2002; Rowland, 2000). Hiebert et al. (1996) suggested that students be given opportunities to grapple with uncertainty when they argued that students need to "problematize" topics; "to wonder why things are, to inquire, to search for solutions, and to resolve incongruities" (p. 12). To decrease risk while maintaining complexity, Rowland (2000) suggested that teachers establish a "zone of conjectural neutrality" where conjectures can be relocated, tested, and proved, refuted, or modified without putting a student on trial (p. 212). Duckworth (1996) extolled the value of *wonder* in children's exploration of the natural world, which is marked in discourse and holds uncertainty open by approaching ideas speculatively. These notions all have a common theme in that they encourage a perception of problems, dilemmas, and questions as fun (Hiebert et al., 1996), and an interpretation of uncertainty as an opportunity to play and explore.

Researchers have sometimes encouraged teachers to remove as much uncertainty as possible from academic tasks. Anderson et al. (1988) suggested that teachers should provide predictable, consistent task environments that give students a sense of control over task outcomes. Bennett and Desforges (1988) argued that teachers should match types of tasks to types of students as closely as possible. However, others have asserted that teachers should deliberately promote the development of mismatches between students and tasks in order to provide students the opportunity to fail and thereby develop flexible, adaptive learning strategies and self-regulation needed to cope with stress in academic tasks and in society (Rohrkemper & Corno, 1988).

Doyle (1988) argued that teachers' inclination to remove uncertainty reinforces students' notions that problems should be solved quickly, inhibits autonomous learning, and hinders the development of problem-solving skills. Teachers' propensity to reduce uncertainty may impede students' attempts to make sense of school environments and of the open and confusing contexts in which they live. If most academic tasks with which students are asked to engage involve low levels of uncertainty, then students may not be getting the practice necessary to learn to manage uncertainty successfully in the kinds of open and ill-structured tasks they are likely to encounter throughout life. Evidence suggests that the most motivating tasks for students are those that challenge but do not overwhelm them (Perry, Phillips, & Dowler, 2004; Turner, 1997) and that opportunities for failure can be productive (Kapur, 2008; Rohrkemper & Corno, 1988).

Limitations of the academic task literature in terms of this dissertation study should be noted. In Doyle's conception of academic tasks, uncertainty was not a very well-developed concept. He referred to only two forms of uncertainty: ambiguity and probabilities associated with failure. Furthermore, by commandeering the term *risk*, Doyle assumed that an evaluation of uncertainty was a threat or danger, an issue further discussed in the next section of this paper. The issue of uncertainty in academic tasks seems not to have been expanded very much by subsequent researchers. No studies I could find conceptualized the forms and sources of uncertainty in the detail suggested by my study. Nor has the literature to date adequately described the range of strategies students use to manage uncertainty during various kinds of academic tasks, how they manage uncertainty in collaborative settings, or the dynamics of uncertainty management across a task or a set of tasks.

Collaborative Design Projects

The robotics projects observed in this study were purposefully selected as academic tasks likely to elicit uncertainty. In particular, I perceived that the final project, a collaborative design task, might especially provide an environment conducive to uncertainty and thereby be an opportune context in which to study students' uncertainty management.

Design tasks entail the creation of an idea or physical artifact through thinking and manipulating tools and/or materials (Bereiter & Scardamalia, 2003). Designing has most often been investigated in fields such as architecture, engineering, and computer programming, and in the post-secondary education literature pertaining to those fields. However, it is well recognized that design takes place in a wide range of activities (Goel

& Pirolli, 1992). Designing is often accomplished in collaborative teams (Brereton, Cannon, Mabogunje & Leifer, 1996; Cross & Cross, 1996), and designers must have the capacity to "think as part of a team in a social process" (Dym, Agogino, Eris, Frey, & Leifer, 2005).

Design tasks promote a "view of knowledge as purposeful, fluid, and conditional" (Penner, Lehrer, & Schauble, 1998, p. 1), and this may affect the ways designers come to manage uncertainty. Designers must learn to cope with undecidable problems, act without imposing inappropriate order, refrain from looking for a single correct outcome, leave room for continuous improvement, and accept and welcome opportunity over certainty (Glanville, 2007). Design tasks are underdetermined because a design cannot be fully defined by the problem statement (Meijers, 2000). Designers must rely on creativity to generate a unique product (Dorst, 2003). However, they are not free to invent anything; problem constraints partly determine a problem. Engaging in design involves continually redefining the problem and choosing among multiple paths that can be taken to infinite, unpredictable solutions (Delisle, 1997; Duch, 2001). Design tasks are complex, with multiple interdependent sub-problems that must be iteratively and recursively approached and integrated across long time periods (Adams, 2001; Jonassen, 2000). Rather than linearly working through each sub-task, designers iteratively revisit them throughout a project.

Although uncertainty management has been identified as a core feature in design tasks (Adams, 2001; Glanville, 2007; Hjalmarson et al., 2007), systematic study of uncertainty strategies used during academic design tasks are rare. Adams (2001), in a secondary analysis of verbal protocols of freshman and senior college engineering students in an experimental setting, found that successful management of uncertainty in design tasks involved revising the problem definition and solution simultaneously through coupled iteration of design phases to resolve ambiguity. Students who went through more iterations out-performed those who ignored uncertainty. Students who have limited experience with design tasks and may expect to be clearly told what to do may become frustrated or "stuck" when new uncertainties arise as prior uncertainties are resolved (Hjalmarson et al., 2007). Cadella and Atman (2005), in a qualitative study of a college engineering design task, found that beginning students often utilized only reduction strategies for managing uncertainty, or became stuck early and were unable to proceed until their uncertainty was resolved. Specific strategies that students employed include verifying questionable information or data, devising strategies for gathering information, estimating to fill in for missing information, breaking the problem into smaller parts, monitoring their progress all along the way, and deciding how many possibilities to consider or pursue.

The collaborative nature of some design tasks adds an additional potential source of uncertainty as students must grapple with social interdependencies associated with collaboration as well as content problem solving. In a protocol analysis of designers working collaboratively, Cross and Cross (1998) found a wide variety of social processes including misunderstandings and miscommunications, avoidance and resolution of conflict, and persuasion to achieve adoption of ideas, perspectives, and actions. The social processes associated with design teams mimic what educational researchers have found in academic collaborative settings. The body of literature on collaboration is immense and will not be reviewed here. Suffice it to say that collaborative grouping can promote understanding through sharing of information (Slavin, 1983, 1995), but primarily when collaborating is necessary to create an assigned product (Blumenfeld & Meece, 1988), and when students are given instruction in effective social interactions (Webb & Palincsar, 1996). Collaborative tasks can also encourage reliance on peers (Webb, 1982), lowered cognitive engagement (Blumenfeld & Meece, 1988), and discourse dealing mostly with visible, tangible aspects of the task rather than abstract ideas (Mercer, 1995), perhaps as a way of ignoring or evading uncertainty.

Only recently, as interest in engineering and technology education has increased, have researchers begun investigating the use of design tasks with young children (e.g., Petrosino, 1997; Roth, 1995; Schauble, Klopfer, & Raghavan, 1991). Engineering design tasks are seen as having the potential for helping K-12 students learn to deal with complexity and ambiguity as well as a means through which to learn science and math (e.g., Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Kolodner et al., 2003; Mahlke, 1993; Sadler, Coyle, & Schwartz, 2000). When engaged in academic design tasks, students are likely to experience uncertainty due to missing information not included in the problem specification, questionable data, information that does not exist, and multiple possible approaches to solving each problem. Because design tasks are creative tasks, students may encounter uncertainty as they generate possibilities about what to design and how to design. Students may experience more uncertainty about their abilities to create something than they do about the content of the task because a tendency to be overconfident in their judgments may prohibit uncertainty about curricular content (Kahneman et al., 1982; Langer; 1975; Sieber, 1969).

Managing Uncertainty through Interaction: How, Why, and When We Express Uncertainty

The interdependence between task and language is well established (Erickson, 1996; Hiebert & Wearne, 1993). It is therefore rational to assume that a task selected to elicit high levels of uncertainty will reciprocally influence and be influenced by peer discourse and language use. Language and discourse are not only tools for *expressing* thinking, but also tools for thinking itself. Language has a primary place in participating in and mediating learning and meaning making (Schallert & Martin, 2001; Vygotsky, 1978). Babrow et al. (1998) noted that communication is "essential to the construction, management, and resolution of uncertainty" (p. 1). As it relates to students' uncertainty during collaborative academic tasks, discourse is a primary means of expressing and managing uncertainty.

Language is not just about expressing things, language does things, and sometimes several things simultaneously. For example, a single comment can describe feelings of uncertainty, manage that uncertainty, manage how others see the speaker, and move a task forward. These coexisting functions can be competing or mutually reinforcing. In many ways, discourse functions to reduce uncertainty. As groups develop joint ways of speaking (Gumperz, 1982; Hymes, 1974), dominant discourses tend to colonize other discourses that might provide alternative viewpoints (Kress, 1989). Individuals implicitly agree to follow maxims of conversation that increase predictability and decrease uncertainty (Grice, 1975). However, as Erickson (2004) pointed out, individuals do not simply follow conversational rules, they use them, often in ways that increase uncertainty, intentionally or not. Sawyer (2003) theorized that improvisation is a required skill in conversation due to the ambiguous nature of discourse.

The ability to manage uncertainty through discourse is crucial for establishing group membership in some communities of practice. For example, scientists must acquire *communicative competence* (Hymes, 1974) in conveying belief about the truth value of propositions in scholarly writing (Hyland, 1996). Medical students must learn how and when to express uncertainty appropriately, and they must recognize which forms of uncertainty are “sanctioned and strategically useful,” and thus safe to express (Lingard et al., 2003, p. 609). It is likely that students managing uncertainty in collaborative groups learn in their groups and over time in school what uncertainties are safe to express and how to express their uncertainty in ways that maintain psychological safety and elicit help in the form of feedback from others. Participation structures that develop in classrooms can create or limit opportunities for students to experience uncertainty during collaborative tasks and can lead students to use reducing or acknowledging strategies to manage their uncertainty.

Using Language to Manage Uncertainty in Classrooms

Teachers and classroom texts often appear to be using language as a means to manage uncertainty by ignoring it, which limits the modeling for children of what to do when they are uncertain (Chapman, 1997; Feldman & Wertsch, 1976). However, teachers can also encourage discourse that accepts or even creates uncertainty for themselves and for their students. Rowland (2000) noticed that teachers often use uncertainty markers as a pedagogical tool during mathematics lessons, weakening the certainty of a claim in order to prolong engagement. I have noted in informal observation how teachers sometimes “fake” a degree of their own uncertainty, pretending to be puzzled during discussion with students to elicit motivation or encourage elaboration.

Of studies examining uncertainty in students’ use of language in academic settings, most have been conducted in experimental contexts, observational settings of talk between a child and adult, or in whole-group classroom discussion. In examining the oral responses of 9th and 10th graders listening to short stories, Squire (1964) noted that students who “search for certainty” or “fail to withhold or suspend judgment” also show comprehension difficulties (p. 47). Rowland (2000), in a series of increasingly standardized clinical interviews, engaged 4^{th} grade students in mathematical thinking tasks and found extensive use of uncertainty markers during interactions in a researcher/student setting. He obtained similar results in naturalistic observations of whole class discourse. Meany (2006), looking across math assessment tasks in discussions between a teacher and a single student, found that elementary students’ use of linguistic uncertainty markers changed across phases of the task.

Peer discourse. Researchers are increasingly turning their attention to the learning affordances of peer discourse in small group classroom discussions (Maloch, 2005). Cohen (1994), in a review of research on group work in educational settings, found that the quality of discourse is particularly important for groups working on less structured problems. Students’ responses in student-led discussions can be complex (Almasi, 1995), and students utilize talk for a variety of purposes (Eeds & Wells, 1989). Peer discourse can lead to the generation and exploration of scientific ideas (Hammer, 1995; Hogan et al., 1999). Problems are also associated with peer discourse. Task instructions, student preparation, and the teacher’s role can unduly constrain discussion in collaborative tasks, particularly around less structured problems (Cohen, 1994). Social inequalities are often re-enacted as powerful students tend to dominate and others are marginalized (Lewis, 1997; Maloch, 2004).

In collaborative settings, students tend to use implicit and subtle forms of help-seeking and help-giving to manage aspects of tasks about which they are uncertain (Kempler & Linnenbrink, 2006). Through their discourse, they voice agreement, make additional comments, suggest alternative explanations, and monitor work naturally in their conversation. These behaviors allow students to hear multiple perspectives on a problem and grapple with their own current understanding of the problem without asking direct questions (Webb, Ing, Kersting, & Nemer, 2006). Although many factors prompt help-seeking, experiencing uncertainty is likely often the reason for engaging in these behaviors. Help-seeking under conditions of ignorance has been found less effective than help-seeking when one is uncertain but has enough understanding or knowledge to ask specific questions (Webb et al., 2006).

Few studies have explicitly examined uncertainty in discourse practices among peers. But it seems implicitly understood as part of that experience (Cazden, 2001; Mercer, 1995, 2000), and it is likely that peer discourse influences the ways students' manage uncertainty. For example, emotional risk often accompanies peer discourse, and students may avoid asking questions that will expose their ignorance and confusion to peers (Nystrand, Wu, & Gamoran, 2003). Patterns in students' collaborative discourse tend to parallel the discourse patterns of their teachers (Webb, Nemer, & Ing, 2006). If a teacher venerates certainty in her/his discourse, it is likely that students will adopt those ways of talking with their peers.

I could find only one study explicitly investigating how young students manage uncertainty through peer discourse during academic tasks, and that was within a larger study. By identifying relevant conversational moves and calculating their conditional probabilities across time, Anderson et al. (2001) showed that fourth graders influenced one another's use of uncertainty markers during literature discussion tasks. The authors found that once an uncertainty marker (a hedge) was introduced by a student, it tended to "snowball," being used by more students and increasingly often. Through their rhetorical moves, students managed their uncertainty by keeping the talk focused on issues about which they were uncertain. Based in part on these findings, as well as on the theoretical frameworks discussed at the beginning of this chapter, I expected that relationship patterns established within a group would affect the uncertainty management of group members (Shiller, 1995). Because of the power of language and discourse to shape experience, strategies and tactics students use to manage uncertainty are likely to be especially influenced by the peer discourse that unfolds in a collaborative group.

Summary

My hope is that the study described in this dissertation might add to our understanding of how students experience and manage uncertainty during collaborative robotics engineering tasks and how the structure of academic tasks and interactions with peers' influence students' uncertainty management. I also see this study as potentially contributing to the academic task literature, particularly to our understanding of the affordances and constraints on learning from open-ended, less structured collaborative tasks. Furthermore, there is the potential for this study to contribute to the literature on peer discourse in collaborative settings, particularly in the STEM disciplines.

In the literature review above, I identified several areas in which we need to expand our understanding related to how students manage uncertainty in academic tasks. First, past studies have primarily focused on between-person differences in the ways students respond to uncertainty in learning contexts. In this study, I focused on within-person differences in uncertainty management. Second, few studies have addressed uncertainty in authentic academic contexts, and fewer still have directly observed how students manage uncertainty while engaged in academic tasks in different curricular disciplines. Furthermore, few studies have examined the intersection of uncertainty management about task and social goals. In my study, I remained alert to the interdependencies between task and social issues.

CHAPTER 3

METHOD

"To forget is to let the grass overflow and prefer to the certain delight, the uncertainty to come."

-Luis Llorens Torres

In this chapter, I describe the methods and procedures I used to collect and analyze data in my investigation of how students managed the uncertainty they experienced while engaging in collaborative robotics engineering projects in one fifth grade class. The chapter is divided into the following five sections: a) overall approach and rationale; b) research context and participants; c) description of the instructional setting; d) data sources and procedures; d) data analysis; and e) methods used to establish trustworthiness.

Overall Approach and Rationale

I designed this qualitative study to focus on fifth grade students as they engaged in collaborative robotics engineering projects. The study was initiated at the beginning of instruction related to robotics engineering and preceded through the completion of several long-term collaborative robotics projects, two of which were more structured tasks and one of which was a less structured task.

In general, the methods used to address my research questions were inductive and interpretive, consisting of naturalistic observation and interviews conducted over the course of one school year. Through this qualitative observational study, I sought to understand rather than to change what was going on during regular task engagement. To observe the management of uncertainty in this setting, I relied primarily on naturalistic observation of small group collaborative sessions, collection of students' written reflections and other written work, and student interviews. My data analysis was inductive and interpretive, using qualitative discourse analysis techniques and methods of grounded theory (Corbin & Strauss, 2008). Given that uncertainty management is a relatively unexplored topic in educational settings and given the open-ended nature of my research questions (Edmondson & McManus, 2002), the approach I took seemed appropriate.

Standards of trustworthiness for qualitative research were adhered to in multiple ways throughout data collection and data analysis (Ary, Jacobs, & Razavieh , 2002; Lincoln & Guba, 1985). *Credibility* of the research was established through prolonged engagement and persistent observation. It was also addressed through triangulation of sources (e.g., students, teacher, researcher, and outside observers) and triangulation of methods (e.g., observations, interviews, audio and video recordings, artifacts). Negative case analysis, peer debriefing, and extended involvement were used to diminish researcher bias. *Dependability* came through overlapping methods to improve the reliability of the data and recruitment of auditors helped me reflect on my processes and products (Lincoln & Guba, 1985), and through ensuring an audit trail to guarantee thorough description of procedures and events (Ary et al., 2002). *Confirmability* was met by involving others in the coding and interpretation process. Member checking with the teacher observed in this study occurred on multiple occasions during which I shared preliminary findings and requested feedback. Peer debriefing was used throughout data analysis in order to make my assumptions explicit, ensure data collected were congruent with the research objectives, verify my interpretations, and manage my feelings of being overwhelmed by the data (Do & Schallert, 2004). Debriefing occurred with colleagues who had also observed the activities that occurred in this study and also with colleagues to whom I presented preliminary and interim codes, working hypotheses, themes and models. My peer reviewers included colleagues in educational psychology, organizational science education, literacy education, and instructional technology. Finally, t*ransferability* was addressed by providing thick descriptions so that readers can make informed judgments about transferability to contexts of interest.

Participants and Context

Participants in this study included 24 fifth grade students (15 boys, 9 girls) and their teacher, a White woman with 23 years of teaching experience and considerable expertise in project-based science and technology instruction. In the section below, I first describe my reasons for selecting this study site and then describe my participants and the instructional context in which I observed them.

Selection of Site

My review of the literature on sources of uncertainty in academic settings suggested that academic tasks with novelty, ambiguity, complexity, and evaluative risk are most likely to elicit uncertainty in students. Therefore, I designed this study to take place in a science-related educational setting in which upper elementary or middle school students were engaged in at least one collaborative ill-structured, generative, or design project because I felt that such projects would offer a high probability of observing students' experiencing and managing uncertainty. As I elicited suggestions for sites from teacher friends and knowledgeable acquaintances and as I visited possible sites, it was difficult to find academic contexts with middle-aged students in which teachers were assigning projects with these characteristics. Finally, upon observing robotics instruction in several elementary school settings located in the same school district, I identified this instructional context as a potentially appropriate setting for my study. Based on twelve observations in eight educational settings in this district during the school year prior to the one in which data for this dissertation were collected, I became confident that robotics engineering offered an optimal space in which to study uncertainty management in academic learning tasks. Because robotics was new to all but one of the students in this study, it provided a unique opportunity to study uncertainty elicited from novelty as well as uncertainty due to the complex intersection of interdependent sub-tasks and the semiotic signs associated with them, and the ambiguity that characterize design activity. Also, because students worked collaboratively, their social practices were made visible (Rowell, 2002) as were the ways they managed the uncertainty they experienced while engaging in robotics engineering practices.

In conversations with several of the teachers who included robotics in their instruction in this school district, Ms. Billings was identified as having been influential in catalyzing the use of robotics in the district. She had encouraged other teachers to participate in robotics training and had championed its use in the regular classroom math, science, and technology curriculum. It was in this teacher's fifth grade classroom from which the data for this dissertation were drawn. I should note that at same time I observed the class for this study I was also gathering data in three other settings in this school district for various lengths of time (i.e., another regular fifth grade class, a pull-out program for fourth and fifth grade students identified as gifted and talented, and an after school robotics club comprised of students in grades four through seven). My observations and analysis of the students in this study were influenced by these experiences.

Ms. Billings taught in a public fifth grade classroom at Midtown Elementary School (names of all persons and places are pseudonyms) situated in Briarwood Independent School District, a medium-sized suburban school district in the Southwestern United States. Located close to a mid-sized urban center, Briarwood Independent School District served a community of approximately 40,000 people. Of the 20,000 students in this district, 34% were Hispanic, 34% were Anglo, 23% were African American, and nearly 9% were Asian American; 42% of the students in the district qualified for free or reduced lunch; 12% of the students were English Language Learners. Although robotics engineering is not a traditional elementary school subject, it was a popular curricular area in Briarwood ISD. Several teachers in this school district had gone through training in teaching robotics and were providing instruction in robotics, often with the help of community volunteers. Robotics instruction in Briarwood ISD was most prevalent in fifth grade classrooms. Six fifth-grade teachers included robotics as part of their curriculum at the time I was collecting data. There had also been a recent initiative to implement robotics instruction in all the gifted-and-talented (GT) pullout programs in the district. Additionally, several elementary, middle, and high schools in the district hosted after-school robotics clubs.

Student Participants

The 24 fifth grade students in the class observed for this study were representative of the diversity in the suburban school district in which their school was situated. In terms of academics, five students in this class received special education services. Isabel was dyslexic and received inclusion services for math and language arts and was pulled out of the regular classroom to receive instruction in spelling. Becky and David were also pulled out for spelling. Dora and Sammy were pulled out for spelling and math. The teacher had initiated the process of having Alicia identified for special education services. Three students, Andrew, Berta, and Satya were identified as gifted-and-talented. These students were pulled out of the regular classroom two times a week as part of a gifted and talented program. All the students pulled out to receive special services sometimes missed part of robotics instruction.

In terms of ethnic and cultural diversity, ten students were Black, seven White, four Hispanic, and two Asian. Although all students were proficient in English, Luis received ESL services. Both of Luis's parents spoke Spanish and had limited-English proficiency. Spanish was spoken along with English in two other households (David and Domingo). Bobby's mother spoke Korean and very little English. Berta's mother also spoke very little English.

Socioeconomic situations varied for these students: 33% of the students at Midtown School were identified as economically disadvantaged, a percentage that seemed to approximate the students in the observed classroom, where parent incomes varied widely. For instance, Satya's mother was a physician; Demetre's father worked as a car wash attendant; Nathan's mother had been laid off from a prominent computer company and the family moved to another state mid-way through the year; Berta's mother worked as a medical assistant; Bobby's mother was a homemaker and his father was laid off from a job related to the computer industry; Ray's mother was a teacher, anxious that he do well on the state standardized assessments. Most of the students came were living in households with two adults, several were members of blended families. Berta lived with both her parents and her younger brother who attended a school for autistic children. Domingo lived with his single mother and his older brother who his mother reported was affiliated with a local gang. Alicia lived with her father and five siblings. Everett lived with his aunt and uncle and was also supported by his grandmother. In short, the class might be said to represent a cross-section of the American experience.

As in many mid-sized communities, many of these students had relationships with one another that went beyond their interactions in this classroom. Some had attended the school throughout their elementary education and been in classes together in previous years. Shamitra and Derrick were cousins. Derrick and Frank lived down the block from each other and had grown up playing with each other. Isabel's brother knew Derrick. Only Shamitra was new to the school the year of the study.

Communication between the classroom teacher and students' families varied across the students. At least one parent of nine students attended back-to-school night (6 White, 1 Hispanic, 1 Black, 1 East Indian). Berta's, Becky's, and Andrew's parents came to Robofair, the end-of-school event to showcase students' final robotics projects. Some parents rarely if ever visited the classroom whereas others I spoke to several times throughout the year. For instance, Isabel's mother occasionally walked Isabel to class, and she always exchanged greetings with me. Satya and Andrew's mothers stopped in occasionally to chat for a few moments with the teacher and drop something off for their children. Demetre's parents attended back-to-school night together, bringing with them Demetre's two younger brothers.

Teacher Participant

The teacher in the classroom observed for this dissertation study, Ms. Billings, was White, with more than 20 years in the classroom. Ms. Billings was well-versed in inquiry-based and project-based instruction and experienced in teaching robotics design. Skilled in the use of technological tools, Ms. Billings created multi-media parent newsletters and maintained a class website to which she frequently posted students' work, upcoming events, curricular materials, and homework. She stressed the role of technology as a "*tool for thinking*," and technology played a large role in her instruction. In the year prior to the one in which I collected data in this classroom, Ms. Billings had been selected as one of the first teachers in her district to have a promethean board installed in her classroom. She and her students used this tool extensively throughout the day. Additionally, the school had two rolling computer carts with a class set of laptops and online access. One of those carts was used on a daily basis in Ms. Billing's classroom. Students utilized laptop computers across the curriculum, for instance, using Microsoft Excel to summarize data from surveys and Picture Maker to organize and visually present information about energy sources and processes. Students utilized the internet to search for information. During a social studies unit about the American colonies, I observed Demetre look up *pearl ash* and *potassium carbonate*, trying to understand how soap was made. Shamitra searched for colonial recipes that she then printed and bound into a recipe book. Finally, students utilized web 2.0 tools. They participated in several book clubs across the year for which they were expected to post to a wiki dedicated to their self-selected reading group. Students were graded in this task based on whether they wrote something meaningful, seemed to know what was going on, and responded to other members of their book club.

In Ms. Billing's classroom, technological tools were often used in the service of project-based instruction across the curriculum. Ms. Billings was passionate about students' opportunities for project-based, hands-on, real-world application of problem solving. She also believed in collaborative grouping. Evaluation of projects often had a collaborative component, and Ms. Billings frequently gave instructions in how to collaborate effectively. Public display and presentation were also a regular part of individual and collaborative projects. For instance, in one assignment, students wrote limericks and presented them to the class. The class voted on their favorite limerick, which was later shared with the entire school during the daily school news program. In another example, after watching *The Design Squad*, a PBS program in which young students participate in a collaborative design process, students were assigned to design and make their own musical instruments at home and to demonstrate them for the class. During a social studies unit, students wrote scripts and enacted various events from the American Revolution in collaborative groups. The teacher recorded and edited them into a film that was later shared with students in other fifth grade classes.

Description of the Instructional Setting

Because robotics engineering is not part of the standard scope and sequence of most state or local curriculum objectives, it may need some explication here. Robotics engineering is generally thought of as the science and technology of designing, manufacturing, and considering applications for the use of robots. Robotics engineering is a field heavily reliant on computer science to create mechanical structures guided by computer or electronic programming that can move autonomously through their environments and respond to sensory input as they complete a specified objective. There is not widespread agreement about what differentiates robots from other machines, but in general, a robot is composed of a mechanical structure, a central computer, motors and sensors, and a power source. A robot uses actuation (converting stored energy into movement), activation of sensors, manipulation, navigation, and locomotion to interact with the environment. Robotics engineering has changed everyday aspects of our lives from the automated doorways allowing easy entry into public buildings to tools used in the exploration of space and the ocean floor, healthcare and warfare applications, and the assembly of automobiles and airplanes.

Based in part on attempts of researchers and practitioners to put into practice the ideas of Seymour Papert (1980) of using computer-based learning environments to support children's construction of knowledge, robotics has become a popular way to introduce young students to computing. Teacher training programs exist in several places around the United States. A few companies provide curricular materials for individuals and for schools. For example, the LEGO Group and National Instruments began collaborating in 1998 to create age-appropriate robotics products for grade school students, marketing them to educators and parents. This was the system used in the class in which I observed.

Robotics engineering as practiced in the observed classroom consisted of building structures using Lego Mindstorms NXT programmable robotics kits. The kit consists of hundreds of LEGO building pieces (e.g., beams of different sizes and shapes, connectors, axles, blocks), servo motors, sensors (ultrasonic, sound, touch, and light), connection cables, and the NXT Intelligent Brick (the “brain” of the robot). When building robotics structures, students manipulated these materials, sometimes referring to attendant texts such as online and hard copy/printed building manuals. These physical objects used for pragmatic purposes carried symbolic weight. Students had to move from looking at meaningless pieces (e.g., motors, gears) to looking at those same pieces for what they afford in a design that students can build (e.g., axles connect wheels to platforms; gear trains transfer energy between parts of a system).

Using LEGO MINDSTORMS NXT software, students programmed the structures they had built with LEGO building pieces. This graphical programming software optimizes the user interface for young children using an intuitive drag-and-drop environment. The user drags pictorial icons, “blocks” from a pallet at the left side of the screen onto a diagram (see Figure 3.1). Each block performs a unique function such as to activate the motors, display a message, detect a sound, or measure a distance (see http://www.ni.com/academic/mindstorms.htm). When an icon is highlighted, information associated with it appears at the bottom of the screen. Students must connect information at the bottom with its individual icon as well as jump between a micro-reading of a particular icon and comprehension of the program as a whole. Programs are downloaded to the NXT via a USB cable. Programming robots required students to recognize and differentiate between programming icons, integrate textual information from multiple places on the screen, negotiate interdependencies between power, duration, and direction, understand linear sequencing, mentally image how program actions would be enacted in robot actions, and recognize programs as they are enacted in robot actions.

Robotic structures and programs are interdependent in the sense of needing one another for full fruition. A constructed structure is not a robot, neither is a computer program. Only through interdependencies among multimodal entities do robots emerge. Learning to coordinate functionally among modes is paramount in science education (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Lemke, 2000), and that was true of robotics engineering as practiced in this class. Continuously revising drafts of a robotics program to enable a built structure to maneuver through or act on its environment requires visual imagery and translation between two-dimensional images to three-dimensional objects.

Prior to the school year in which I observed her class, Ms. Billings often had help from community volunteers familiar with the tasks and tools of robotics instruction. Volunteers were not available the year I collected data. In the year I collected data for this study, robotics instruction consisted of direct teacher instruction reinforced with online support, teacher and student modeling of tools and practices, and three long-term, collaborative small-group robotics engineering projects assigned over the course of the year. The first two robotics projects could be considered *more structured* tasks. During these projects, students were introduced to the semiotic sign systems associated with robotics and they re-produced largely pre-designed robots. The third and final task was a *less structured* task in which students used a design process. In each of these projects, students worked independently in their groups during collaborative robotics sessions while the teacher circulated among the groups, assessing their progress and helping them move forward. Pre-project instruction and each project are briefly described below. Table 3.1 summarizes the time devoted to each project.

Table 3.1 Description of Robotics Engineering Projects

	More Structured Tasks		Less Structured Task
	Project 1	*Project 2*	*Project 3*
Start & end date	Sept 19 to Dec 12	Jan 9 to May 1	May 5 to May 28
Total Sessions	13 sessions	14 sessions	14 sessions
Days per week and time spent	Once a week 40 to 90 minutes each	Once a week 40 to 90 minutes each	3 to 5 days a week 40 to 120 minutes each
Culminating experience	Classroom competition; points awarded for each successful action; described process and challenges to class	Classroom competition; points awarded for each successful action; described process and challenges to class	Robofair; showcased and demonstrated their design to the student body and to community members; included a poster board of research

Pre-project instruction. Prior to assigning the first robotics engineering project, the teacher presented information about systems, robotics, and engineering and provided several experiences related to that information. Ms. Billings set robotics engineering instruction within a larger context of designed systems analysis. She introduced students to the idea of systems by showing them cross section diagrams of several everyday systems (e.g., a fire extinguisher) and having them analyze, diagram, and label simple classroom systems (e.g., staplers, mechanical pencils). The following week, the teacher introduced students to control systems and assigned them the tasks of modeling processes (flow of actions, steps and actions) by creating flowcharts and by acting them out in collaborative groups (e.g., automatic doors at the grocery story; automatic towel dispensers in public restrooms). Ms. Billings connected this instruction to engineering and robotics, telling students that when they built robots, they would need to describe the parts of the robotic system, explain how the parts work together, and explain how the user operates the robot. Finally, the class discussed robots: What is a robot? What are robots used for? Why should we learn about robotics?

Project 1 description. For Project 1, Ms. Billings assigned students to collaborative groups of two or three members. Students were introduced to building from an instruction manual (primarily using pictorial representations), and to basic programming to enable locomotion (e.g., move forward, stop, turn) and trigger a touch sensor. Project 1 can be described as a more structured task. The primary cognitive demands students faced in this project were to acquire comprehension of the basic signs in the multiple semiotic systems associated with robotics engineering and to re-produce a robot pre-designed to do a pre-specified task. All groups were instructed to build the same rover from a printed instruction manual and to program their rover to maneuver through an obstacle course, hit a wall, trigger a touch sensor to reverse direction, and land on an X. Before describing the assigned project, Ms. Billings introduced students to the Lego Mindstorms NXT building kit; naming the pieces, functions of pieces, and how pieces fit together. Students began by building a rover from the building instruction manual included with each kit. The print-based manual was comprised almost entirely of pictorial inscriptions and numeric text indicating the sequence of steps and quantities and sizes of pieces. The teacher demonstrated the first few steps in the manual, showed students to put the pieces down on the instruction manual to check sizes, and hold pieces in the same orientation as the picture in the book at every step.

Programming activity during Project 1 was structured but not as highly structured as building activity. No step-by-step instruction manual was provided for programming.

The teacher introduced students to the Mindstorms programming environment and modeled the programming practices on the promethean board. The teacher introduced students to the Mindstorms software and modeled programming practices of selecting programming icons from a palette and dragging and dropping them in a sequence. She instructed students as to what icons they were allowed to use in their program (i.e., move blocks, wait for blocks, stop blocks, a sound sensor) and gave mini-lessons throughout the project in executing turns, switching between palettes, selecting motor icons, differentiating between motors A, B, and C; choosing between rotations, degrees, and time to measure distance.

Right from the beginning of the year, Ms. Billings emphasized design processes. Although Project 1 was more structured in most of its parameters, there were opportunities for student choice and decision making. Ms. Billings encouraged students to re-design the original rover to fit their own needs, presenting optional changes to the structure (e.g., groups changed out their wheels, re-configured their touch sensor, and made cosmetic changes) and conveying the expectation that every group's program would "*look a little different*." For instance, after two instructional sessions dedicated to math instruction in measuring and calculating wheel rotations and degrees and correlating them with distance travelled, she said of decisions about measuring distance, "*With degrees you have to count with large numbers, right? Your numbers got pretty big. Rotations is a lot easier. How many people preferred rotations? Anybody prefer degrees? Does anybody really want to work with time today?"* [102408]. She also introduced the idea that students would eventually design their own robots: "*You're going to have a lot of opportunity to make up your very own, what you want. That time is going to come...*

And I'm not going to tell you how to build it. There's not going to be a plan. There's not going to be directions… But you can't do that until we build some basic skills."

Throughout Project 1, the teacher worked with individual groups, giving mini-lessons on issues related to building structures and programming. She also led peer debriefing sessions in which members of each group described their difficulties and students from other groups as well as the teacher offered advice. At the end of Project 1, the groups showed their work publicly, demonstrating their robot to class members and explaining their process and design changes, and were awarded points for each action their robot completed in the obstacle course. Project 1 took place over 14 sessions across four months. Sessions ranged from 40 to 90 minutes during which the teacher provided whole-class instruction and facilitated short, whole-class debriefing sessions, and the groups worked alone and with teacher support.

Project 2 description. Ms. Billings re-assigned students to a different group for Project 2, again with two to three students per group. This project was well-structured, much like Project 1. Students built a robopuppy structure using online directions (see http://www.nxtprograms.com/puppy/index.html) and programmed it to move forward when a sound sensor was triggered, stop and reverse when an ultrasonic sensor was signaled by the presence of a cardboard "cat," turn and move forward until it hit a black line at which point a light sensor followed the line into a doghouse. New knowledge and skills were introduced during this project. The robo-puppy was a more complicated structure than the rover students had built in Project 1. The programming was also more complicated. Students learned to trigger sound, light, and ultrasonic sensors, use a loop to initiate repetition of a sequence, a split task to respond differentially to multiple stimuli, and a move block to initiate movement of two motors simultaneously. The teacher's whole-class instruction varied from Project 1 only in that she utilized voice-recorded directions downloaded from the Internet in some of her instruction. It was also during Project 2 that Ms. Billings called students' attention to the help guide associated with the Lego Mindstorms programming software and demonstrated its use. Project 2 took place over 14 sessions across four months. Just as in Project 1, the teacher provided whole-class instruction and groups worked alone and with teacher support.

Project 3 description. Project 3 was a less structured task that could further be differentiated as a design task. Assigned to collaborative groups of three to four students, students were charged with designing, building, programming, and testing their own robot to address an environmental problem they had identified. The materials constraints were identified (e.g., each collaborative group could only use one NXT) along with other parameters of the project. In explicating the task, Ms. Billings explained that each group was going to design and create an *invention* that (1) makes life easier, (2) lets us do things we couldn't do before, (3) improves something from the past, and (4) helps solve a problem. She defined *environmental* and *design*, reminding students of a PBS program they had viewed earlier in the year called *The Design Squad* (http://pbskids.org/designsquad/season1/index.html, *Rock On* downloaded 022710). In that recording, design was depicted as a process of brainstorming, building, testing, troubleshooting, and presenting. Ms. Billings reviewed the process prior to and throughout Project 3.

After handing out small notebooks that would become students' *design journals*, Ms. Billings asked students to individually brainstorm ideas for robotic products they could create to address an environmental problem they themselves had identified. She then instructed them to discuss their ideas with their group members and decide on a product they would create together. Instruction in Project 3 included whole-group debriefing sessions during which students displayed their design sketches and/or robotic structures on the promethean board. Ms. Billings also consulted with small groups about their specific design processes. She provided "just in time" instruction in different building and programming issues that surfaced for a particular group. For instance, she suggested that one group look up online building instructions for a product that had a chassis similar to what the group needed for their design; she explained and demonstrated gear trains to a group that needed to increase the force of the blades they were using to cut brush.

There were more opportunities for written reflection during Project 3 than in the previous two projects and reflection through a wider range of media. Students chronicled their progress by posting to group wikis, reflected on their group process in individual design journals, and displayed their research on poster boards. Students used more forms of technology in this project (e.g., the promethean board for presentations, web searches, Excel).

There were also more frequent opportunities for collaborative reflection within each group and among class members during Project 3 than there had been in either of the first two projects. For example, on at least five occasions, the teacher explicitly instructed students to put all their materials down and plan with their group members for five to ten minutes before building. There were also frequent whole-class debriefings about the progress of each group’s product design. These debriefings were sometimes called "face the jury," reflecting the challenges and questions from the teacher and classmates after a project had been presented. After the first debriefing, four groups completely changed their problem specification. Berta's group changed from designing a pressure gauge to designing a garbage grabber; Kisha's group changed from designing a swifter cleaner to a device for smashing cow manure for fertilizer; Dora's group switched from designing a dog feeder to designing a brush cleaner; and Andrew's group changed from designing a toy launcher to designing a cup dispenser. Derrick's group modified their design from a pool heater and cooler to a lake cleaner. Only Satya's group stayed with their original basic design, a recycling transporter.

Instruction during Project 3 varied from Project 1 and Project 2 in one other important respect. Although in years past, other fourth and fifth grade teachers in Midtown school had taught robotics, this year Ms. Billings was the only one. Ms. Billings felt it was important that every fifth grader have the opportunity to participate in robotics, and she arranged with the other fifth grade teachers to monitor her class while she facilitated robotic engineering projects with their students. Thus, the students in the class in which I observed spent a significant portion of time working without Ms. Billings during Project 3. Every fifth grade student in Midtown School showcased a robot in the end-of-the-year Robofair that was the culminating experience for this project. Students in kthrough fourth grade were invited to this annual demonstration of projects, as were community members. During Project 3, students worked several days a week over one month in 14 sessions ranging from 40 to 120 minutes.

***Skills and practices associated with robotics projects*.** Collaborative robotics engineering projects can be thought of as being composed of interdependent skills and practices associated with building structures, reading and writing programs, testing, and designing. I describe in Table 3.2 some of the skills and practices students encountered as they learned to participate in robotics engineering activities and to meet the goal of successfully completing the projects. In Table 3.2, I present skills and practices students needed to learn in order to engage successfully with each type of task activity while working collaboratively on robotics engineering projects. The list of skills and practices is not exhaustive; it is meant only to give the reader a sense of the richness and complexity of these tasks. Note that I differentiate in Table 1 between programming and testing. Although programming and testing are highly interdependent activities and not completely distinguishable in practice, I differentiate between them here in order to highlight two sets of skills and practices.

Table 3.2 is organized from top to bottom in the order in which students were exposed to each type of task activity. Skills and practices associated with each type of activity are also sequenced chronologically within each type of activity in accordance with which skill students were introduced first. The first three types of activities (*building*, *programming*, and *testing*) were associated with Project 1 and also with Project 3. Design activities were associated primarily with Project 3.

Table 3.2 Skills and Practices Associated with Robotics Engineering Activities

Building Structures - recognizing and naming pieces (memorizing & creating vocabulary) -developing intuitions about how pieces tend to fit together -recognizing common functional relationships among pieces -reading print and online instruction manuals (translating from 2-dimensional media to 3-dimensional media, checking size by placing against page, counting bumps)
Reading and Writing Programs -basic computer skills (opening the program, locating the correct palette, clicking, dragging) -recognizing and naming icons -associating bottom of screen information with specific icons (recognizing that bottom changes as you click on an icon, understanding that information contained in an icon changes when you change information at the bottom of the page) -associating icons with their functions (e.g., stop, wait, move, sensors) -understanding methods for turning (e.g., stop or slow down motor on one side) -sequencing (directionality of influence, labeling, programming in parts) -comprehending that seconds, rotations, and degrees are all different ways of measuring distance of travel and understanding those measurement systems (e.g., 1 rotation means one time around the wheel) -physical support (wheel size changes distance traveled in one rotation, attaching and programming to ports, understanding relationship between NXT and motors) -accessing and utilizing programming instructions on the LEGO Mindstorms software
Testing: The interface between structure and programming -navigating the menu of NXT bricks (robot brain) to initialize a program -developing intuitions about distance relative to measurement (rotations, degrees, seconds) -choosing % battery power (link to speed, effects on turns, minimum needed, effects of low charge) -recognizing issues about precision (one cannot be infinitely precise: how precise is it possible to be, how precise do you need to be, is there one right answer, using partial rotations tools for increasing precision: tape, rulers, robot placement, effects of wobbly wheels) -recognizing issues of accuracy (use multiple runs of the same test) -recognizing interdependencies between robot structure, distance, duration, direction, & power
Designing Products: Brainstorming, Building, Testing and Troubleshooting -identifying an environmental need and deciding what product to design -generating ideas and models for how to enact their product -evaluating options and calculating feasibility based on material and time constraints -sketching; drawing out and labeling design sketches in journals and on whiteboards -seeking out pre-designed structures and programs online and combining ideas -producing and testing a product, continuously re-evaluating and re-defining the relationship between expected and actual outcomes and between outcomes and goals -participating in debriefing meetings (use design language, accept criticism, make suggestions) -navigating websites for information about similar products to check the product uniqueness -using design journals to record progress, reflect on progress, use as a discussion/planning tool -using a wiki to communicate with others about design, make & seek suggestions -presenting: talk about and demonstrate your design to an audience

Data Sources and Procedures for Data Collection

Data sources for this study included naturalistic observation. I used audio and video recordings and field notes of what occurred in the classroom during whole-class instruction and during collaborative small group sessions to document talk, physical interactions, and manipulation of materials. Transcripts were later made from the audio and video recorded data. I also collected artifacts pertaining to robotics instruction in the form of photographs of structures and programming files, and individual and group written work (e.g., written reflections, sketches). Additional data consisted of multiple interviews of all students and especially of the focal students, teacher interviews, informal group interviews, and spontaneous think-a-louds that a few students left on the audio recorders. These were conducted to gain participant perspectives on classroom interactions and to get a sense of students' underlying mental processes (Bogdan & Biklin, 1982; Op't Eynde & De Corte, 2002). In the sections below, I first describe in more detail the naturalistic observation and data collection activities related to it. I then describe my process for conducting interviews.

Naturalistic Observation

A vital aspect of this study was the direct, naturalistic observation I used to try and understand how the students were learning from their experience in robotics. I observed in this classroom a total of 51 days across the 2008-2009 school year. I was present in the classroom for all robotics activity, with the exception of three sessions. I took field notes and audio and video recorded whole-class instruction and collaborative small group sessions to document what happened in the class and capture the nature of students' interactions with the teacher, peers, objects, and tools. The main focus of my observations was on peer interactions that occurred among group members in collaborative small-group sessions. However, I observed and recorded all instructional activity related to robotics engineering, including whole-class instruction. Additionally, I observed and recorded the teacher as she moved in and out of interaction with individual groups, so data consist also of groups working with and without a teacher. Finally, I observed in other subject area across the curriculum as I arrived early to observe robotics instruction, observed as I waited to interview students, or when two robotics sessions occurred on the same day with other instructional activities intervening. These non-robotics observations added richness and depth to my understanding of what occurred during robotics instruction.

My observations began with the beginning of the robotics instruction unit, three weeks into the school year. At this time, the teacher introduced me to the students as a researcher interested in collaborative group projects and in robotics. I, with the teachers' help, described the study to the students and gave them two copies of the consent form for their parents along with a short letter of introduction by the teacher. Consent was also sought from parents at Back-to-School Night and when they visited the classroom at different times. All parents consented to their child being in the study, after which I explained the study to students once again and gave them the opportunity to sign an assent form. In the forms and in my presentations, I made it clear that participation was voluntary and students would not be penalized if they did not participate. All students signed the assent form.

As the teacher began the first few sessions of instruction associated with robotics engineering, I mapped the classroom, made notes about individual students, and began memorizing names. I set up the video camera so that students could get used to its presence prior to beginning small group work. For the first three observations, I limited my observational activities to recording field notes because I had acquired only the teacher's consent at that point in time. One of my objectives for this early observation was to develop an understanding of how the unit and the task are conceived by the teacher and students. Another reason for such intensive observation over an extended time was to facilitate participants' trust in me. Because later in the study I would be asking students to talk about their feelings and thoughts, interactions with other students, and reasons for their actions, it was imperative that students feel I was trustworthy, that I respected them, and that I would not reveal their words to others. I tried to limit the amount of time I spent conversing with the teacher in the presence of the students. Students' perceptions that I was affiliated or aligned with their teacher could create anxiety that I might share their personal responses with the teacher or mistrust my motives for observing.

Physical space constraints in the classroom were prohibitive of closely observing all collaborative groups, as was the sheer volume of data that would have been created. Early in the first collaborative robotics project, I rotated myself and recorders around the room, trying to help members of the class become comfortable with my presence and the presence of the recording equipment, trying to be unobtrusive and respectful of their work by refraining from interrupting, responding to their questions briefly and politely, and trying not to stare or make eye contact that might be distracting. I took notes on my computer and /or a small notebook, which students at first wanted to know about (e.g., “What are you writing?”) and later ignored. My other reason for moving around was to get a good sense of the entire class in order to select focal students.

Following Weiss’s (1994) suggestion that one try to acquire samples that maximize range, I focused on selecting students from several contrasting collaborative groups who were also diverse from one another in terms of academic achievement, gender, ethnicity, and social interaction style as identified by my early observations and confirmed by the teacher. Fifth graders are highly variable in their metacognitive awareness and therefore in their ability to reflect on their experiences (Keating, 2004). Because of this, the quality of information obtained from student interviews varied from student to student. I selected focal students who exhibited in early interviews the ability to reflect explicitly and directly on their own experiences during collaborative robotics sessions. The process of identifying focal students proceeded slowly, and I did not make any hard and fast decisions at first, trying to stay open and to get a general sense of as many students as possible. By the sixth collaborative session of Project 1, I was following eight initial focal students (members of four out of eight groups).

For Project 2 and Project 3, I continued to follow my initial focal students. Because students were re-assigned to new collaborative groups for each projects, this led me to observe students I had not focused on up to that point. In this way, I was able to collect longitudinal data on a greater number of students and observe a high percentage of students without becoming overwhelmed. I recorded only the collaborative groups with members who were focal students. I moved the video recorders between these groups, which meant that I did not capture on video all of the interactions of any group. Some of these groups were seated next to each other, which enabled me to video record two groups at a time. I primarily rotated myself among focal groups, taking field notes and photographs. However, I also spent some time with the other groups in order to check the representativeness of what I was seeing in focal groups. Table 3.3 shows the groups for each project, with focal students bolded and focal groups in grey.

Table 3.3 Student Assignment to Groups in Project 1, Project 2, and Project 3

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
Project 1	**Demetre** Nathan **Luis**	**Satya** **Kisha** Kim	**Isabel** **Becky** Everett	**Derrick** **Berta** Bobby	Shamitra Dora Fernando	Miguel Domingo Gerald	Ray Andrew Sam	Alicia Leon Eddie
Project 2	Andrew **Bobby** **Demetre**	**Ray** **Luis** Everett	**Satya** **Kisha** **Derrick**	**Isabel** **Kim** Dora	Berta Domingo Alicia	Becky Shamitra	Leon Miguel Fernando	Geraldo Eddie Sam
Project 3	**Demetre** **Satya** **Kisha** **Becky**	**Derrick** **Isabel** **Ray** **Bobby**	**Berta** **Luis** **Shamitra** Sam	Alicia Kim Eddie Fernando	Domingo Leon Dora Geraldo	Andrew Miguel Everett		

Audio and video recording. Because I expected students' experience of uncertainty and their management of uncertainty to be partially reflected in the language they used as they collaborated with their groups, it was vital that student discussions be captured for analysis. Additionally, in this hands-on science activity, much interaction occurred around objects, and so it was also important that I capture non-verbal interactions, especially gestures, gaze, and physical manipulation of and positioning around tools and materials.

Collaborative sessions that occurred in the focal groups were audio and video recorded as often as possible. I solicited support from my peers in monitoring the recording of focal groups during parts of Project 2 and all of Project 3. Efforts were made to minimize the intrusiveness of recording, for instance, by having equipment set up before students entered the room. I audio recorded two to four collaborative groups each day, two of which I also video recorded. Because testing of the robots occurred in the hallway outside of the classroom, I placed one video recorder in the hallway and requested that one member of each focal group carry their group's audio recorder with them to the testing area. Each day before recording, I asked all group members if it was ok if I recorded. I continued this practice for about half the year, at which point the recording was part of robotics instruction.

Students did not ignore the audio recorders; they treated them as interesting artifacts. They sometimes passed the audio recorders around to talk into as their conversation progressed, acting as interviewers. They reminded each other to take the recorders out to the hallways when they went to test. Some students assigned themselves the role of recorder carrier. This occasionally proved to be distracting. For instance, Derrick sometimes paid the recorder too much attention, tapping and breathing into it. When this occurred, I gently extracted the recorder from him, explaining that I needed to move it to another group. Shamitra at first seemed highly aware of being recorded, glancing at the video recorder often with what I interpreted as a look of embarrassment. However, she also seemed to enjoy being recorded and often inquired as to whether I was going to record her group and requested that I do so. On three occasions, students reminded their group members that they were being recorded. This occurred twice during social talk that students might have considered inappropriate and once during an argument.

The naturalistic observation made at least two students uncomfortable in ways they were willing to be explicit about with me. Dora requested that I not take her picture or video record her. I was careful to honor this request, assuring her when the camera was near that I was making sure to keep her out of the frame. She later confided in me that another student in the class had used her picture on facebook without her permission and she was concerned about that being dangerous. On three occasions, Shamitra asked me move the recorder out of her group. Both of these requests happened when Shamitra was having interpersonal difficulties with her group members. I complied each time this occurred, abstaining from recording her group for the rest of the day and making a point the next day to ask her explicitly if it was ok if I recorded. At other times Shamitra asked me to please film her group. I took these requests to mean that she really did want to be part of the study and did not feel obligated to do so.

Field Notes

I had realized as I designed my study that it would be difficult to observe carefully in a hands-on context such as the one selected for this study, and I tried to design in ways to overcome that difficulty. For instance, part of the reason for enlisting help in collecting video-recorded data was so that I could concentrate on taking field notes. Although I had planned for it, I still found myself unprepared for the feeling of being overwhelmed and paralyzed in my early observations by all the action taking place simultaneously in the classroom. I quickly developed strategies to help me manage these feelings. I disciplined myself to concentrate on no more than two collaborative groups per day, rotating between them as I recorded notes in a small notebook. I left my laptop open in a corner of the room and retreated there to write more extensive field notes during whole-class instruction and during breaks. Thus, I took copious field notes during whole-class instruction, whereas my notes were less detailed for small group interaction and relied more on my memory as I later expanded them. I also made notes into audio and video recorders as I walked around the room. As I observed, I tried hard to keep my research questions in mind so that they could inform my observations. As I made observational field notes, I tried to capture students' interactions around materials and tools, students' gestures, facial expressions, and the general tone of peer discussions.

I expanded my field notes following each observation, usually within 24 hours. This expansion sometimes began on the drive home as I audio recorded memos to myself and later converted them to digital documents along with my handwritten notes. Once home or at my next destination, I recorded my impressions, emotional responses, questions, and wonderings. I summarized whole-class activities and the groups' progress as near as I had observed and could remember. I catalogued artifacts associated with the day. I added theoretical, personal, and methodological memos (Corsaro, 1982), placing these in a column separate from my observational data. Some of my field notes were informed by my first pass through the recordings; I made additional notes as I viewed video or listened to audio.

Photographs

Not until the end of October did I begin taking photographs during observations. In my informal observations of students creating robots, I had noted that while video recordings adequately captured the large-scale interactions among collaborating students, they could not at the same time capture close physical interactions and manipulation of materials and tools. Short of training two cameras on each group (a close-up and a long-range view), which seemed overwhelming in this setting, the best I could do was to take photographs. Although photographs could not yield data about every interaction, they served the dual purposes of depicting some physical interactions around physical artifacts and tools and documenting the history of students' projects as they progressed with their projects. I tried to capture physical changes in the robotic structures. I was not able to obtain permission to use screen capture software to capture the progression of programming. Therefore, I depended on photographs of programs in flux to supplement the collection of programs at the end of each day.

Collecting Artifacts

Having obtained a copy of the Mindstorms program, I downloaded to a thumbdrive every group's program at the end of each day. I also photocopied, transcribed, or took digital photos of all written work associated with robotics instruction. This included individual and group descriptions of groups' decision-making processes and description of their design during Project 3, the poster boards they prepared for the Robofair and which included their multimedia resources, research and product surveys, and sketches made on paper and white boards. It also included every individual written reflection during Project 1 (two reflections per student) and Project 2 (three reflections per student), and design journal entries for Project 3 (six entries). See Appendix A for reflection questions assigned by the teacher. Finally, I downloaded all the pages on the teacher's website related to robotics instruction and the robotics wiki in which the class members had participated during Project 3.

Interview Data

In addition to observing what occurred in the classroom and what resulted from the classroom activities, interviews were used to enrich and confirm my understanding of students' cognitive and affective responses to uncertainty and to build a picture of uncertainty management in collaborative design activities that was informed by students' points of view. Prior to conducting any student interviews, I explained to the whole class what they could expect to happen during interviews and that interviews were confidential (i.e., I would not share what they said with anyone at their school, including their group members or their teacher). Interviews ranged in length from three minutes to 20 minutes. The majority of interviews were between six and 12 minutes long.

Who I interviewed on any given day depended on availability, rotation, and whether I had specific burning questions for a particular student or students from a particular group. On each day I interviewed, I tried to get the perspectives of at least two group members in order to facilitate comparison of their interpretations. Students from each focal group who were willing were recruited to participate in individual interviews about their experiences during collaborative design sessions. It was not necessary that every student in a group be interviewed, but multiple perspectives on each session would help make the picture of each group clearer and richer. I concentrated on interviewing focal students. However, I occasionally interviewed other students in order to broaden my observations. I interviewed every student in the class at least once.

When possible, interviews were conducted the same day as the observations with which they were associated. At most, they were done the next school day and always before the next collaborative design session. For Project 1 and Project 2, robotics sessions took place on Friday afternoons. Thus, many interviews occurred the following Monday morning. During Project 3, when robotics sessions occurred several times a week, I interviewed students the same day or early the following morning. Otherwise, I did interviews after observations or in-between observations when robotic work was interrupted by other events such as recess, lunch, or other instruction. Care was taken to minimize any disruption of instructional time. Interviews were held during students' free periods such as lunch or recess or early in the morning before the school day began. I tried to respect students' and the teacher's time; asking if and when I could interview and trying to be sensitive to any reluctance.

Interviews usually took place at a desk in the hallway around the corner from the classroom. This was private and away from class members, but it also served to indicate to school officials that I was being open and transparent with what I was asking of students. The principal was frequently a visitor in the hallways, and I felt this was a respectful move. Occasionally, interviews took place in the library or in the classroom during recess or lunch.

Interview protocol. Aspects of my interview techniques can be described as non-standard (Bogdan & Biklen, 1982; Goetz & LeCompte, 1984) and semi-structured (Spradley, 1979) with open-ended questions to initiate dialogue (Fontana & Frey, 2000). The questions in Appendix B were designed to explore issues concerning the participants' experiences of uncertainty and their thoughts and feelings concerning their management of uncertainty, and they were guided by early interviews. Questions were structured around four themes: (1) group process and decision making; (2) what an interviewee had said or chose not to say to his/her group members; (3) an interviewee's thoughts about his/her group members; and (4) An interviewee's thoughts about the project, product, and process of the robotics engineering projects. I revised the protocol throughout the study, adding or deleting questions. For instance, because students often used the term *not sure* rather than *uncertain* to describe their experiences, I integrated that term into my questioning (e.g., How sure were you that…?). Rather than function as a list of questions I asked each student, the evolving interview guide simply helped me continue to stay aware of my research questions and facilitate students' talk in ways I hoped would elicit information about their responses to uncertainty during robotics projects.

With respect to the tone of the exchange, I tried to think of the interview not as a regular discussion with equal talk turns, nor as simply a line of questions followed by answers (Plummer, 2001). Because I believed the interviews would yield better data if students felt more as if they were having a conversation than being interrogated, I did not take field notes during the interviews (interviews were audio recorded and later transcribed). The beginning of an interview is important for setting a tone and for making participants feel comfortable (Spradley, 1979). My opening conversational turn in my first interview with each student, although not scripted, went something like the following:

> *Two things I want to make sure you know before we start is that, one, anything you say to me is confidential. That means it stays between you and me. I am trying to learn about what you think and how you think about robotics. So I do not tell anyone in your group what you say. I do not tell your teacher and I do not tell anyone in your school what you say. The things you tell me you're telling me in order to help me learn. Ok, the other thing, one of the things I'm really interested in is what people do when they're building robots and they're not sure about something. Any time you're working with your group and you're unsure or uncertain about something, I'm interested in that. Ok? Are there any questions you want to ask me before we get started? [transcribed from an interview on 100309]*.

The establishment of trust and students' perception of psychological safety in regards to me and the study was a potentially crucial determinant of the quality of data generated from the student interviews. With full knowledge that trust must be established and maintained over time through multiple positive interactions, I attempted to reinforce trust between me and my study participants during each interview. In addition to focusing students' attention, it was my hope that being open about my intentions would help me avoid evasiveness that students were likely to notice and of which they might become mistrustful. A danger in this openness is that participants may have tried to respond to my questions in ways they thought would please me. Also, by explicitly discussing uncertainty, some students may have become more sensitive to uncertainty, and this might have affected their behavior in their collaborative groups in ways that I was unable to detect.

Interviews followed up on events from the immediately prior collaborative robotics session. When interviews occurred the same day as the observation to which they referred, I simply began the interview with an open question, such as, "So how's it going today?" "What are you working on today?" When interviews were conducted on the Monday after a Friday observation, I roughly transcribed as much observation data as possible over the weekend and used these transcripts as well as my field notes to guide interviews on Monday. In my field notes, I documented interesting events and the group members involved in them and I wrote questions I wanted to ask these students. When beginning these interviews, I reminded students of events and activities that had occurred during their last collaborative group session. I often selected photographs, short video clips, short quotes from transcripts, or pulled up their Mindstorms program to aid/trigger students' memories. I tried to pick out two or three salient events; ones I thought would bring back vivid memories for the interviewee or events in which key decisions were being made about the robotics project. My selection of events was also based on my interpretation of those events as points at which uncertainty originating from aspects of the task was being managed by the student or other students in the group. After reminding students of the event, I began with a general open question such as, “What were you thinking or feeling when that happened?”

The number and nature of follow-up questions differed according to an interviewee’s response to my initial prompt, the hypotheses I had formed throughout this and prior observations, and comparison of students’ explanations with my ongoing interpretations. I allowed each interview to be guided by students’ responses while at the same time attempting to elicit information about the students’ level of uncertainty as well as her/his attributions, appraisals, and emotional responses to their uncertainty, and about how an interviewee saw her/himself in terms of responding to uncertainty. I tried to hold off on explicitly asking about students’ experiences of uncertainty while working with their collaborative groups. Instead, I listened carefully for clues as to what I could direct students toward that might address my research questions. However, if no such opening ensued, I explicitly asked, “Was there ever a time when you felt uncertain or unsure about something while you were working in your group today?” Students often said no, which I took as evidence that they were not being too overly led to please me. I also asked students, “Did you ever notice a time today when one of your group members was uncertain or unsure about anything?” In my analysis, I always noted to myself when a student’s comments about uncertainty had been elicited from a direct question.

There were two divergences to note in terms of my usual interview protocol. First, as the year progressed, I used interviews to assess students’ learning and understanding of robotics-related concepts (e.g., “Can you explain your program for me?”). When I made these inquiries, I did so at the end of the interview, and I did not do it very often because I did not want student to think of interviews as a quiz. Also, I approached these inquiries from a place of ignorance. I truly was unschooled in robotics engineering, which I think made students comfortable explaining their knowledge. Second, my final interviews consisted of one set of six questions asked to all interviewees (see Appendix C). These questions grew out of my observations over the year.

Informal group interviews. In addition to formal student interviews, I also talked with students informally as a group when opportunities presented themselves, as for example, when groups were waiting for computer software to load or when they had cleaned up a few minutes early. My purpose was to get a different sense of students' experiences; my thinking was that students might reveal something different in a group than they would reveal in an individual setting. I usually let these interactions grow naturally out of students' initiations to me, rather than initiating them myself. More of these occurred during Project 3 than in the two prior projects due to my changing role in the classroom (see below).

Teacher interviews. Although interviews with the teacher were not a primary data source in this study, they did give me insight into the nature of students' individual characteristics and backgrounds and into the nature of robotics instruction. Although questions for my first teacher interview conducted at the beginning of the year were pre-planned (see Appendix D), subsequent interviews varied in style and content. I sometimes directly requested information from the teacher, particularly in regards to specific information about individual students, her plans for upcoming scheduling, and her evaluation of progress. More often, however, I tried to make myself available as a listening ear to facilitate Ms. Billing's reflection from which I hoped to gain insights about her instruction, the nature of the task, and her students.

Researcher's Evolving Role in the Classroom

Because I was in this classroom for an extended period of time my changing role in the class bears some explanation. I had attended several instructional sessions the year before my formal observing in this class, and even attended the previous year's Robofair. I was a novice in robotics engineering. I knew next to nothing and decided to keep it that way, rather than try to become an expert, both as a way to give myself space to "be uncertain" in order to consider students' uncertainty and also because doing so helped me sustain my role as more of an observer and less of a participant. During Project 1 and Project 2, my role might be described as *a friendly outsider*. I was not asked to instruct and on the rare occasions students asked for my help, I pleaded ignorance (which was true) or reflected their questions back to them ("Hmm, I can help you look at it, but I don't know how to do it. We can look at it together"). During Project 3, I took a more active role as Ms. Billings left the room for significant periods of time to teach robotics in other classes. Although another fifth grade teacher was always in the room, students tended to approach me with questions and problems. Prior to this, I had resisted the urge to talk with students as they worked. However, that began to feel artificial to me during this phase, as my interactions with students became more overt and necessary, and so I began informally interviewing groups at opportunistic times (e.g., lulls in the action, points at which I had been called over for consultation or to seek permission to use materials). During this time period also the likelihood of my being asked for advice increased, although not by a lot.

Researcher effects. Taking a complexity stance toward research design, I was aware that in my efforts to observe, I would likely influence the classroom system in ways I could not predict ahead of time (Jordan, Lanham, Anderson & McDaniel, 2010). My understanding is that the only way possible for researchers and participants to work together is to co-evolve through mutual influence. Accepting this, I tried to stay aware of the ways that students were being influenced by my presence rather than trying to eliminate my influence, and I tried to shape/contour my relationships in the classroom in ways that would inform the study. I set about doing so in a respectful, humble, and truthful manner, and I tried to communicate my respect, humility, and truthfulness.

To be respectful and to communicate respect, I repeatedly checked with participants before recording them, and I removed recording equipment, including myself, when requested or when I sensed that one or more students were significantly uncomfortable with its presence. To be humble and to communicate humility, I listened closely, I tried to learn from my participants, both about robotics and about uncertainty management, and I curbed my "teaching" tendencies to direct and to advise. To be truthful and to communicate truthful and trustworthiness, I was up front with the students about my lack of knowledge of robotics and about the purposes and processes of my study. I hoped my honesty about the purposes of the study would foster trust rather than suspicion or caution that I feared might result were I to be vague or evasive. One exception to this truthfulness was in my communication with the teacher of the observed classroom. Not until late in the year in which my observations were made did I share with her my interest in uncertainty and the ways that students respond to uncertainty. My reason for withholding this information was out of concern that knowledge might influence her instruction in ways that could influence the ways students managed uncertainty.

Analysis of Data

My data analysis progressed in four phases. Briefly, Phase 1 occurred during data collection and broadly consisted of making extensive memos and annotations focusing on uncertainty, uncertainty management, and literacy, and also of organizing and summarizing the data in multiple ways to facilitate coming to understand it. Each of the next three phases focused on addressing one of my three research questions, although each step of analysis informed all three questions. In Phase 2, I focused on identifying and describing the issues about which students experienced uncertainty and the strategies they used for managing uncertainty. In Phase 3, I concentrated on understanding how the nature of the academic tasks with which they were engaged was influencing students' uncertainty management. In Phase 4, I attended to how uncertainty management played out in context and this shed light on the influence of peers on students' uncertainty management. One way of depicting this process is in terms of what Corbin and Strauss (2008) described as a concentration on structure followed by a concentration on process. Another way to describe my data analysis is that in the first phases, I paid attention to *what* was happening, and in the later stages, I attended to *how* it was happening. I describe more fully each phase of data analysis in the sections below and explain the theoretical frameworks influencing me at each phase.

Phase 1: Data Organization, Transcription, and Preparation

Organization of data occurred throughout data collection. I downloaded video and audio recorded and digital picture and computer programming data on a laptop harddrive every night following observations. I put all data pertaining to a particular day in the same folder, and each type of data in a subfolder. Every folder was labeled with a date and type of data (e.g., video 050509). Each piece of data was labeled with a date, collaborative group it pertained to, and its overall content (e.g., AM group building trailer 051209). I created a database of all data sources for each day of observation, creating a column for video recordings, audio recordings, interviews, photographs, and written assignments, and wiki postings. In these columns I noted whether that type of data existed for each day and for which groups. I obtained NVIVO7, a qualitative software program, at the end of October and began transferring data and memos. As video files are usually too large to upload directly into NVIVO, I kept those on my hard drive and added video data in a column of the audio transcript files.

Early transcribing. In addition to helping me organize data, NVIVO greatly increased the efficiency of transcribing data. Transcription occurred in several stages as follows. All student interviews were transcribed as soon as possible after the interview itself while my memory was fresh. I also began making rough transcripts of the observational data soon after it was collected. Because I found transcribing observational data with its multiple and simultaneous voices too arduous a task for the evenings after observing, I created rough transcriptions of observational data as much as possible on weekends. I also transcribed large amounts of data during winter break and spring break.

Given how much data I had, transcription decisions were based in part on managing the unwieldiness of transcribable data (Edwards & Westgate, 1984). Although I had some data for most collaborative groups, I transcribed only data from the focal groups. Because my field notes about whole-class interaction and direct instruction were sufficiently thick for my purposes, I chose not to transcribe those data except for portions that seemed to pertain directly to managing uncertainty (e.g., on 050109 the teacher suggested that students might combine their design ideas). I used my field notes as a guide for deciding what could be left un-transcribed from the collaborative group data. For example, there were a few days when the computer network was slow and the computer programs loaded very slowly. Having noted in my field notes that students seemed off task during much of this time and that they engaged in little meaningful discourse related to the task, I did not transcribe much of these data. I simply made notes about the activities in which students were engaged for sections of the audio recordings that were difficult to transcribe because of background noise or other interference and for sections in which little of consequence seemed to be occurring.

Transcription decisions were guided also by theoretical hypotheses and emerging insights at all phases of analysis, thus transcriptions evolved over the life of the study. Transcription decisions such as punctuation, placement of speaker turns, and inclusion of verbal and nonverbal behavior that might affect interpretation always require tradeoffs between legibility and accessibility (Ochs, 1998; Edwards & Westgate, 1987). Given the purposes for my early transcriptions, rough transcripts sufficed for much of the recorded data (Swann, 1993). I captured all vocalized words and noted whenever I could not catch a comment or a part of a comment. I wrote "..." to represents significant pauses (or inserted the approximate length in seconds) and "//" for interruptions. I underlined words or phrases that were strongly emphasized by a speaker. For my early analysis I transcribed mostly from audio recordings because the sound quality was much higher than from the video recordings and because I found it too distracting to transcribe from video. I reviewed the video recordings and made notes about non-verbal interaction. However, video data were used more extensively in later steps of analysis at which time I added detailed information from the video recordings for audio transcripts for which I had video data.

Early analysis. Data were subjected to multiple readings and/or listenings even as data collection continued. My purpose for these activities was to increase my sense of coming to know and of making sense of the data in order to inform, guide, and focus further analysis. As I transcribed interviews and observational data, I immediately began making theoretical and methodological memos in a separate column, identifying broad patterns in different data sources to facilitate my understanding of students' uncertainty management and how it was related to task structure and peer interaction.

Soon after data collection was completed, I began creating various tables, charts, and graphs. Piecing together data from various sources, I summarized each focal group's progress, noting important events, key decisions, and major shifts in topics and activities. I created summaries of whole-class activities at multiple grain sizes and at multiple scales of time (e.g., daily, for each project, for robotics instruction across the year). I created several synopses at multiple grain-sizes for each focal group and later for each focal student. Using the *cases* function in NVIVO, I collected all data related to each individual student from field notes and whole-class transcripts into a node dedicated to them (case nodes) so that I could examine them all together. I looked across all the interviews for each focal student and across all the interviews for particular groups on specific days. In this way, I formed multiple representations of the data across several time scales.

Phase 2: Developing Coding Schemes for Uncertainty and Uncertainty Management

In order to get an overall sense of the uncertainty experienced by students engaged in collaborative robotics projects, the second phase of my analysis was focused on identifying issues about which students were uncertain and the ways they attempted to manage the uncertainty they experienced. Because the management of uncertainty has not previously been systematically addressed in collaborative educational settings, the coding of issues about which students experienced uncertainty (i.e., uncertainty sources) and uncertainty management strategies (i.e., actions that students took to respond to their uncertainty) was done using a combination of grounded theory (Corbin & Strauss, 2008), and discourse and linguistic analysis techniques. Analysis was inductive and interpretive, guided by emerging patterns identified in the data and informed by prior research.

I operationalized uncertainty and uncertainty management based on language and discourse, broadly defined as interaction using language and tools, including one's own body in the form of manipulating the environment through sketches and moving things, and gesture (pointing to things; bringing things into being through gesture). The verbal unit of analysis was the talk turn. Overlapping speech by two students was treated as two separate turns, with the overlap indicated in the transcript. I looked for evidence in students' discourse that they were experiencing uncertainty (words, phrases and gestures that tend to indicate uncertainty), and for evidence of how students were managing that uncertainty, as indicated in their discursive interactions (see Appendix E) and in the thinking they shared with me during interviews.

Important in my interpretation were my understandings of linguistic uncertainty markers (e.g., Bernstein, 1962; Feldman & Wertsch, 1976; Green, 1984; Lakoff, 1973;

Meaney, 2006; Prince et al., 1982; Roland, 2000) of paralinguistic uncertainty markers (e.g., Barr, 2003; Maclay & Osgood, 1959), and of gestures that may indicate or otherwise relate to uncertainty (Alabali, Kita, & Young, 2000; Gilvry & Roth, 2004; Kendon, 1994; McNeill, 1992; Roth, 2003; Wells, 2000). I was also informed by Mercer's conception of exploratory talk (2000) and by Scardamalia and Berieter's (1991) differentiation of *basic questions* from *wonderment questions*. Finally, I drew on politeness theory (Brown & Levinson, 1978) and work on uncertainty in communication theory (Brashers, 2001).

I used caution in interpreting linguistic markers as indicating psychological uncertainty, recognizing that words and expressions that mark uncertainty may serve various discourse functions, and one needs to be cautious when interpreting them, relying heavily on speaker-listener context (Feldman & Wertsch, 1979). I also kept in mind that individuals of different genders, abilities, socioeconomic backgrounds, and cultural groups differ in their use of uncertainty terms that may not be related to differences in uncertainty experienced (Bernstein, 1962; Feldman & Wertch, 1976; Gee, 1996; Major, 1974; Meaney, 2006; Michell & Lambourne, 1979; O' Barr & Atkins, 1980; O'Neill, & Atances;2000; Piaget & Inhelder, 1975; Turner & Pickvance, 1971).

Because linguistic markers of uncertainty are used to do multiple functions and thus cannot be taken at face value, it was important for the purposes of this analysis to discern the intended use of each uncertainty marker. The analysis process was interpretive, requiring me to make inferences about students' discursive moves that were often ambiguous, especially when considered in isolation. Cues as to what an uncertainty marker is being used for by an individual must be construed from prior comments by the speaker, subsequent comments by the speaker, as well as the relationship between the speakers' comments and the comments of others. I examined comments before and after the comment under consideration. I also considered individual student's history of participation across multiple turns and across episodes (Singer, Radinsky & Goldman, 2008). Comments were only coded as exhibiting uncertainty or uncertainty management when a hypothesis was supported by surrounding discourse. Although I was conservative in interpreting comments as being about uncertainty, I was fairly liberal in that I coded even momentary, seemingly inconsequential uncertainties.

I limited my initial analysis to the first four days of Project 3, the less structured task. I began with these data because of my sense that uncertainty was particularly salient during these days and thus, provided the highest likelihood of capturing the phenomena of interest. I also limited myself to analyzing transcripts, field notes, and interviews related to three focal groups (half the class), which is restrictive in terms of being representative of all students in the class. Finally, I included in this phase of analysis only data related to interaction among group members working alone, excluding data related to groups working with the teacher (except when they sought her out as a way of managing uncertainty) and also whole-class instruction.

The grounded theory aspect of this analysis proceeded in three steps, open coding, axial coding, and selective coding. Reading through the data, I first conducted open coding to identify salient categories related to two phenomena of interest. Using NVIVO, I organized my codes into two parent codes (tree nodes), *uncertainty issues* and *uncertainty management* and all related child codes were placed in these folders. As I created new codes, I wrote definitions and made short notes about the nature of each code. These definitions evolved as I continued to refine my understanding of each coding category as I attempted to apply it across the data. At the same time, as I coded for uncertainty and uncertainty management, I tried to note evidence of students' affective responses to their uncertainty and their attributions, and appraisals of their uncertainty. I also created free codes (unattached to a hierarchical structure) about issues I thought might be important in terms of uncertainty responses (e.g., outside influences on uncertainty, intergroup interaction, interpersonal difficulties, social talk).

Axial coding to refine categories was then done by collapsing and expanding codes. Axial coding was facilitated by NVIVO with its capability of cross-referencing codes and memos. In order to check my consistency, I compared codes within and across categories. One strategy I used was to print all pieces of data attached to a code and compare them against one another to see if they all made sense/hung together. I did this for each code. It was also at this point that I experimented with clustering codes under overarching categories. For this step, I drew on my knowledge of previous research investigating uncertainty management in non-academic contexts. For example, I tried to group the data in terms of strategies for *absorbing* and *reducing* uncertainty as per work by Boiset and Child (1999). However, I found these categories too broad and difficult to distinguish in practice and so I dropped this scheme.

Seeking confirmation of my coding schemes and to establish trustworthiness, I solicited peer review and member checking at this point. Further revision resulted from these activities. For example, I originally categorized sources of uncertainty as pertaining to task, self, or social issues. Feedback from peers helped me understand that uncertainty about one's self pertains either to uncertainty about one's self in regards to the task or in regards to one's social context and I eliminated the *self* category.

I next applied these initial coding schemes to data from the first five days of Project 1, concentrating on data related to interaction of group members from four focal groups (half the class). My purpose was two-fold. First, I treated this part of the analysis as a second data set, a new context, if you will, in which to check transferability. Second, I wished to compare my results from the less structured task (Project 3) with the more structured task (Project 1). I elected to use data from Project 1 rather than Project 2, also a more structured task, because I wanted to examine the possible effects of unfamiliarity and novelty on uncertainty management. Just as for the less structured task, I limited my coding to the transcripts of collaborative group sessions involving only group members, not the teacher, observations made in field notes (not interpretations of observations), and transcripts of student interviews. It should be noted that different students were involved in analysis of Project 1 versus Project 3, although there was significant overlap (see Table 3.3). Further revision occurred when I compared codes from Project 1 and Project 3.

Because I coded three data sources that overlapped in terms of representing the same events, there were times when a single act might have been coded three times (once in the transcript, once in the field notes, and once in an interview). Thus, frequency of codes represented occurrence *in the data* rather than in the collaborative sessions. I did not consider this redundancy a problem because my purpose for this qualitative categorical analysis was to describe the range of ways students managed uncertainty and not to identify the frequency with which they occurred (Lankshear & Knobel, 2004).

My decision to use all three of these primary data sources was based on the fact that each of these data sources was better and worse at capturing different categories of uncertainty management. For example, although it can be quite difficult reliably to observe students *ignoring uncertainty* through direct observation, students themselves sometimes revealed having used this strategy during their interviews. Even with multiple sources, some categories of uncertainty management may have been systematically under-observed.

These processes yielded two final coding schemes. The overarching categories of *uncertainty issues* are differentiated in terms of *project activity uncertainties* and *social system uncertainties*. The coding scheme for *uncertainty management* consists of four overarching categories, *reducing*, *ignoring*, *maintaining*, and *increasing* uncertainty, under which are clustered 26 tactics (see Appendix F). Another product of this analysis was the extensive theoretical and methodological memos I continued to make throughout Phase 2.

Phase 3: Examining the Relationship between Uncertainty and Task Structure

In Phase 3 of data analysis, my hope was to gain insight into when and why students use various uncertainty management strategies and tactics by linking them to characteristics and activities related to aspects of the tasks in which students were engaged and by re-interpreting those strategies in light of task structure. From my sustained observation, I easily identified Project 1 and Project 2 as more structured tasks with their fully-specified parameters and defined objectives and solution paths leading to pre-determined objectives. Project 3 was easily identifiable as a less structured task with its open-ended opportunities for generating multiple representations and solutions. For the analysis described below, I used only data from Project 1 and Project 3. These two projects adequately captured the important task characteristics of all the projects, one project being more structured (Project 1) and the other being less structured (Project 3). Given the similarity in task structure between Project 1 and Project 2, I elected to analyze Project 1 rather than Project 2 to represent the two more structured tasks because Project 1 had the added characteristic of being a novel task in that it was the first time all but one of the students in this class had engaged in a robotics project.

I situate Phase 3 of this analysis in the strand of sociolinguistic analysis of classroom discourse identified by Florio-Ruane (1987) as studies of the conversational nature of teaching and learning that seek to define and describe the teaching and learning process and to illuminate the interdependencies among conversation, activity, and learning. Included here are studies of the social and academic functions of language in classrooms and studies of the relationship between event structure and academic content (e.g., Cazden, 2001; Mercer, 1995, 2000). These studies focus on individual learners' understandings and intellectual change by looking at the dynamics of discourse in a classroom social group and by analyzing the conversational support teachers and peers provide for learners.

Attempting to clarify the relationship between task structure and students' uncertainty management, I first examined more closely the activities in which students were engaged during the project with the more structured tasks (Project 1) and during the project with the less structured tasks (Project 3). To identify the activities associated with each project, I examined transcripts and field notes of whole-class activity and for all focal groups across Project 1and then across Project 3, noting and categorizing activities, sequences of activities, and interdependencies among activities. These broad codes captured large segments of transcripts. The grain size was a single segment of a collaborative session in which the students sustained engagement in the identified activity.

The large-grained categories of activity I identified for Project 1 included *building*, *programming*, and *testing the robot*. For Project 3, although students also did building, programming, and testing, these activities were enacted quite differently because of the recursive and iterative nature of the design process in which students were engaged. Therefore, I found it more helpful to categorize the activities during Project 3 in terms of the design process as students in this class were exposed to it: (a) *brainstorming* what problem they would address and possible solutions, and (b), *building*, *testing*, and *troubleshooting* the actual physical product. *Building* in this sense, refers not only to the physical structure, but also to the computer program.

While coding activity into large-grain categories, I also sought a more fine-grained look at the data by identifying the skills and sub-activities associated with the identified activities. I noted also characteristics of the physical and textual tools and materials that students were using to engage in these robotics engineering projects. Finally, in both projects there were sections of transcripts coded as the activity of *social talk*. I excluded these from further consideration in this phase of analysis.

Next, looking across all the segments coded for a single type of activity, I examined the ways that students tended to manage uncertainty in each activity. I examined all the coded segments of each identified activity and the uncertainty management that had been previously coded. This was facilitated by NVIVO's *query* and *find* functions also to examine relationships among codes by filtering out all the coding bars not associated with all but the codes of interest. I looked for patterns of uncertainty management related to each type of activity identified in the project with more structured tasks and for each type of activity identified in the project with less structured tasks. Informing my analysis was my knowledge of previous literature related to uncertainty and task structure. For example, as I examined the relationship between uncertainty and academic activity, I paid attention to novelty, complexity, evaluative risk, and ambiguity, all previously identified as task characteristics that elicit uncertainty.

I next selected for deeper examination two collaborative groups from Project 1, a group of three boys (Demetre, Nathan, and Luis) and a group of three girls (Satya, Kisha, and Kim), and one collaborative group from Project 3 (Demetre, Satya, Kisha, and Becky). I transcribed all audio recordings and viewed all video recordings from these groups. Incorporating information from all data sources, I refined my summaries of each group's activities and identified for microanalysis events in which uncertainty was sustained for a significant amount of time in the various activities associated with each project. For each group, I microanalyzed episodes associated with each activity, attending to how students responded to uncertainty in each one.

This second phase of analysis required that I continuously compare data across sources and analysis techniques with each other and with emerging hypotheses looking for reasonable explanations and interpretations about the relationship between task structure and uncertainty management. I adjusted emerging categories, hypotheses, and themes as substantiating or disconfirming evidence was encountered. As in previous phases of analysis, I wrote memos and annotations throughout this process.

Phase 4: Sociolinguistic Microanalysis of Rich Points

Informed by my first passes through the data, I proceeded to a more informed and holistic approach, identifying and selecting rich points in the data and conducting a microanalysis of discourse in order to understand how students' uncertainty management played out within a group over discourse events and over robotics projects. My objective for this fourth phase of analysis was to address the research question, *How does peer interaction influence uncertainty management during robotics engineering tasks?*

My techniques in Phase 4 of analysis can be best described as what I am calling *sociolinguistic microanalysis*. By *sociolinguistic microanalysis,* I mean that I conducted a fine-grained examination of purposefully-sampled discourse events in short segments of peer interaction selected for their rich salience to this study from across and within collaborative groups, trying to understand individuals in a group context as they attempted to manage uncertainty elicited during academic tasks. This is very time consuming process, but I found it necessary in this study because of the subtle nuances of meaning that I was trying to identify. Using restricted purposeful sampling of both recurring and unique events, microanalysis of discourse can allow an examination of processes in greater detail than large-scale coding, and is thereby useful for validating interpretations of intent and meaning, and for identifying *how* processes of interaction become organized (Erickson, 1992).

My techniques were influenced most directly by Erickson's (1992) ethnographic microanalysis of discourse. I was also guided by interactional sociolinguistics (Erickson, 2004; Gumperz, 1982) in that I focused on how language is used in a particular social context (i.e., elementary students' collaborative robotics groups) and on how it creates and reflects meaning and structure in those contexts (Schiffrin, 1994). By focusing on the dynamics of how language operates as a social practice in particular contexts, sociolinguists seek to understand how things get done in the world through language and "with what consequences for people," (Lankshear & Knobel, 2004). For the analysis described below, I defined each collective group as a "speech community" (Hymes, 1974) with its own social practices, and I closely studied the routine talk and activity that took place there. Specifically, I was interested in how individual students accomplished the management of uncertainty within the context of their collaborative groups.

My other objective for Phase 4 of analysis was to examine the potential variance between and within individual students in terms of how they managed uncertainty while engaging in the robotics projects. Pulling together information from across data sources, I created "mini-portraits" of focal students (Do & Schallert, 2004). I noted their patterns of uncertainty management and how those patterns varied across tasks, collaborators, and time. I limited these mini-portraits only to students for which I had data from at least two robotics projects.

Choosing selections for microanalysis. Because my hope for this step of analysis was to understand the influence of peers on uncertainty management, I needed to identify selections of collaborative group discourse in which uncertainty management played an important part. With my peer reviewers/advisors, I thought about what constitutes a rich point in terms of uncertainty management, what Erickson called an *episode of interest*. We decided on the following criteria:

- incidents for which uncertainty was the best interpretation of what was going on, not simply a plausible explanation

- uncertainty was sustained for a significant length of time by at least one group member (as opposed to momentary or transient uncertainties)
- Uncertainty seemed at a high level by at least one group member as exhibited by language, physical, and emotional cues
- The thing about which the individual/s was/were uncertain was of importance to the group's completion of the robotics task in which they were engaged and related to important decisions

After defining my operationalization of rich points, I began to look for them in my data for each focal group for Project 1 and Project 3. I used multiple search strategies including the following: (a) thinking back through my memory from previous passes through the data of events, (b) reading through field notes and interviews to identify potentially interesting events involving uncertainty, (c) looking at the density of code stripes associated with uncertainty management in transcripts of collaborative group sessions to identify events thick with them, (d) attending to events mentioned by more than one group member during interviews, and (e) reading through all the summaries of the sequence of activities for each focal group in Project 1 and Project 3. When I identified events in which uncertainty was prevalent, I color-coded them in the summaries I had previously created for each focal group (adding some events that I had failed to include in my initial summaries) and began making memos and annotations.

Recognizing that there were still too much data to micro-analyze, I decided to begin microanalysis on episodes from the first day of Project 3 for each of the three focal groups. Previous steps of analysis had revealed that these transcripts were particularly rich in that uncertainty had been pervasive for members of all three groups on this day.

Also, all three groups had engaged in similar activities associated with problem finding and problem defining. My next selection of events for fine-grained microanalysis was guided by my emergent understandings and emergent questions from analysis of these first segments. To narrow my possible selections, I confined my search to events in which one or more focal students played a central role. I tried to select instances for which I had rich additional data (e.g., photos, interviews, teacher interviews, etc). I also attended to the need for heterogeneity in the events analyzed in terms of sources of uncertainty, activities, and so on, in order to refine my understandings of how uncertainty management played out over different timescales and in various situations and groups and by diverse individuals. I also identified events with little or no uncertainty for contrasting analysis.

As I prepared to begin my microanalysis of each of the selected discourse episodes, I first prepared more detailed transcriptions of students' interactions in order to reveal fine-grained information about the actual conduct of social interactions (Lankshear & Knobel, 2004). I followed methods set forth by Erickson (1992) for ethnographic microanalysis of video data. As I reviewed recorded interactional events, I refined my transcript of the talk and the nonverbal behavior of the various speakers and listeners. I replayed short segments of the recording repeatedly, intentionally switching my attention from verbal to non-verbal information, from one participant to another, oscillating between video and audio recording when both media were available. I added more detailed information about overlaps, pauses and hesitations to the verbal data. Because NVIVO is inhibitive of using multiple codable columns, I exported the rough transcripts so that I could add a full column for detailed nonverbal information. I used one column for verbal information, another column for non-verbal activity, and still another column for memos in order to avoid privileging one over the other (Ochs, 1998; Swann, 1993).

Given the nature of the robotics engineering projects that were the site of my investigation and the nature of the research questions I was addressing through this analysis, I labored to depict and interpret students' spatial orientation, gaze, gesture (Gilvry & Roth, 2004; Wells, 2000) and their manipulation of and contact with physical objects (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Lemke, 2000b) in order to account for the interaction of individuals and tools. These may be particularly important in science activity because artifacts such as books, computer graphics, or other materials are likely to mediate talk (Wells, 2000; Radinsky, 2008), and because gestures can represent absent entities and embryonic ideas (Alibali & Goldin-Meadow, 1993; Brereton, Cannon, Mabogunje, & Leifer, 1996) and afford joint attention and negotiation of meaning around newly encountered concepts in collaborative contexts (Singer, Radinsky, & Goldman, 2008).

Even as I refined the transcripts, I added theoretical and methodological memos to the third column of my transcripts. Concentrating on interpreting how individuals were managing uncertainty and on group members' responses, I asked myself the following questions: Who is uncertain? Can I identify a trigger for the uncertainty? What is the relationship between uncertainty management and collaborative group discourse? What could one be uncertain about in this situation that students do not seem to be uncertain about? Can I identify a stance, attribution, or affect associated with the uncertainty? Do others seem to notice a group member is uncertain? Do they share the uncertainty? What was the outcome of the issue? Can I tell how uncertainty management and group members' responses to it influenced the outcome? How could this have gone, but did not go?

Once I felt I had conducted interpretive analysis of a sufficient number of events, I tried to determine the typicality or atypicality of the episodes. I looked at the entire corpus of data, comparing and contrasting across data sources and across analytic techniques. Working from hard copies, I cut selections apart, posting them on note cards, organizing and re-organizing them in various clusters. In this way, I proceeded with a sort of axial coding at the microanalytic level, re-assembling the data that had been broken into pieces by open coding, from which emerged clustering of concepts around fewer organizational themes. Returning to each episode, I tried to ascertain internal generalization by comparing it against events from the larger corpus of similar instances to check for consistency and negative cases. Emerging categories, hypotheses, and themes were continuously adjusted as substantiating or disconfirming evidence was encountered. I consulted with expert peer debriefers (Corbin & Strauss, 2008). The data were recursively reviewed and checked until I felt I had "tuned the picture" (Do & Schallert, 2004) of how peer interaction was influencing students' uncertainty management.

CHAPTER 4

RESULTS

Science is a journey into the unknown with all the uncertainties that new ventures entail.”

-Mary Budd Rowe

Analysis of data revealed that rather than the exception, uncertainty was the norm for students as they attempted to collaborate to complete their robotics engineering projects successfully. Students seemed to experience uncertainty almost continually. Rather than diminishing when one uncertainty was resolved, the psychological load of uncertainty was maintained as uncertainties were linked or chained across time. Also, when uncertainties were sustained over long periods, students often used several strategies to manage uncertainty related to a single issue.

The data revealed an interesting pattern. Uncertainty in these collaborative academic tasks was constrained by the structure of the task itself. There was always uncertainty about two aspects of the tasks: the project activities and the social system. Students navigated this labyrinth with different degrees and types of skill, but they navigated it, nonetheless. The pattern is illustrated in the model in Figure 4.1.

	Project 1 **More Structured Task Setting**	**Project 3** **Less Structured Task Setting**
Project Activity Uncertainty	*Cell 1* Sources of Uncertainty Strategies for Managing Uncertainty	*Cell 3* Sources of Uncertainty Strategies for Managing Uncertainty
Social System Uncertainty	*Cell 2* Sources of Uncertainty Strategies for Managing Uncertainty	*Cell 4* Sources of Uncertainty Strategies for Managing Uncertainty

Figure 4.1 Managing Task and Social Uncertainty in a More Structured and a Less Structured Task Setting

Even though Project 1 and Project 3 were similar in that they both involved the tools, skills, and practices of robotics engineering, they varied from each other in how structured the task activities were that comprised the projects. Project 1 was composed primarily of a set of *more structured* tasks, by which I mean that specific objectives were generally pre-determined and tightly defined by the teacher and that the sequence of steps for "getting there" were pre-determined or highly constrained. Project 3 was composed primarily of *less structured* tasks, by which I mean that the objectives were open-ended, defined in part by the teacher and in part by the students, and the possible paths for project success were not highly constrained, but open and ambiguous (Jonassen, 2000). The reader might note that Spiro et al. (1991) would differentiate these tasks as *well-structured* and *ill-structured*. I elected to signify this distinction as more and less structured to highlight that structuredness is not a dichotomy. The task activities observed in my study exhibited varying degrees of structuredness in different ways. Project 1 and Project 3 are broadly distinguished in this study in their overall structure. Additionally, as students proceeded with Project 3, their sources and strategies for managing uncertainty became more like those of Project 1, as indicated by the directional arrow in Figure 4.1.

As for the rows in Figure 4.1, students experienced uncertainty related to project activity and to social system issues as they collaborated to fulfill the requirements of the robotics engineering projects. By *project activity*, I mean aspects of the task directly related to tools, concepts, skills and practices of the tasks with which students were engaged. My definition of uncertainty about the *social system* is not limited to uncertainty about social relationships and social power; it encompasses uncertainty that students experienced about their interactions with other individuals in their group or outside of their group as they engaged with the robotics project. Project activity uncertainty and social system uncertainty interacted with each other across both projects, but in different ways. This is represented by the bi-directional arrow in Figure 4.1. The sets of sources of uncertainty and the sets of strategies students used to manage uncertainty were not identical in any of the cells of Figure 4.1, but there was overlap in all the cells in both sources and strategies.

The remainder of this chapter is organized as follows: I first discuss in four sections each cell of the model in Figure 4.1, describing the sources of uncertainty and the strategies for managing uncertainty that I observed by reviewing transcripts and field notes of whole-class and small group activity in Project 1 and Project 3 and then closely examining data from two collaborative groups from Project 1 and one collaborative group from Project 3. Following that, I present a catalogue of ways students managed uncertainty across the two projects. This catalogue was constructed based on my analysis of data related to interaction among group members of four focal groups for the first five days of Project 1 and three focal groups for the first four days of Project 3. I then describe individual propensities students exhibited for using these strategies. Finally, I describe the importance of peer response to individuals' attempts to manage the uncertainty they experienced while engaged in a collaborative effort to create a robot and achieve the assignment objectives. The importance of peer response was established through analysis of rich points in episodes of interest I had identified from the session transcripts of focal groups for Project 1 and Project 3. The chapter concludes with a summary of the findings.

Several students figure prominently in the following report of my findings. I have included a short description of each of these students in Appendix G.

Cell 1: Managing Uncertainty about Project Activities in a More Structured Task

The primary cognitive demands students faced in Project 1 were to acquire comprehension of the basic signs of the multiple semiotic systems associated with robotics engineering and to re-construct a robot pre-designed by someone else to complete a pre-specified objective assigned by the teacher. During Project 1, most of the uncertainty that students experienced about project activities was related to their ability to make meaning of the robotics functions, tools, inscriptions, and practices. They experienced uncertainty about their understanding of novel concepts, their ability to participate in new practices and Discourses associated with robotics engineering, and how to proceed with the unfamiliar activities of building, programming, testing. The students in the two groups that were the focus of this part of my analysis overwhelmingly managed uncertainty about project activities in Project 1 with a combination of tactics for reducing and ignoring uncertainty as they worked with their peer collaborators to fulfill the requirements of Project 1.

"I Really Don't Know What This Is:" Managing Project Activity Uncertainty While Building Structures

The most structured of the activities in which students engaged during Project 1was building structures. In this activity, students' assignment was to follow an instruction manual step-by-step until they met the well-defined objective of completing a rover structure exactly as the manual prescribed. Both the objective and the process for accomplishing the objective were clear and pre-determined. When building structures, students experienced uncertainty about project activity primarily about and whether their actions and structures were right or correct, and the primary strategy they used for managing this uncertainty was to *refer to the instruction manual as a source of authority*. The printed manual became the source of expertise to which students turned to reduce their uncertainty about whether they were building the rover correctly. Students learned to pay careful attention to the correspondence between the instruction manual and their physical structures: turning the pieces in their hands to match the slant of pieces in the manual, placing pieces against the page on which it was illustrated or counting the number of bumps on pieces to resolve uncertainty about sizing. At times that these strategies did not resolve uncertainty, students often turned to their group members for help, *requesting information* and *seeking confirmation*.

While building their rover, one group of boys (Demetre, Luis, and Nathan) had adopted a practice suggested by their teacher of rotating roles as builder, materials gatherer, and observer at every page turn. In the middle of the group's first building session [091908], Demetre took a turn as the builder. He had the instruction manual and was trying to attach a motor to his group's developing structure. When he was unable to resolve his uncertainty about whether a piece was placed correctly by referencing the manual, Demetre addressed his group members, *"Does it have this huge thing?"* Nathan reached for the structure, taking it from Demetre's hands without referring to the book and moved the motor, saying, *"I think you put it on the other side."* He handed the structure back to Demetre who looked at the page, skeptical. Without looking at the book but noticing Demetre's skeptical look, Nathan asserted, *"It should be right."* Pointing back and forth between the book and the structure, Demetre argued, *"No, these two things should go together."* Luis, who had also been referencing the book, agreed. Finally, Nathan looked at the book and said, *"Oh, that's right,"* and Demetre proceeded to attach the motor in the correct spot.

Note that Demetre had been referring to the building manual before he addressed his partners, but was unable to resolve his uncertainty by referring to the manual alone. Demetre's uncertainty was only resolved once he had acquired the input of his peers about the matter. This input seemed necessary for Demetre to move forward, even though it was he himself who identified the correct placement of the motor from the manual. Sometimes the strategy was *referring to the manual with one's partners*.

"But Our Program was Good:" Managing Project Activity Uncertainty While Programming and Testing

As students created their computer programs and tested their robot's ability to maneuver through the assigned obstacle course, problems with comprehension of the relevant scientific reading and writing practices abounded. Students had difficulties differentiating between types of programming blocks and with navigating the complicated structure of the programs themselves. They experienced varying amounts of uncertainty about their comprehension of textual features and practices and about their comprehension of the association between specific aspects of a "written" computer program and the actions of their built structures (e.g., which icon represents the wheels turning, the touch sensor being activated, stopping). They managed their uncertainty by *requesting scaffolding of participation* by their peer collaborators, by *requesting information* from their group members, and by *seeking out expertise* (primarily the teacher's) or *calling on the teacher's authority*.

Most students demonstrated in their group discourse and in their interviews that they were increasing their comprehension across Project 1 to greater and lesser degrees and in varying amounts of time. Kim's progress was less marked than that of her group members as evidenced in her talk, reflections, and interviews, which also revealed her uncertainty about programming. One day in the middle of Project 1, Kim sat on the floor with Kisha and the robot as the group tested their robot's ability to run in a straight line for one meter, a feat that was proving difficult. Kim relayed information about programming changes to Kisha from Satya, who called them out from her place at the computer. After a few tests, Kim moved next to Satya and leaned in to watch her change the program. Finally, after a particularly successful and exciting test of the robot, Kim requested, "*Let me try it now*." Satya moved to sit by Kisha while Kim sat down, looked at the screen, mumbled to herself, and called to Satya:

Kim: *I'm typing… How many seconds do you want?*

Satya: *I don't know… like 17.*

Kim: *Ok, 17 seconds. (She types it into the program) And then what do I do?*

The session proceeded with Satya calling out changes to Kim, who typed them. Only near the end of the session did Kim initiate her own idea, *"Wait, I know another one. Let me try."*

Apparent in this transcript is that Kim had learned to recognize at least some of the icons needed for particular actions. However, she had difficulty recognizing their enactment in the actions of her robot, and it was this aspect of programming with which Kim requested help from her group members. In using the uncertainty management strategy of asking group members to scaffold her participation, Kim was still turning part of the task over to her group members, but in a way that enabled her to take action that felt legitimate to her and to her group members.

The feedback students received when testing their robot's ability to maneuver through the assigned obstacle course was difficult to interpret because students had incomplete knowledge and only partial understanding of the relationships among the variables in the system. Each robotic action was enacted in the interplay of amount of power directed toward two motors simultaneously and uniformly, toward two motors simultaneously but differentially, or toward one motor at a time; the direction of the motors (forward or backwards); the distance as measured by rotations, degrees, or time; the interaction of programmed actions and the physical structure (e.g., drag caused by rubbing pieces, wheel size, wheel material); and the interaction of the robot with its environment (e.g., locomotion was different on carpet versus tile). These relationships had to be worked out for long sequences of actions.

Because insufficient knowledge or strategies for solving problems associated with identifying causal linkages in systems with multiple variables existed in most groups, students often experienced uncertainty as they tested the correspondence of their written programs to the actions of their robots. They were unclear about to which variables to attribute a particular test result, and their thinking was fuzzy about how variables together influenced test outcomes. Under these conditions, students primarily focused on reducing uncertainty about what to do, how to proceed, rather than addressing uncertainties about why results occurred. This is exemplified in Kisha's response when I asked if she knew why her group's robot was curving off course: "*Not really. But we're trying to fix it.*" This type of t*rial and error experimentation* was common, although students also attempted to manage their uncertainty about how to proceed through *analysis* and *systematic testing*. However, students' abilities to reason about the cause and effect relationships in the robotics system with which they were engaged was limited and often did not yield results that resolved students' uncertainty.

Finally, students sometimes experienced uncertainty about the wrong thing and at other times failed to experience uncertainty because they did not know what to be uncertain about. While programming their robots, students encountered not only complicated scientific texts with new inscriptions and semiotic signs, but also new ways of thinking about scientific concepts such as sequencing and precision. There were several examples in the data of students expressing the belief that an icon they added near the end of a program was "messing up" actions located before it. For example, Demetre said in an interview, *"I think we put something in the second turn that's confusing with the first turn."* This comment reveals a misconception about sequencing that led Demetre to experience uncertainty about the wrong thing and to manage his uncertainty by engaging the wrong actions. The uncertainty Demetre was experiencing was not about whether it was true that the second turn icons were interfering with icons that came before them; the uncertainty he grappled with was why it was true and what could be done about it.

Students had to develop accepted engineering practices for testing sequences of programming actions. This involved recognizing that they should be uncertain at each action step of programming and should resolve that uncertainty before programming in the next action. The teacher identified this as the correct strategy to use for engineering tasks, both in her whole group instruction and several times with Demetre's group. One day, Ms. Billings looked over the group's program and asked, "*Why do you have so many steps? Are you that confident?... You have to plan it one step at a time*." After the teacher left, Nathan started the program from scratch. It became clear to Detmetre that Nathan was rewriting the entire program at once rather than working action by action as suggested by the teacher and the following discussion ensued:

Demetre: *You're only doing the same thing again?*

Nathan: *Yeah.*

Luis: *We have to.*

Demetre: *Oh, forget it… I thought... I thought it was best to… do it a little bit different, you know?*

Nathan: *Yeah, but our program was good.*

Demetre: *Okay, we'll keep it.* [100809]

For Luis, there was no uncertainty. His declaration "*We have to*" implies that the possibilities for action were severely constrained. Likewise, Nathan expressed no uncertainty about his present course of action, which was to re-do the entire program. Demetre was the only group member to express doubt, which was brushed aside by his group members. Demetre gave in, perhaps because he was unable to articulate his concern well immediately. What is clear in this case is that the group member who expressed the most certainty and who was willing and able to take action quickly ended up with the upper hand in this situation even though his actions clearly went against the teacher's suggestions about programming and testing step by step.

In the example above, Demetre's group members failed to take up the uncertainty that might have facilitated a successful outcome. I present below an example in which the members of this group moved from feeling certain about their actions related to project activity to experiencing uncertainty about their actions. Early during the second day of programming, Demetre, Nathan, and Luis made several trips to the hall to test their robot, each time making a change in their program: shifting from measuring in rotations to measuring in degrees, lowering the power, taking out a "wait for completion," and increasing the number of degrees. All three group members made suggestions for changes. Their suggestions were accompanied by little to no explanation or analysis of the issues. When arguments arose about how to proceed, they were met with, "*I know what I'm doing*" or "*This will work.*" Although the group as a whole could be said to be in a state of uncertainty, the group members themselves expressed great certainty. Heading to the hall, Demetre would often make a positive prediction, "*Now it's going to* *work*." Although the expression was one of great certitude, these positive predictions may have been a strategy for ignoring uncertainty, a way to keep going in the face of not being sure what to do. After one failed test, Demetre and Luis both respond with "*WHAT?!,"* seemingly unprepared for this outcome. This expression of surprise supports an interpretation of students' failing to experience uncertainty up to this point in the episode. That these students were surprised at the outcome of their tests suggests that they had a strong expectation about the results of the test, an expectation that was not met.

As time went on, both of these boys exhibited signs that they were becoming less certain about their predictions of success. Demetre's positivity was finally tempered on this day by repeated experiences in which the results of testing did not match his confident predictions, "*Now it's going to work. Maybe. Please, please work*." While Demetre's response to uncertainty was to plead and hope, Luis's behavior took an opposite direction. His response was to predict failure, "*It's not going to do it*." Interestingly, this could be a strategy for ignoring uncertainty, just as much as expressing great certainty about success. Perhaps Luis's prediction of failure was a way to avoid negative emotions associated with dashed hopes.

After multiple unfruitful tests throughout the morning came a shift in uncertainty management strategies. The shift began with Demetre openly acknowledging his uncertainty:

Demetre: *We need more something different. We just don't know what it is.*

Nathan: *I told you, we need to do rotations.*

Demetre: *Rotations is not going to do any good.*

Nathan: *Yes it will.*

Demetre: *[turning to a nearby group] Are you guys doing rotations? We're doing degrees.*

Nathan: *I told you, Ms. Billings said we should always do it on rotations.*

Nathan's response to Demetre's expression of uncertainty about what to do was to assert that he himself did know what to do, "*We need to do rotations."* Demetre argued the opposite, in terms just as certain. However, it is Demetre who then makes another shift, a strategy to enable action by seeking an outside resource in his classmates. By contrast, Nathan referred to the authority of the teacher to assuage uncertainty and to justify his preferred plan. After several more failed attempts to make progress with testing, there was another shift, this time as Nathan gives in to uncertainty.

Nathan: *Ok, guys, how are we going to get this to work?*

Demetre: *I have no idea.*

Nathan: *This thing is so complex!*

Demetre: *So complicated.**

Demetre: *I'm going to go get the meter stick and we can just test it right here.*

Luis: *Let's do 100 rotations; that's what Satya did.*

Nathan: *I'm crazy, but ok.*

Having exhausted their own ideas about what to try, the group first acknowledged their shared uncertainty and attributed it to the complexity of the task, something they previously had not done, choosing instead to experiment and hope for a positive outcome. Demetre, seeming at last to realize they might be running many tests, brought closer to the computer the measuring stick against which they tested. Finally, Nathan acquiesced to

Luis's suggestion to adopt a solution he had observed in another group. Although he did not have any reason to believe the idea would work, he could not think of reasoned alternatives. Thus, experimentation continued, but with expanded options for drawing on available resources to facilitate action and learning.

Cell 2: Managing Uncertainty about the Social System in a More Structured Task

During Project 1, students experienced uncertainty about the social system primarily related to their social standing in the group (e.g., who has social power), how their group members would respond to an idea or action, and to how much they trusted their group member's knowledge of robotics engineering. When students had differing ideas about what actions to take, how they would proceed had to be negotiated among group members, and this entailed social uncertainty about group process (e.g., what is going on in this group, what is okay to do or say in this group, how does one acquire the right to participate/make decisions in this group). Students managed these uncertainties by negotiating with their group members about what actions to take and about who could participate in what ways (e.g., who would move the robot or make decisions about what experiments they would try when testing their robot). This negotiation progressed with students using multiple strategies to manage social uncertainty. Furthermore, it was influenced by the level of trust that students had in each other's robotics engineering knowledge and skills. In the next example, Nathan was sitting in front of the computer, controlling the mouse, as he often was. Demetre and Luis were standing behind him, leaning in to look at the screen.

Nathan: *Let's see,… let's change.. okay… (trails off)*

Luis: *We only got two motors [icons]. Make it 2 rotations.*

Nathan: *No, if we want to get up to the first cone, let's make it 5.*

Luis: *5 rotations?*

Luis: *Yeah, 5 rotations for both of you ["you" refers to the motor blocks]. But first I need to change it to 50% power.*

Demetre: *Are you sure you don't want to put it for 100%, or do you think 100 would waste all of our batteries out in one minute?*

Nathan: *Yeah, it would.*

Demetre: *Then we should put it 30.*

Luis: *Then it will only have a little bit of power, it won't… (trails off)*

Demetre: *Ok. (reluctantly) **

Luis: *So now what?*

Nathan: *Now we do another A, but this time the motor's going to go back//*

Luis: *//No, she only said to do two motors… The teacher only said to do two.*

Nathan: *No, she said we can program it to at least go around one cone.*

(2 second pause)

Luis: *Excuse me. (sounding offended)*

Demetre: *No, I think she said to go around two cones, or one.*

Nathan: *Well, I'm just going to program it to go around two cones, ok?*

Luis: *One cone. Then we're going to get in trouble.*

Nathan: *Fine, one cone. Okay, but this time the A will wait till completions.* [101709]

Luis and Demetre both exhibit a greater trust in their group member's knowledge and skills than in their own, both of them asking Nathan questions and acquiescing to Nathan's expressed beliefs about the correct thing to do. Demetre acquiesced also to Luis's belief that 30% was too little power. Demetre's deference to Nathan went deeper than trust in his robotics knowledge. He attributed to Nathan great intelligence, "*He's like, the smartest one that helps me fix my mistakes*." As the boys continued to negotiate action, calling on the authority of the teacher won Luis the right to the decision about how many motor blocks to add to their program. Even though he thought Nathan was more knowledgeable than he about programming, Luis felt that he himself was more knowledgeable about what the teacher had said.

Interestingly, Nathan was as unsure of what to try as were his group members, exhibited by his hesitation in the first comment of this episode and in his questions following Luis's suggestions. In an interview later that day, Nathan admitted to being uncertain about how to proceed with their project: "*When we were doing the robots I didn't know why it wasn't doing the stuff that we wanted. So we kept going back to the computer and downloading it, but we weren't really sure what to do*." Nathan is describing a situation in which he and his group members were not sure about what would lead to the outcome they knew they wanted. The way Nathan described it, the decision rules they were using were "do something." To "do something," they had to negotiate what would be done. Negotiating what would be done was influenced by more than just who was sure about the task. Clearly, social uncertainty was influencing task decisions in the group.

As well as influencing what was said in collaborative sessions, uncertainty also influenced what was not said as students managed their uncertainty about how group members would respond, would think, or did think about them. For example, Demetre sometimes did not share ideas with his group members because he was not certain that he would be understood. Demetre explained why he had decided not to tell his group members his idea for measuring the distance a wheel traveled in the same way you would measure the earth spinning: "*I think they wouldn't understand. I use more detail than they do. If you don't describe detail then they'll never understand. But sometimes I just don't have enough detail so that...[inaudible]... I wanted to get enough description to describe how we would do it. That's what I usually do before I even say anything" [100808].* In this explanation, he seemed to be describing a strategy of *waiting to get enough description* to ensure he would be understood. He was uncertain about how his group members would respond to his idea and also about his ability to express the idea. He gave himself time and space, feeling that he was not ready to share his idea because he had not yet reduced his uncertainty about the ideas enough to know what to say.

On a day when Luis and Demetre were working alone, Demetre became frustrated with Luis's failure to inform him of changes he was making to their program. The situation led Demetre to experience social uncertainty about *what is happening in this group.* He had difficulties managing this uncertainty because he was also concerned about how efforts to do so might affect Luis and what Luis would think of Demetre. Demetre explained in an interview: "*Sometimes we argue about what are you doing and he doesn't tell me things before he changes. And sometimes he's got to let me see what he's doing and sometimes he's like, just go with it. And I want to be sure to know what* *he's doing because I was just checking on what he was doing. I mean, I don't want to hurt his feelings or anything, but I just want to check his work*" [11/14/08]. Demetre was describing a dilemma; he did not like being unsure about what his group member was doing, but he was also unsure about how Luis would respond if Demetre complained about the situation (i.e., will it hurt Luis's feelings). In addition to being unsure and worrying about how Luis might respond to his actions, Demetre also experienced uncertainty about Luis's perception of Demetre (i.e., what does Luis think of me? What is it okay to say to Luis?). Demetre continued in his interview: "*Sometimes I do think he thinks that I'm a little bossy, but I'm actually not… I don't like people to think I'm really mean…*" These social uncertainties were salient to Demetre because he cared about the ramifications of Luis's interpretation of Demtre's actions on their unfolding relationship.

Cell 3: Managing Uncertainty about Project Activities in a Less Structured Task

In contrast to the more structured activities students encountered in Project 1, the design activities students encountered in Project 3 fell much farther to the less structured side of the continuum, as the task of generating product ideas and coming to agreement on which idea to pursue was open-ended. Its large space of possibilities of possible paths to successful completion of the project and its objectives were not clearly defined. In Project 3, before students could deal with the micro-elements they had dealt with in Project 1, more macro questions had to be addressed: What elements of the environment are we trying to impact? What is the role of the robot? What will the robot do?

When academic tasks are presented to students as initially less structured, then part of students' challenge is to create structure themselves. This has to be accomplished in order to end up with a robot. Students took the less structured task and tried to transform it into a more structured task, giving meaning to the problem, so that they could solve it. Much uncertainty lies in getting from a less structured to more structured task. In addition to the sensemaking afforded by collaborative discussion, students attempted to increase the structuredness of an initially less structured task by using as resources for organizing their thinking, textual tools they either created or found.

In this less structured task, uncertainty expanded and uncertainty management exploded. Rather than primarily experiencing uncertainty about the project activities related to the adequacy of their knowledge or understanding, students also experienced uncertainty about their evaluation of and preferences for ideas and designs. A much richer and broader set of strategies was used for managing uncertainty about project activity in Project 3 than in Project 1. In addition to reduction and ignoring tactics, uncertainty management in Project 3 included tactics for maintaining and even increasing uncertainty temporarily. Additionally, one tactic for reducing uncertainty, *seeking agreement*, was greatly increased in Project 3 as students navigated the ambiguity of multiple options associated with brainstorming product ideas and design solutions, and attempted to produce and troubleshoot their designs.

Before illustrating these findings with examples, I wish to make two notes. First, keeping in mind the design steps indentified and described in Chapter 2, I nevertheless adopted the in vivo terms used by the participants in this study to describe design activities. Also note that although I differentiate here between *brainstorming* initial design ideas and *troubleshooting*, these activities were not necessarily so different in practice, except in that brainstorming occurred prior to production and troubleshooting occurred during production. Some groups changed significant aspects of their product designs throughout the project.

"*But How Is That Possible?:" Managing Project Activity Uncertainty While Brainstorming*

When brainstorming, students were engaged in the activities of deciding two things: (a) what product to make, and (b) how to make it. These were iteratively, recursively and sometimes simultaneously enacted in students' engineering practice. In addition to the reduction strategies associated with Project 1, students responded to the uncertainty they experienced during brainstorming by tactics for *maintaining uncertainty*. They gave themselves time to reflect by *delaying decisions*, resisted closing options too quickly by *expressing doubt*, and kept several ideas in play at one time by *sustaining multiple options*. For example, on the first day of Project 1, as they shared their design ideas, the members of the Recycling Rover Group simultaneously considered Kisha's idea of a food transporter, Becky's idea for a robotic garden waterer, and Kisha's idea for a television that senses when there is no movement in the room and turns itself off. They discussed one, then another without attempting to make decisions or trying to reach agreement, but instead, keeping all the ideas on the table, maintaining uncertainty about all of them at once. *Expressing doubt* helped this group sustain attention on each of these ideas for several comments. Demetre was a particularly vocal introducer of uncertainty: *"But how will it be able to…?," "don't they already have that?," "But they have to set it themselves?," "wouldn't that be the same thing?"* Demetre's expressions of doubt spurred much discussion about each idea that was introduced, thereby increasing clarity of initially vague ideas.

Another way students in this group maintained uncertainty while brainstorming about problems and solutions was to *make temporary decisions*. For example, although everyone in the Recycling Rover Group expressed interest in the idea of the food transporter, Satya expressed doubt about the idea of transporting food, and the group brainstormed different things to transport. When they could not come to consensus, Satya wrote down "food transporter" saying, "*Okay, well, let's just stick with the food transporter for now*." By tacking on, "*for now,*" Satya implied that the decision was temporary and subject to revision. This example demonstrates the willingness of this group to make decisions to move an idea forward while maintaining sufficient uncertainty that backtracking was possible and the search for alternatives continued.

A major challenge for students in Project 3 was to make decisions and act when there were multiple correct paths and when paths had to be created by the students themselves. In such circumstances, collaborating with one's group members to reduce uncertainty about how to proceed was often enacted through tactics of *seeking agreement*: group members combined ideas, emphasized the similarities rather than the differences between their design ideas, sought to *obtain consensus*, and summarized the state of their project to check that all group members were "on the same page." For example, when Satya realized that they would have to use two motors for the wheels if they wanted their robot to turn, and that this would leave them with no motors to activate a claw if they were going to stay within the materials constraints of the assignment, she suggested the members of her group vote as a way of reducing uncertainty about their options about how the robot would move.

Finally, design activity spurred strategies for temporarily *increasing uncertainty* with tactics such as *opening the problem space* by *seeking to generate multiple perspectives*. For example, once consensus had been reached about the purpose of their product and ideas had been discussed about how to build and program their robot, Satya suggested that they all draw independent sketches of the product they had agreed on: "*We could each draw our own idea of how it looks in our journal and then we could look at them together."* So while students in the other groups continued noisily to discuss their design ideas, the members of the Recycling Rover Group bent over their design journals, sketching out their individual conceptions about the ideas they had been discussing. They then compared their ideas. By engaging in this action, members of this group were essentially agreeing temporarily to increase their uncertainty about what their product would look like so that they could take advantage of their diverse perspectives.

"Maybe We Should Put This Right Here?:" Managing Project Activity Uncertainty While Producing and Troubleshooting a Product

Developing and troubleshooting a robotics product entailed managing uncertainty related to enacting their design ideas: Can we make this? How can we make this? Will this work? Is it useful? To resolve these uncertainties, students drew on a variety of textual resources to bring their conceptions into being, organize their thinking, and clarify initially hazy conceptions. For example, students drew and labeled sketches, posted questions to a wiki page to obtain responses from their teacher and from their classmates, referred to the help section of the programming software, and wrote reflective entries in their design journals.

Types of textual resources students utilized in their attempts to manage uncertainty can be clustered according to whether they were self-created or found (i.e., came from outside resources). Textual resources can further be differentiated based on whether they used online or print media and on whether they were primarily language-based or consisted of inscriptions or icons. These characteristics of textual resources are represented in Figure 4.2. The figure is organized so that the textual resources that were self-created are displayed on the top row and the textual resources that were available in the environment are displayed on the bottom row. *Wiki postings* is situated in the middle because, although members of collaborative groups created their wikis, they relied on responses from outsiders to respond to the questions they posted.

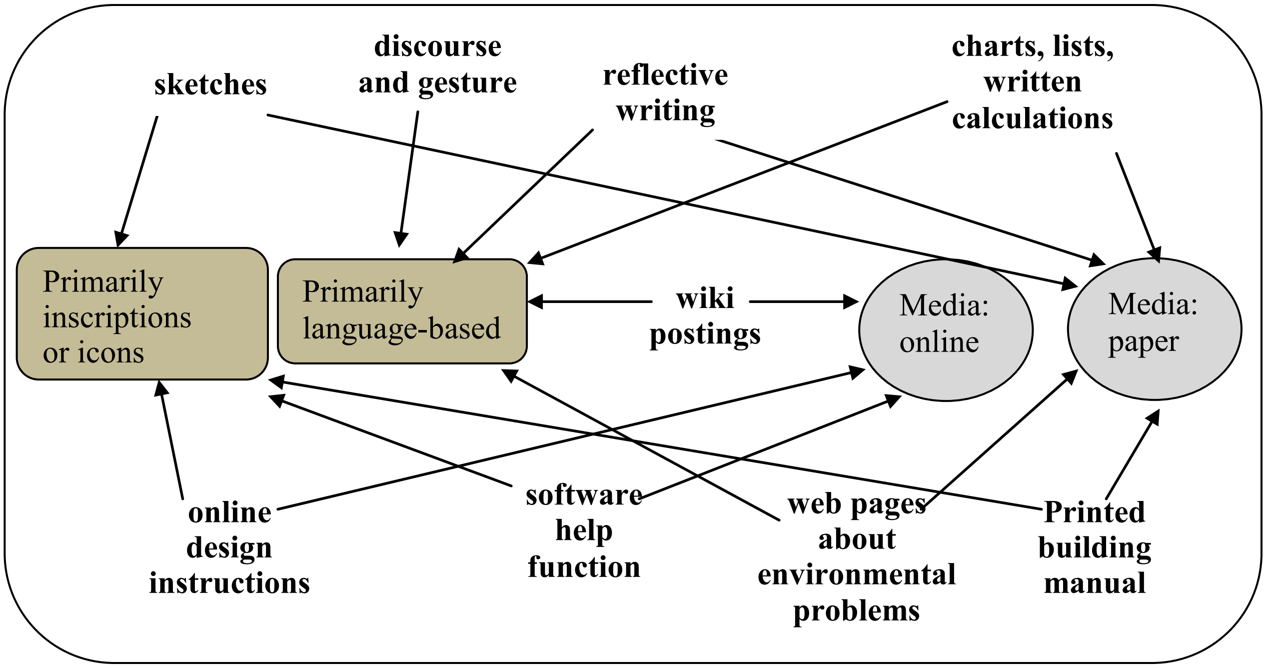

Figure 4.2 The Nature of Textual Resources Used to Manage Uncertainty

The different textual resources created by students themselves had in common that they can be considered tools for modeling something that existed only in one's head for example, a process or sequence of steps for finishing the project, a strategy for enabling robotic motion, or a method for stabilizing a structure or part of a structure. By modeling processes and products using textual tools they created themselves, students transformed an initially fuzzy idea into an examinable artifact that could be constructed, tested, and/or implemented. When utilizing textual resources to model an idea that had previously existed only in one's own head, or when transforming a model from a verbal or gestural representation of an idea to a written representation of that same idea, uncertainty decreased for students as they developed a clearer conception of their ideas, but it also increased as students realized the weaknesses of their under-developed ideas, weaknesses that were made apparent by the act of trying to model an idea.

Outside textual resources could act as models, but they could also function to provide relevant information or alternative design ideas. Like self-created textual resources, interaction with outside resources could either decrease or increase uncertainty as students encountered new alternatives to consider. Students drew on outside/environmental textual resources from their prior experience in the first two robotics projects. For Project 2, the robopuppy obstacle course, the teacher had introduced students to a website dedicated to sharing building and programming instructions for different LEGO Mindstorms robot designs. For Project 3, all six collaborative groups assigned used this or similar websites as a tool in structuring an originally less structured problem. The members of the Recycling Rover Group used online elements in the design of their structure and their program. In both cases, rather than wholly appropriating an entire design from the Internet from top to bottom, students combined pre-designed elements and their own design ideas into an amalgamation, in effect *frankensteining* together a robotic product. For example, on the third morning of Project 3, as they moved from talking about and sketching their design ideas to production and troubleshooting, group members stood surrounded with building materials and their design sketch, discussing options for building. Demetre was holding a motor in his hand and Kisha had the NXT. Satya had the print-based instruction manual and held it up:

Satya: *Hold on, look how it looks here, see, like this? What we could do is we could start building it like this (points) until… [inaudible](Sayta is flipping through the Mindstorms building manual)*

Demetre: *It sure is going to take a while.*

Satya: (*closes the book) : What we should do, we should get on the computer and you know the bottom part of the puppy? (gestures toward the computer) We could build that. We could start with that.*

Demtre: *Are we going to build all 4 wheels just like the example..?*

Kisha: *It's going to be like the wheels that are on the puppy.*

(They move toward a computer in the corner of the room. Demetre and Satya both start logging in to computers that are side by side.)

Satya: *And then we need to build a platform on top of it (gestures with right hand over left hand to indict a platform)*

(Demetre and Satya both go to NXT building.com and search for the robopuppy instructions. Becky and Kisha stand behind them.)

Kisha: *What wheels are we going to use? The same as they're using, or different?*

Demetre: Are *we going to have to program it backwards like we did on this?*

As the group began considering how to translate their design sketch into a three-dimensional product, they used several written resources the teacher had introduced in prior projects to help them resolve uncertainty about how to get started (e.g., the print manual, a website). As they contemplated Satya's suggestion to integrate the building instructions they had previously used for the robopuppy in Project 2, the group members went beyond simply appropriating the pre-designed robot, instead exploiting some of its aspects to suit their own needs.

Cell 4: Managing Uncertainty about the Social System in a Less Structured Task

Rather than a single correct answer, many of the decisions with which students were faced during Project 3 had more than one correct path to multiple successful outcomes; problems were open to multiple interpretations, the nature of problems/decisions was vague and unclear, and these problems had more than one possible meaning. In addition, mutual understanding among group members was made more difficult by the fact that students were often discussing things not physically in front of them; they had to bring their ideas into being through their words and gestures, and through the inscriptions they created. During Project 3, in addition to the uncertainties about the social system that students experienced in Project 1, uncertainty was also elicited about whether individuals understood their group members, whether they were being understood by their group members, and about how their group members would evaluate their ideas. Because managing uncertainty about project activities in the context of Project 3, with its less structured tasks associated with design activity, required mindreading among group members, experiences of social uncertainty occurred. When students were socially uncertain, they sometimes made indirect overtures to try to get information. Also, in addition to using these to manage task uncertainty about their own ideas, students managed social uncertainty using language, gesture and inscriptions to increase the probability that they would be understood by their group members. Additionally, more and longer explanations were requested and offered as students attempted to manage these uncertainties about the social systems in which they were operating during Project 3. As one illustration, I offer the following discussion that occurred after Kisha described to her group how the idea for a robotic food transporter had come to her when she was leaving a restaurant with leftover food.

Demetre: *Can you slow down a little? I have no idea what you just said, like from the beginning.*

Kisha: *Uh, so like, if you don't , so if, I don't know if this could work, but you could make like a... where you could put food in it and then it could like transport it to somewhere else… I don't know.*

Demetre: *But how is that possible?**

Demetre: *Are you talking about, like, a car that will transport it to somewhere else?*

Becky: *No, it's like, uh, the, like the…, like at the bank, you know, how they have the thing, the suck-up thing// **

Satya: *I mean, it's not a bad idea//*

Demetre: *//We could make a claw to grab it.*

As Demetre experienced uncertainty about his understanding of Kisha's idea, he made several moves to address his uncertainty about his understanding of Kisha's idea, *requesting information* about what she was thinking in several ways: asking that she repeat her explanation, trying to imagine how it would work, and checking to see if his image of a car-like structure matched hers. As Kisha re-explained her idea, she revealed her own uncertainty about the feasibility and conception of her idea. Thus, by attempting to resolve his own uncertainty, Demetre introduced uncertainty in other group members.

Furthermore, in response to Demetre's attempts to manage his own uncertainty, Becky attempted to help him resolve his uncertainty. Becky addressed Demetre's uncertainty by creating an analogy about a pneumatic bank teller. Having resolved his social uncertainty about his understanding of Kisha's idea, Demetre then shifted to addressing a task uncertainty, how such a project could be created using their available materials.

Students also experienced social system uncertainty about how a group member would evaluate or respond to her idea or action, even when she was sure about her own evaluation. For example, while Satya was out of the room at her gifted and talented class, her group members decided to make a major change in their design, taking apart a trailer and replacing it with a claw mechanism. As Becky and Kisha commenced to taking apart the trailer, standing side by side, the following discussion ensued:

Becky: *Satya's going to come in here and yell at us. I just know she is, don't you?*

Kisha: *Yep.*

Becky: *(speaking in a high squeaky voice meant to animate Satya): Why are you taking the trailer apart?*

Kisha: *Cause then we're going to make the claw, then we're going to program it and then we'll be able to pick up up (lifts right hand high, fingers pressed together), move it (swings arm out to the side), and… Oh! (opens her fingers in a letting go motion, points, turns, and looks directly at Becky, eyes wide) and instead of doing the box, the claw can pick up the trash! (excited voice*)

Becky: *Yeah.*

Kisha and Becky were uncertain about how Satya would respond to their design decisions, and they were managing that uncertainty by imagining her response and practicing telling her. Kish was dealing with her social uncertainty socially, by playing it out with a group member to see what might happen. Because her partner, Becky, was willing to engage in this strategy with her, Kisha was able to enact this strategy of *scenario planning* in which she imagined how Satya might react to their actions and planning how she herself might respond to concerns she imagined that Satya would introduce. As these girls continued to work, they continued to play out scenarios, waffling between predicting Satya's pleasure and her anger.

In a strange way, this social uncertainty was productive in terms of facilitating reflection on the academic task with which these two girls were engaged. Attending to a social uncertainty caused Kisha and Becky to think through what might be problems with their design and to practice talking about their design. In the process, Kisha actually increased her certainty about the benefits of their design change, convincing herself of its value, although not necessarily reducing her uncertainty about Satya's response to it. Given Satya's central position as the unchallenged leader of this group, it is interesting that these girls went ahead with the plan they had conceived when she was not present, especially as their teacher often stressed the need to make decisions as a group. By dismantling the design Satya had largely conceived and experimenting with another design when they faced a problem without her, they potentially learned something they might not have learned if she was there. This opportunity cost them in the form of anxiety about their social situation.

Interesting also is the response of Becky and Kisha to Satya's actual response to their design changes. Kisha had evidently been watching for Satya's return from her gifted and talented class, likely nervous about breaking the news. When Satya walked through the door, Kisha called across the room to her, "*Satya, we took the trailer apart.*" When Satya's initial response was first to express dismay, Kisha whispered to Becky, "*See, I told you; I told you she'd be mad,*" and Becky agreed. It is difficult to say exactly what prompted this interpretation of what had transpired, but this interpretation of their prior conversation may be a form of uncertainty avoidance, a way of maintaining control in what is largely an unpredictable future. Once things played out as they did, these girls responded with, "See, I knew all along; I was never uncertain," Perhaps there were some kudos to be gained from determining that one has chosen to do this in the face of what one knew would be bad consequences.

Summary of Sources and Strategies in the Four Cells

The sets of sources of uncertainty and the sets of strategies students used to manage uncertainty were not identical in any of the cells of Figure 4.1, but there was overlap in all the cells in both sources and strategies. Uncertainty was elicited by more sources of project activity and more aspects of the social system in the project with less structured tasks (Project 3) than in the project comprised of more structured tasks (Project 1). In Project 3, part of students' challenge was to structure the task themselves, and this complicated the task with additional sources of uncertainty that had to be managed. Thus, the sources of uncertainty present in the more structured tasks of Project 1 were also present in Project 3 as represented by the directional arrow in Figure 4.1. However, the opposite was not true.

Social uncertainty was more prevalent in Project 3 because there was a greater need for students to understand each other's ideas in order successfully to design and make a robot. Students had to engage in mindreading (Bloome, 2002) in order to bring into being the ideas of their group members, and they utilized gesture and created inscriptions to facilitate such mindreading. Additionally, during Project 3, there was more space, more possibilities for "what should I be doing here" and "What is it possible to do in this group." So uncertainties about one's relationships with peers and about one's social position/standing were more salient in Project 3 than in Project 1.

In both projects, students exhibited a variety of ways for managing their uncertainty. However, students used more strategies for managing uncertainty in Project 3 than in Project 1. Many of the uncertainty management strategies that students used in Project 1 were also used in Project 3. However, the opposite was not true. Specifically, in the more structured tasks of Project 1, students primarily used uncertainty reduction tactics and tactics for ignoring uncertainty. In the less structured tasks, in addition to those same tactics, they used other reduction tactics and also strategies for maintaining and increasing uncertainty. In both projects, when uncertainties were sustained over long periods, students often used several strategies to manage uncertainty related to a single issue. Furthermore, attempts to manage uncertainty related to project activity could introduce social uncertainty and vice versa. Thus, social system uncertainty and project activity uncertainty were reciprocally influencing.

A Catalogue of Uncertainty Management Strategies

One of the objectives of this study was to identify the range of uncertainties and uncertainty management strategies used by these students. Although many of students' sources of uncertainty and their responses to that uncertainty were described above, not all of them were captured there. In this section I present an overview of the issues about which students experienced uncertainty, I present the strategies and tactics they used to manage their uncertainty, and then I discuss the interaction between sources and strategies.

Issues about Which Students Experienced Uncertainty

Students' levels of uncertainty remained high through much of the collaborative design projects in which they were participating. Rather than trying to escape from a high psychological load of uncertainty, students shifted attention from one uncertainty to another; the resolution of one uncertainty led them to another uncertainty and/or freed up cognitive attention for another uncertainty. Students sometimes experienced and managed multiple uncertainties in quick succession. The majority of uncertainty in both projects was about project activity issues, including uncertainty about assignment parameters and constraints, product/problem definition, building the robot, programming and testing, their own knowledge, comprehension, ability, opinions, and outside evaluation by the teacher, classmates, and audiences. Of the 254 instances of uncertainty I identified in my analysis of data from five days of Project 1 and four days of Project 3, 178 of them pertained to project activities. Additionally, students seemed to expend considerable energy addressing uncertainty about the social system, including uncertainty about what was happening in their group, the group process, what their group member(s) were thinking and how their group member(s) would respond to an event or idea, and their own social standing and relationship to their group member(s). I identified 76 instances of uncertainty identified in the data related to the social system. These frequencies may be misleading, as students may have been more likely to discuss uncertainty about project activity and more likely to hide uncertainty they experienced about the social system.

Although I did not attempt this level of distinction in my coding scheme, instances of uncertainty could be further differentiated by whether the uncertainty pertained to (a) truth of a proposition, (b) underlying meaning of an event or statement, (c) an individual's comprehension or understanding of a proposition or event, (d) his/her opinion or preference in regards to a decision [idea or alternative], or (e) the possibility/probability of occurrence of an event. For example, two students expressed uncertainty about *product/problem definition*. However, Berta expressed her uncertainty as pertaining to truth, "*Let me think, does this [product] already exist?,*" whereas Isabel voiced her uncertainty as a question of meaning, "*What if it's already been invented?*" Both students were expressing uncertainty about the existence of a product similar to the one they were designing; however, whereas Berta was expressing uncertainty about the true state of the world - does a similar product exist or doesn't it, Isabel was concerned with what it would mean for the group if a similar product did exist.

Strategies and Tactics Students Used to Manage Uncertainty

Students had many ways to manage uncertainty as they engaged in these collaborative robotics engineering projects. I identified in my data 27 tactics for managing uncertainty, and I elected to group these tactics under four overarching categories: (1) reducing uncertainty, (2) ignoring uncertainty, (3) maintaining uncertainty, and (4) increasing uncertainty. These are identified, illustrated, and the frequencies tabulated in a table in Appendix F. Below, I briefly describe a few of the tactics within the four strategies for managing uncertainty.

Reducing uncertainty. Individuals most often seek information when uncertain, information that will reduce uncertainty (Babrow & Matthias, 2009), so it is not surprising that this was true also for the students in this study. *Reducing uncertainty,* referring to tactics that seemed intended to decrease uncertainty in the short-term, was represented by the most variety with 15 tactics. These tactics might be differentiated based on the resources that were utilized in their execution, whether they utilized resources from one's peer collaborators within the group or from some other source.

Five tactics could either be done by individuals in a group or could be enacted as a group: *analyze the issues, test systematically, trial and error experimentation, scenario plan, and refer to past experience.* Five tactics were associated directly with seeking help from one's group members: *request information or explanation from members, directly ask for help, seek confirmation, think aloud,* and *seek agreement*. One tactic for reducing uncertainty was specific to managing uncertainty about one's social system, *explain clearly/show to group members to increase your chance of being understood*. Finally, four tactics for reducing uncertainty utilized outside resources: *seek out an expert-outsider, seek information from textual resources, refer to the authority source or figure,* and *observe others*. In addition to seeking the teacher's expertise, students sought out the expertise of classmates not in their group, classmates whom they perceived as being more knowledgeable in one or another aspect of robotics engineering. One example is offered below.

Luis: *Let's ask Andrew.*

Berta: *Are we going to have a whole segment called, "Let's ask Andrew?"*

Luis: *Let's ask Andrew. (repeats five times)*

Shamitra: *Well, he's good.*

Berta: *I know it.*

In addition to being comprised of the largest and most diverse set of tactics of the four overarching strategies, reducing uncertainty was also the strategy most frequently occurring in the data across both projects, with 540 of 808 total instances identified. The most commonly utilized tactic for reducing both social system and project activity uncertainty was to *request information/explanation from group members* (115 instances identified). Instances of *requesting information/explanation* might be categorized as a type of help seeking *(*see Webb, Ing, Kersting, & Nemer, 2006). Another frequent tactic for managing uncertainty that might also be considered help seeking is *asking for confirmation*. This tactic was used across all four cells in Figure 4.1.

Ignoring uncertainty. Ignoring uncertainty encompassed five tactics that closed off discussion or contemplation of uncertainty: *avoid* (hide the truth, drop consideration of an idea, minimize problems), *pass a task off to a group member, dismiss or fail to consider an introduced uncertainty, blame/justify uncertainty on an external source, keep going* (persist, bluff). I identified 63instances of ignoring uncertainty. Tactics for ignoring uncertainty were the most difficult of all the strategies to identify. It was difficult to tell whether students were ignoring uncertainty, intentionally avoiding the experience of uncertainty, or whether they were failing to become uncertain when it seemed to me that uncertainty was warranted in the situation.

At times, both tactics for *reducing uncertainty* and for *ignoring uncertainty* were problematic for a group's work in that they curtailed reflection that might have led to productive action. Although reducing uncertainty sometimes seemed to enable action, keeping a group from "stalling out" and thereby allowing them to make progress with their robotics project, it sometimes caused students to "spin their wheels," taking lots of action but getting nowhere. Likewise, ignoring uncertainty could enable one to try out his or her untested ideas or to continue acting in the face of repeated failure. However, ignoring uncertainty could also limit discussion that would facilitate meaning making and comprehension, decreasing the possible conversational directions of the next conversational turn, and thus potentially inhibit future successful action. Temporarily *maintaining uncertainty* was a strategy for holding the tension between taking action and gathering information.

Maintaining uncertainty. Tactics intended to delay decisions in order to examine uncertainty, and there were five types that fell in this category, were described as temporarily *maintaining uncertainty* (198 instances identified*)*. One tactic required only the *acknowledging* of uncertainty, thereby creating the possibility that an issue could be considered. One tactic, *admit incompetence*, was used to diminish negative emotion and continue action in the face of uncertainty. Several more tactics were used when active resistance to immediate decision making was required to enable reflection and forestall closing options quickly: *delay decisions* (wait, hold off, reflect, make several drafts), *hedge your bets* (recognize and maintain multiple options), *express doubt,* and *participate in idea sharing to socially construct actions, decisions, or solutions*.

Increasing uncertainty. Finally, students appeared to use uncertainty in order to "play with ideas," perhaps for enjoyment, to relieve boredom, or to facilitate better decisions, and I labeled this a strategy for increasing uncertainty. Only one tactic, *open* *up the problem space*, was subsumed under this fourth over-arching strategy. This was by far the least frequent strategy; I found only seven instances. Such behaviors may be difficult to observe or interpret, or truly did not occur often in this academic context.

Rather than striving simply to meet evaluation criteria, students in this class were motivated to explore, and this led them purposefully to seek out uncertainty about what they were capable of making their robot look like and do. When I asked why their robot had changed so much over the course of Project 3, Kisha replied, "*Because we're always coming up with new ideas that may work even better and we just want to add those to our robot to see if they would really work*" [052209]. Kisha was expressing that it is enjoyable to be uncertain; it is fun to play with uncertainty. Making changes to her robot was motivated by curiosity, uncertainty about whether the ideas of her and her group members would work. Intentionally increasing one's uncertainty by generating ideas one had never seen or tried was motivated by the enjoyment such uncertainty produced.

Interaction of Sources and Strategies

To say that individuals manage uncertainty is not to imply that they seek simply to reduce or eliminate it. Effective responses to the experience of uncertainty may at times entail attempting to reduce, but at other times, seeking to ignore, maintain, or increase one's level of uncertainty, or to change the issue about which one is uncertain from one topic to another (e.g., to shift from experiencing uncertainty about whether one's group members are mad at you, to experiencing uncertainty about what to do about one's group members being mad at you). Solving complex problems such as collaborative robotic design projects that take place over a long period of time and have several phases requiring multiple iterations may entail "a complex interactional weave of multiform uncertainties" (Babrow, Kasch, & Ford, 1998, p. 3). Managing uncertainty in such situations may require not only multiple strategies, but also that multiple strategies be used in conjunction with one another to address a single uncertainty event. As a simple example, I offer an instance in which Isabel was experiencing uncertainty about how her classmates would respond to her presentation of her group's project. Immediately prior to the presentation, she used a reduction tactic of *scenario planning*: "*I was thinking, what is the worst thing they can say, like, I'd think they would say, so like, how is it going to do this, and, why is it going to do that, and keep asking more and more questions, things like that*." As she was giving the presentation, she used an ignoring tactic of *bluffing*: *"I was just kind of, like, kept presenting, and I was acting like I really wasn't stressed out."* By using these joint tactics, Isabel enabled herself to take action in the face of social uncertainty, how her classmates would respond to her group's design ideas.

Some sources of uncertainty elicited all types of management strategies and other sources garnered only a few strategies. *Requesting information/explanation from group members* was used to address all kinds of uncertainty. However, students rarely sought to maintain uncertainty about understanding of how to use the tools associated with robotics engineering. By contrast, they did intentionally maintain uncertainty about their evaluation, preference, and opinion of design ideas. Therefore, strategies for maintaining or increasing uncertainty were used primarily in Project 3, where evaluation of alternatives, preference, and opinion, and grappling with ambiguity were more prevalent. Nor did students use maintaining or increasing strategies to address uncertainty about social relationships. Students' responses to uncertainties about the state of their social relationships in their group were to ignore them or to try to reduce them; individuals did not try to maintain or increase their uncertainty about their social relationships.

Because students were engaged in an engineering task where the goal was to produce a desired outcome rather than science experimentation where the goal is to understand cause and effect relationships (Schauble, Klopfer, & Raghavan, 1991), students were more likely to experience and manage uncertainty about how they could get their robot to work than uncertainty regarding *why* their robot worked. Students exhibited what might be called a design mentality as they engaged in both of these collaborative robotics projects. They tended to reduce uncertainty about how to proceed as much with *trial and error exploration* as with *analyzing the issues* and *testing systematically*. For example, during Project 1, when I inquired of Satya, Becky, and Kisha why their robot was working, Kisha replied, "*We have no clue*," and Becky responded, "*If it works, it's good enough for me*." Another time, Becky elaborated, "*I'm not really interested in how it works; I wonder if it can do the things we need it to do.*" During Project 3, when Berta asked Luis how he had fixed a structural problem that had been plaguing the group, Shamitra interjected, "*It doesn't matter, Berta, as long as it's not knock-kneed*." Thus, in both projects, the uncertainties most salient to students were not about cause and effect relationships they may have attended to in a science project; rather they were about the practical questions of engineering, "How can we make this work?" That is not to say, however, that students did not also participate in analysis and systematic testing. For example, this type of thinking was used by Satya and Kisha as they programmed and tested their robot.

Satya: *Well, ok, maybe we should start working from here, right? Right here? Ok. 1200 rotations is too much. I don't know. Maybe six?//*

Kisha: *//I have no clue. Because if the turn is too long and it started to go crooked, then we do need to shorten that turn.*

Satya: *(taking over) Ok, so six?*

Kisha: *If it was twelve, yes, six, yeah.*

Satya: *That's half if it. Ok, let's go people.*

Had Satya and Kisha been participating here in an engineering design activity, as they were about to in Project 3, they might have experienced uncertainty from additional sources necessitating additional management strategies. In the act of designing, uncertainty arises not only from insufficient knowledge or lack of experience, but also from intractable ambiguity. Also, much uncertainty in design tasks is uncertainty about what one will do, not about what is the correct thing to do.

Finally, it is worth noting that in neither project did students express much uncertainty about the evaluation criteria or how they were being graded. Nor did they seem to experience much uncertainty about the parameters or constraints of the assignment, though there were two exceptions to this: (1) students voiced concern in both projects about whether their group could finish by the due date and also about how far along they were compared to other groups, and (2) there was some uncertainty expressed during Project 3 about whether their design ideas were staying within the constraints of the task.

Variation in and the Interaction of Propensities for Managing Uncertainty

Although uncertainty management was highly influenced by aspects of the tasks with which students were engaged, it was also dependent upon individuals' previous experience and their developed habits for managing uncertainty. Whatever their individual propensities for managing uncertainty, efforts to implement uncertainty management strategies in this collaborative academic context were almost always dependent on students' abilities to garner peer support. In this section, I briefly discuss ways that students varied in their patterns of uncertainty management. I then describe how the ways they managed uncertainty were influenced by the social interactions that occurred within their collaborative groups.

It is no great surprise that individuals differ in the ways they tend to manage uncertainty. To the collaborative robotics setting, students brought with them tendencies for managing uncertainty that had developed through experience, their habits and histories of participation in prior groups. The students in this class all used a range of strategies, but at the same time, they had individually identifiable patterns of uncertainty management. Some students had many ways to manage uncertainty; some students had only a few ways. Below, I discuss how students varied from one another in their willingness to take up uncertainty, the issues about which they experienced uncertainty, and in the sets of strategies at their disposal.

Variation in the Strategies Students Used to Manage Uncertainty

The purpose of this study was not to differentiate or categorize individual students based on strategies they used or even to identify patterns of use of uncertainty management strategies within individuals or within groups. However, in order to understand the importance of peer response, it is helpful to know something about how individuals varied from their classmates and within themselves across time. Table 4.1 lists the key strategies I identified for six students who were members of two focal groups I observed during Project 1; a group of three girls and a group of three boys. I elected to present the profiles of these students because they had clear discernable patterns of uncertainty management. Note that I only had data for Nathan during Project 1 because he moved away early in the year. However, his pattern of uncertainty management was so clear and so interesting that I include his profile here.

Table 4.1 Focal Students' Characteristic Uncertainty Management Strategies

Demetre	Nathan	Luis	Satya	Kisha	Kim
-analogy (far transfer) -delay decision - "I don't know" -make positive predictions (hope for a positive outcome) - express doubt	-take risks -make positive predictions	-avoid uncertainty -blame -trail off sentences -prepare for failure -say, "I know what to do"	-seek consensus - compare perspectives -create plausible explanation -think aloud -summarize -take tentative action -plan to be uncertain	-"Ms. C said"… - rely on robotic experience (near transfer) - "let's experiment" (little or no analysis)	-avoid uncertainty -turn task over to group members -rely on outside expertise -request scaffold for participation -observe other groups

Each set of uncertainty management strategies attributable to an individual student can be said to have a distinctive flavor. Taken together, Demetre's pattern of uncertainty management, with its mulling over experience, freely admitting uncertainty, and relying on hope, might be described as *delay action in order to think*. Nathan's set of characteristics, gung-ho and forward-oriented, might be considered a *learn by taking action* pattern. Luis was unique in this class in his dogged denial of uncertainty and avoidance of admitting uncertainty to his group members. His pattern could be called *What? Me uncertain?* As for the girls, as a whole, Satya's preferred strategies for managing uncertainty could be called *I need a plausible explanation to take action.* Perhaps because she attributed much of her uncertainty to being "*new to robotics*" and so was not threatened by her own uncertainty, Satya seldom hesitated to express uncertainty as she pursued multiple avenues for generating plausible explanations. Kisha's pattern could be *let's do something*. Always eager to experiment and see what happened, Kisha rarely let analysis stand in her way of the next test, either prior to or subsequent to action. Finally, Kim's characteristic way of managing uncertainty might be called *can somebody please help me?* Kim preferred to fly under the radar, requesting help with immediate uncertainty and rarely considering the long-range use of that help.

Also of interest is the set of strategies from which each student drew. Kim and Nathan both had a relatively small set of ways to respond to uncertainty, in terms of number of strategies in Nathan's case and in the diversity among strategies for both students. In comparison, Satya had a large and diverse set of strategies for managing uncertainty.

Variance in Willingness to Entertain or Take Up Uncertainty

Besides varying in the ways they attempted to manage uncertainty they were experiencing, students varied also in their willingness to take up uncertainty as they engaged in robotics engineering projects. To illustrate the actions of a student who often exhibited reluctance to take up uncertainty, I offer an episode in which the Water Washer Group had reconvened to grapple with the negative feedback they had received about their design during a whole-class debriefing. Ray seemed reluctant to take the feedback fully to heart, resisting change and the incumbent uncertainty that frequently attends change. Trying to minimize the effect of his teacher's and classmate's input, rather than use it as an opportunity to improve their design, Ray opened the discussion with, "*We could prove Ms. Billings wrong*," and he interrupted his group's conversation about design alternatives several times, calling for a vote to stick with the original design. Because Ray was not a student who typically rebelled against his teacher or who was socially insensitive to the flow of conversation, I interpreted these actions as stemming from reluctance to take up uncertainty associated with changing his group's project. Ray exhibited this reluctance to take up uncertainty time and again across the project.

In contrast is an episode that illustrates Satya's propensity to entertain uncertainty and even to welcome taking up uncertainty. Satya responded to an announcement by Kisha that she and Becky had taken apart the trailer that the group had been laboring on for days, intending instead to make a robo-claw to pick up garbage. Satya's immediate response was to request an explanation, "*Why?!*" and then to express horror "*No!*", and then to return again to requesting information, "*Why would you want to do that?*" before stating her belief about the situation, "*We were already good.*" Satya was visibly upset by her group member's decision to change the design. Yet, even in the midst being thrown off kilter by the change of direction, Satya rather quickly gave up her commitment to her past work, distracted by the new set of problems she now saw needing to be solved in what had become her new reality. In the process, she introduced Kisha to many uncertainties she had not considered.

Satya: *But is it going to be able to move, like, go like this and then go like this?*

Kisha: *I don't know.*

Satya: *But if it doesn't do that we just//*

Kisha: *//Oh, yeah, it has a motor. Yeah, it should, yeah, hu hu.*

Satya: *No, it needs two motors then, right?*

Kisha: What?

Satya: *It needs to be able to move; go like this and then move this way like this.*

Kisha: *It should be.*

Satya: *You're sure, 100% sure?*

Kisha: *I'm 90% sure.*

Satya: *Well then…**

Satya: *I'm going to cry. Wait, how many motors does it need?*

Satya's response could have been to be quite certain that the new idea would not work. Instead, she was willing and able to entertain uncertainty about the situation in which she found herself, and to consider her present options. Satya asked Kisha to quantify her certainty about the change, and Satya took Kisha's response into consideration as she continued to collect information and reflect on the situation. This type of response was evidenced by Satya again and again across the year. In some ways, the fact that Kisha and Becky forged ahead with their idea to take the trailer apart and construct a robo-claw presented Satya with an opportunity to grapple with a new reality, to enjoy the process of solving a new problem. Although Kisha and Becky had anticipated a negative response from Satya about their new design and had practiced their reaction to it, they never got a chance to give their spiel to Satya because she so quickly adjusted to the design detour.

Variation in Issues About Which Students Experienced Uncertainty

Students varied in the uncertainties to which they most frequently attended. For example, social uncertainty was nearly always prominent for some students while others tended to focus primarily on managing task uncertainty. The relevance or centrality of some issues to one's needs and goals likely leads an individual to pay attention to those issues over others, and uncertainty will be experienced about those issues. Of all his classmates, Ray was a student who perhaps experienced the most uncertainty about the social system. Ray's social uncertainty was likely prompted by his unusually high need for group harmony.

Ray frequently checked to make sure all his group members were "*on the same page*", and would frequently initiate group consensus building. He often experienced uncertainty about his social relationships within his group, as in the episode from which the transcript below is drawn. As Bobby and Derrick worked together to construct a set of paddles for their Water Washer Robot, Ray tried inserting himself into their work several times and was rebuffed. Uncertain about where he stood, Ray observed, made overtures, and tried to make eye contact to ascertain how his group members were feeling toward him. When these methods did not resolve his uncertainty, he tried a more direct approach, asking, "*Bobby, Bobby, Bobby, are you mad at me?"* Neither Derrick nor Bobby responded to Ray; instead, they continued to talk to one another.

Ray: *Bobby, are you mad at me?...Bobby, are you mad at me?*

Derrick: *(not looking at Ray) Why are you always thinking people are mad at you?*

Ray: *Well, he's not even talking to me.*

Derrick: *Maybe he's just trying to work. And you keep bugging him.*

Ray: *Yalls hobby is, like, to make friends and then pick on one person.*

Derrick: *Oh, that's a lie.*

Ray: *OK, well, if it's a lie, why wouldn't you be nice to me?*

So salient was Ray's need for group harmony that his uncertainty sequenced through different questions. Once he has information about where he stood, that indeed his group members were mad at him, his uncertainty shifted to why this was happening, making a charge that partnering up to "*pick on one person*" is a habit with Bobby and Derrick. Finally, Ray's uncertainty shifted to what he could do and to why his strategy to change it was not working. Ray's group members respond with irritation, resistance to helping him address his uncertainty, and perhaps even attempts to feed his insecurity as evidenced in their body language and lack of eye contact with him. Their response could have stemmed from their desire to concentrate on task uncertainties whereas Ray was interrupting with social uncertainty that was not salient to them.

In contrast to Ray's attention to social uncertainties is Isabel's propensity for ignoring them. This is illustrated in this transcript taken from an episode in which Isabel's attempts to reduce her uncertainty and increase her understanding of Derrick's plan for controlling the locomotion of their robot had worn thin Bobby and Derrick's patience.

Isabel: *So all we have to do is program this to turn? (2 second pause, no response) So Derrick, is it going to go like this, out of the water and into the water?*

Derrick: *Yeah.(continuing to work on the structure, does not look at Isabel)*

Ray: *Wait, the motors are making, look, the motors make that spin and the remote control makes that move.(gesturing to the structure)*

Bobby: *(overlapping, looking at Isabel) I think you're lost in confusion.*

Isabel: *(looking at the robotic structure) Kind of, actually. So the whole thing's going to come out of the water and the whole thing's going to go into the water?*

Isabel's first question received a clipped response from Derrick, and from Bobby, a putdown for her uncertainty, "I think you're lost in confusion." One can imagine that Ray might have reacted to such socially threatening responses by shifting his attention from managing task uncertainty to managing social uncertainty. However, Isabel's response was to acknowledge to Bobby that she may indeed have been "*lost in confusion*" and to continue to concentrate on getting her task uncertainty addressed. Rather than becoming concerned with or uncertain about Bobby's scathing comment, Isabel allowed that it might be true and again asked about the spinner coming out of and going into the water. Even after Ray's direct social acknowledgement that Isabel was in a socially precarious situation, the issue that remained salient to Isabel was her project activity uncertainty about how the paddles worked, and this was the uncertainty she persisted in trying to resolve.

Peers as Social Support of Students' Uncertainty Management

No matter the profile, enacting most of the uncertainty management strategies students used as they engaged in robotics engineering projects required a socially supportive response from one's peer collaborators. Different strategies required different types and different levels of participation from one's group members. For instance, Satya’s propensity to think aloud necessitated only that her group members be attentive listeners, whereas her frequent requests for confirmation required her group members to affirm her thinking, perhaps a more effortful response. Kim’s request for scaffolding of her participation in robotics activity entailed that a group member provide information to facilitate that participation. A strong finding from my data analysis was that when students were unable to garner social support from peers for managing uncertainty, their options for managing uncertainty narrowed significantly. Although each of the examples above involved a different level and type of peer response, in all of these cases it would it have been impossible for the uncertain student to enact the strategy alone.

In the next section, I first describe the nature of peer response to attempts to manage uncertainty and illustrate the importance of those responses for students’ ability to manage uncertainty in this collaborative academic task setting. I follow that with a discussion of how the nature of peer response influenced students’ subsequent attempts to manage uncertainty while engaging in collaborative robotics engineering projects.

The Nature of Peer Response to Uncertainty Management and Factors that Influenced It

Mustering peer support was not always easy. Students could respond in a variety of ways to their group members’ attempts to manage uncertainty. Some of their responses were socially supportive responses and some of them were not. I identified the following peer responses as socially supportive: (1) experience the same uncertainty and join in a collective strategy to address it (e.g., tool gathering, idea generating, scenario developing), (2) not share the uncertainty but inquire and be open, listen, become convinced of the uncertainty, and assist in addressing it, and (3) not share the uncertainty and not become convinced, but help one's group member with his or her uncertainty by arguing, challenging, explaining, or offering information. For this to happen, students had to believe the uncertainty was at least legitimate, warranted, or reasonable. I identified the following peer responses as not socially supportive: (1) dismiss the uncertainty as unreasonable and chastise, ridicule, or disparage the individual experiencing the uncertainty, or (2) ignore the uncertainty altogether.

Individual predilections for managing uncertainty varied among students in the class, students who were assigned to the same collaborative group for one or more robotics projects, and differences among individuals influenced the options students had for managing uncertainty. In each group, members varied in how similar they were in terms of tendencies for managing uncertainty. Whether students' tendencies were contrastive or mutually enhancing influenced students' ability to manage uncertainty they experienced while engaging in a collaborative robotics engineering project.

In addition to being influenced by the interaction of individual propensities, whether peers offered socially supportive responses necessary for their group members to enact uncertainty management strategies depended on several factors. Socially supportive responses to uncertainty management were more likely when one's peers either shared the uncertainty or at least considered it warranted, reasonable, or legitimate. When uncertainty about the same issue was shared by group members, each individual could lean on her or his collaborators for social support. In the example below, the members of this group went from alert, focused scurrying to test their latest program change, to slow dejected walking over to course of an unfruitful, non-progressive day of testing. After describing the nervous frustration she experienced with repeated failed iterations of tests and re-programming, Shamitra described a pattern that emerged in her group for supporting each other in managing uncertainty associated with repeatedly failed tests:

> *It just all builds up until we explode. You just quit. And then the other group member tries, and then they explode and they quit, and it just keeps turning around… There are many different ways of making it go straight and programming. So if what they used doesn't work, you try it again and... or you use a different way and sometimes that helps. [102408]*

The members of Satya's group worked in cycles, with one member taking over when another "exploded." This strategy can be seen as a way of continuing to take action while not knowing what to do next. Satya also exhibited her recognition that there are multiple design paths to a solution. That knowledge seemed to give her hope in the face of uncertainty, hope that enabled her and her group members to use a *continuous search of the solution space* strategy for managing uncertainty under conditions in which feedback is difficult to interpret due to lack of knowledge or understanding.

Another factor that influenced whether a peer responded in a socially supportive manner was prior experience with the individual expressing uncertainty. For instance, individuals could wear out the goodwill of their group members if they continuously requested help with the same type of uncertainty. The response of Ray's group members to his uncertainty expressed as, "*Are you mad at me*?" is one clear example. Social positioning could also influence the response that students received when expressing uncertainty, as could the need of the respondents to acquire social backing for their ideas. For instance, although Derrick usually ignored or disparaged the questions that Isabel posed to resolve her uncertainty about her group's design, he was quite forthcoming in one instance in which he wanted her vote of confidence about his plan to build a particular type of paddle for the Water Washer robot.

Finally, whether an individual was already focusing his or her attention on a different uncertainty also influenced his or her response to a peer. At the time any particular individual in a collaborative group was experiencing and attempting to manage uncertainty about a particular topic, his or her group members were also experiencing varying degrees of uncertainty on similar or different topics. Thus, interacting with one's group members while engaging in a robotics engineering task required that individuals negotiate with one another about to what uncertainties the group would attend as they worked together. At times, group members focused on and managed different uncertainties simultaneously, and this made it difficult for them to help one another manage uncertainty.

The issue of simultaneously managing multiple uncertainties is well illustrated by an episode taken from the Water Washer Group on the first day of Project 3 in which Isabel repeatedly attempted to get her group to address her uncertainty about how their project would float and was stymied in these attempts by the continual introduction of uncertainties about different topics. After coming to agreement that they wanted to create a robot that would heat and cool a pool and clean it by collecting trash in a net, the Water Washer Group began discussing how they would construct their robot. The following episode was preceded by Ray holding up his journal in which he has been sketching design ideas and describing a design for a hatch hooked to an octopus-shaped structure and containers for hot and cold water. Isabel interjected:

Isabel: (overlapping) *Ray… Ray…Ray, how are we going to get it to float? (points to Ray's journal)*

Derrick: *Dude, it's an octopus. (with a dismissive tone, looking at Isabel, left hand goes out, palm up in an "it's obvious" gesture)*

Ray: *And then in the end we'll decorate it// (looking at Isabel, points to his journal)*

Isabel: *I know. But how do you make it float?*

Bobby: *It* <u>*can*</u> *float.*

Derrick: *(looking at Isabel) It will float, it will just float.*

Bobby: *(overlapping, looking at Isabel) Yeah, it will just float, because it's so light.*

Isabel: *(smiling) It's not going to be a real octopus.*

Bobby: *(looking at Isabel) No, it's not.*

Derrick: *I know.*

Bobby: *It could have 4 legs*.

Ray: *And if not, we can like, buy a mini floaty and… (trails off)*

Isabel: *Oh yeah, we can put, get a floaty and stick it in there (makes a downward sticking motion with both hands)*

Derrick: *(overlapping, glances at Ray, then looks at Bobby as he speaks) Look, let me show you something. Look, look, look.*

Bobby: (overlapping) *We can, let's call it a squirty.*

Derrick: *(looking at Bobby) Look, we have eight legs.*

In this example, Isabel was the first person in the group to express uncertainty about how the robot would float. Isabel was largely unsuccessful at garnering support from her group members for helping her manage her uncertainty. The boys were not completely ignoring Isabel's uncertainty, but they did not share her uncertainty and were largely dismissive of it. After calling Ray's name three times, Isabel succeeded in getting her group members to focus on the problem of getting the robot to float, but she had their attention for only a few conversational turns. Bobby was distracted by the idea of the octopus, and he switched topics, suggesting that the robot could have four legs. Ray tried to continue to address Isabel's uncertainty in the next conversational turn, suggesting that the group use mini floaty. However, he and Isabel were drowned out when Derrick took up Bobby's idea, adding octopus legs to his sketch of their design.

Isabel faced an uphill battle in trying to get help managing her uncertainty about whether the intended structure would float because different uncertainties were simultaneously salient to different group members. Over the course of a lengthy conversation that continued following the excerpt above, each individual tried to attract the others' attention to the uncertainties salient to him or her, largely without success. While Isabel was concerned with floating (buoyancy), Bobby was unsure about how to design the net, and Ray continued to consider how they might make the water hot and cold. Group members talked about issues almost in parallel, overlapping and interrupting speech. Seldom did their concerns intersect; seldom did one person's uncertainty become another person's uncertainty. Having no mechanism for focusing everyone's attention on resolving uncertainty about a single issue, the group could not generate threads of discussion lengthy enough even to establish the intersubjectivity needed to garner socially supportive response. This state of affairs seemed also to block movement in task progress. Because competing uncertainties remained largely unaddressed by most of the group members, it eventually became difficult for the group to stay focused on designing their robot, and the discussion dissolved into off-task topics.

Adapting One's Uncertainty Management Based on Peer Response

The relationship between the strategies students used to manage uncertainty in this collaborative context and the ways that peers responded to that management was iterative and recursive. My analysis suggests that individuals did not appreciably change the individually characteristic patterns of strategies they used to manage uncertainty across time or across groups. However, they adapted the ways they enacted their preferred strategies depending on the social support they received from their group members. This adaptation of strategies is most easily seen in the ways that students reacted to socially unsupportive responses to uncertainty.

When individuals were not able to garner socially supportive response to their attempts to manage uncertainty, they had different reactions to that experience. Sometimes they stopped trying to manage the uncertainty or even withdrew their participation in the group for a time. At other times, they feigned new found understanding, badgered their peers, or modified their approach. Interactively, multiple failed attempts to receive help with uncertainty about the task could result in a student experiencing social uncertainty. For uncertainty specific to one's social position and relationships or about group process, students sometimes resorted to passive, indirect seeking of information and feedback from their peers after more active, direct strategies had failed to elicit socially supportive response for managing these types of social uncertainty. They passively sought feedback in the form of (1) non-verbal information by searching faces or attempting to make eye contact, and (2) verbal information by making overtures to a group member and gauging their response.

Sometimes students persisted with a strategy when faced with non-supportive response, in effect *badgering* their peer collaborators. An example of badgering was Ray's unrelenting efforts to seek information about his social standing in his group. When his group members repeatedly ignored this concern, or in fact, purposefully acted in ways that fed his uncertainty, Ray continued to badger his group members with the same unvarying question: "*Are you mad at me?*" What is more, Ray's badgering seemed to catalyze the animosity and disrespect of his group members. Even in the face of evidence that his strategy was creating the very situation he feared, Ray persisted. It is plausible that this badgering behavior stemmed from Ray's difficulty living with social uncertainty. When he sensed social uncertainty, he could not help but attend to it, in effect, *seizing and freezing* on a solution as described by Webster and Kruglanski (1994). Although Ray was hyper-regulating the state of harmony in the social relationships in his group, he seemed unable to regulate his overwhelming impulse to know with certainty that he was of one accord with his group members. It is hard to know whether to interpret his behavior as courageous social metacognition or as situated social incompetence. Perhaps his badgering was a self protective response to uncertainty about a negative, unpredictable outcome.

Another way that students responded to lack of supportive response was to adapt or modify their preferred strategies. Like Ray, Isabel at first badgered her group members with her uncertainty, "*How will it float?*" Unlike Ray in the example above, Isabel adapted her strategy in the face of negative feedback, rephrasing her original question in several ways: "W*hat's going to be the octopus?" "How is it going to float? That's my question." "Are we going to use a floaty?" "*So *how is it not going to sink? I just have that one question." "What will hold the octopus up?"* Isabel accepted negative feedback, persisting in the face of non-response, not ignoring it, but changing the way she expressed her uncertainty.

Peer response to efforts to manage uncertainty influenced not only an individual's ability to resolve the uncertainty being expressed in the moment, but also how students responded to subsequent uncertainty. When students continuously experienced similar responses to attempts to manage uncertainty over time within a particular group, this shaped their strategy use over time. This was equally true for experiencing repeated socially supportive response as it was for receiving unsupportive response. For instance, although Isabel was usually actively involved with each project, her persistence flagged at times when negotiation of uncertainty with her Project 3 group had too long proven fruitless and unproductive. At such times, Isabel busied herself with clean up work, in essence avoiding uncertainty by letting her group members make decisions without her input. This was notable because it markedly differed from her usual information-seeking style. It was also notable in that this type of participation was quite peripheral, and choosing to limit her participation in this way also limited Isabel's ability to learn from engaging more centrally in the project and in the discussion around the project.

Summary of Findings

I set out in this dissertation to address three questions. I re-iterate each one here and briefly summarize the findings related to each.

How do students manage psychological uncertainty as they engage in collaborative robotics engineering projects?

Uncertainty was a pervasive experience for the students collaborating in this instructional context. Students experienced uncertainty related to task issues and social issues as they collaborated to fulfill the requirements of their robotics engineering projects. They managed their uncertainty in a variety of ways, including a diverse set of tactics for reducing, ignoring, maintaining, and increasing uncertainty.

How do task characteristics influence students' responses to uncertainty as they engage in collaborative robotics engineering projects?

Students experienced uncertainty from more different types of sources in the project with the less structured tasks than in the project comprised of more structured tasks and they used more and different types of uncertainty management strategies in the less structured task setting. In particular, in the less structured project students used more types of reduction strategies and they also used strategies for maintaining and increasing uncertainty that they had not used in the more structured tasks.

How does interaction with peer collaborators influence students' responses to uncertainty as they engage in collaborative robotics engineering projects?

Finally, peer interaction was influential because students relied on supportive social response to enact most of their uncertainty management strategies. When students could not garner socially supportive response from their peers, their options for managing uncertainty were greatly reduced. Socially supportive response was more likely when one's peer collaborators shared the uncertainty being expressed or at least considered it warranted or salient. Response was likely to be unsupportive when peer collaborators were already focusing on a different source of uncertainty that was more salient to them, or when previous experience with the person expressing uncertainty had tried their patience.

CHAPTER 5

DISCUSSION

"Life is fundamentally risky, reflecting the pervasive out-of-equilibrium nature of the surrounding world. Risk is synonymous with uncertainty about the future, leading not only to potential losses and perils, but also to gains. The uncertainty results from the numerous dynamical factors entering our life, giving it space and color as well as its dangerous flavor."

-Sornette, 2006, XI

The purpose of this study was to investigate how students managed the uncertainty they experienced as they engaged in collaborative robotics engineering projects. I focused on identifying the range of strategies students used to manage uncertainty, the influence of task structure on the sources of students' uncertainty and on the ways students managed their uncertainty, and the influence of peer interaction on uncertainty management.

My interest in the management of uncertainty in academic tasks stemmed from my belief that students are likely to experience a lot of uncertainty during academic tasks because learning is fraught with uncertainty and that the way students manage that uncertainty affects their ability to engage successfully in academic tasks. In addition, students are likely to experience high levels of uncertainty in their lives because of fundamental unknowablilty and unpredictability in the world and that good skills at managing uncertainty are needed for people to live well (i.e., to be innovative and healthy). Therefore, educational institutions need to attend to providing students with opportunities to develop skills and practices for managing uncertainty.

Few researchers have addressed uncertainty in authentic academic contexts, and fewer still have directly observed what students do as they manage the uncertainty they experience while engaged in academic tasks, particularly in science, technology, engineering, and math (STEM) disciplines.

The robotics engineering instructional context in one fifth grade class allowed me to observe students at an interesting place in their developmental trajectories. Collaborative robotics engineering projects offer students complex multimodal literacy experiences in which scientific print literacies interact with hands-on production. Data collection involved methods of naturalistic observation, semi-structured interviews, and collection of artifacts. I observed right at the very beginning of the school year, when the tools, concepts, and practices of robotics engineering were largely new to these students, right up to the end of the school year when their practice was becoming more sophisticated. Analysis of data was inductive and interpretive and relied on techniques of grounded theory and ethnographic microanalysis of discourse.

In this chapter, I begin with a discussion of what my research has contributed to our understanding of how students manage uncertainty during academic tasks presented in three subsections. I interpret my findings using the three theoretical frameworks that guided this research. In the first subsection, I present a model of uncertainty management as revealed by my analysis, and I identify and explain four insights derived from this model and driven by the three systems frameworks. In the second subsection, I introduce a proposed model of how the environment might interact with issues of uncertainty management in a collaborative group. Finally, in the third subsection I offer an exploratory analysis of the relationship between managing uncertainty and accomplishing academic and social goals while engaged in collaborative academic tasks. Following that, I identify limitations of the study. Then I discuss the practical implications of my study and suggestions for educational practice. Finally, focusing on two main themes, I discuss the theoretical implications of my study: (1) the importance of studying uncertainty management in educational contexts, and (2) the importance of taking a systems view of uncertainty management in academic contexts.

Discussion of the Findings

This study identified ways that students experience and manage uncertainty during collaborative projects and how the structure of academic tasks and interactions with peers influence students' uncertainty management. Students in collaborative academic contexts experience psychological uncertainty from many sources and respond to these experiences using a diverse set of strategies. Because the students in this class were trying to learn about concepts related to robotics engineering as well as how to think and talk like engineers; because they were dealing with sophisticated, complicated practices that were new to them; because they were endeavoring to design their own robotics products; and because they were attempting to collaborate with peers, much uncertainty surrounded the academic process in which students were engaged.

As students navigated a complicated collaborative robotics engineering project, aspects of the project activities and aspects of the social system elicited psychological uncertainty. Students responded to their uncertainty using a range of tactics for reducing, ignoring, maintaining, and increasing uncertainty.

The issues about which students experienced uncertainty and the tactics they then used to manage their uncertainty were dependent on the structure of the academic tasks as framed by the teacher and as interpreted by the students. Students were influenced in their uncertainty management strategies by task characteristics. The project with the more structured tasks elicited primarily reduction strategies whereas the project with less structured tasks elicited a wider range of strategies, including attempts to reduce, ignore, maintain, and increase uncertainty. Because both tasks changed over time, this was a dynamic process.

Social and intellectual factors are mutually intertwined in learning tasks. At the same time that students were influenced by the task structure, their uncertainty management was dependent also on the willingness and ability of peer collaborators to respond supportively to attempts to manage uncertainty. Students had individually characteristic ways of managing uncertainty; however, implementation of their preferred strategies depended on their group members' responses to them. Whether socially supportive responses were forthcoming in any specific moment depended on whether uncertainty was shared, whether peer collaborators believed uncertainty was warranted or salient, and whether they were experiencing uncertainty about a different topic. Whether peers gave a socially supportive response also depended on their previous experience with their group members. The ways students' enacted their tactics for managing uncertainty evolved as a result of the feedback they received from peers.

A Model of Uncertainty Management in Collaborative Robotics Engineering Groups

Combining insights from each of the themes that were generated from this research, I derived a model of students' uncertainty management during robotics engineering projects.

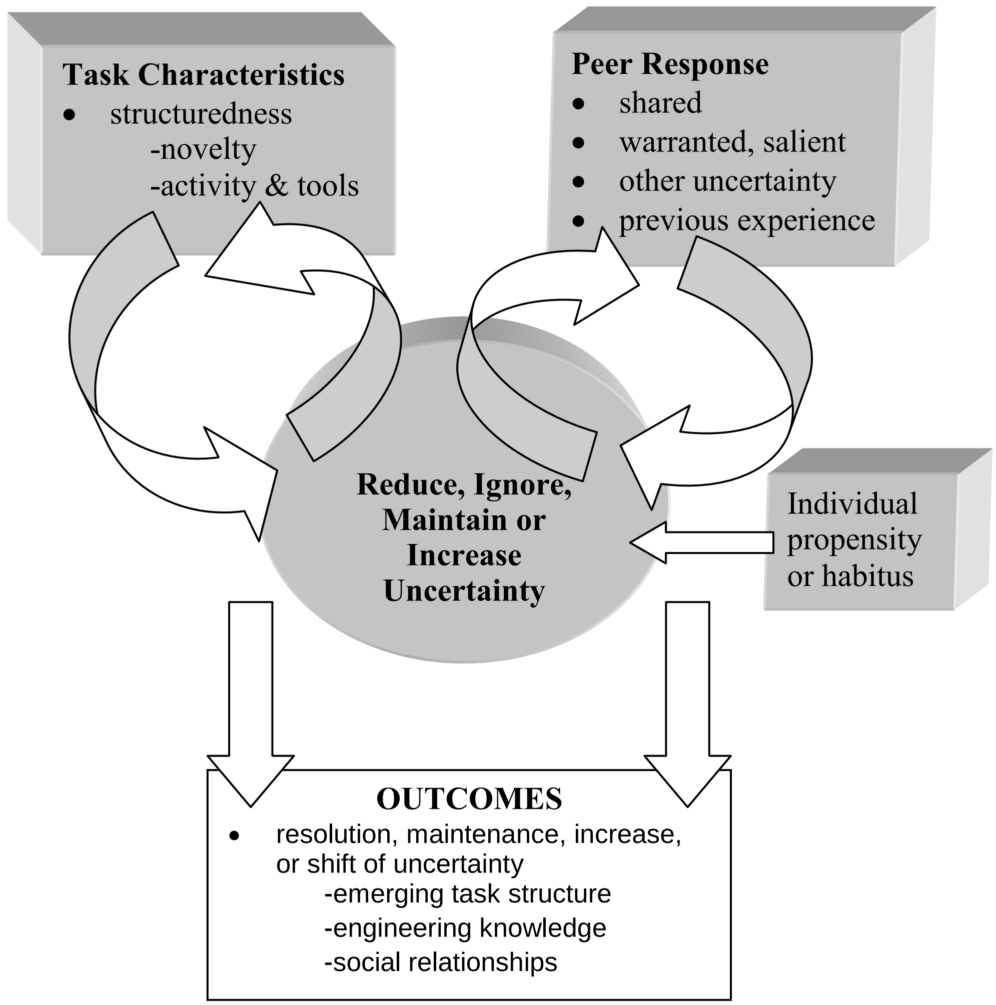

Figure 5.1 Uncertainty Management in Collaborative Academic Tasks

This is a model of an individual student operating in a small group as that group attempts to negotiate a collaborative academic task. This model depicts the moment-by-moment unfolding of uncertainty management that a student did during the execution of collaborative robotics engineering projects. Modeling the results of this research in this fashion reveals that uncertainty management is neither a simple process nor is it a solitary endeavor.

Moving away from the notion of students managing their own uncertainty on their own to how students manage uncertainty as part of collaborative group, I drew on three theoretical frameworks to help me interpret my findings; communities of practice theory, distributed cognition theory, and complex adaptive systems theory. Taking *the individual in collaborative context* as my unit of analysis, I conceptualized students as members of small collaborative groups assigned to design and produce robotics products. The three theoretical lenses I selected to frame this study all move us away from the notion of an isolated student managing uncertainty to students managing uncertainty as part of a system, a community of practice, a distributed cognitive system, or a complex adaptive system. Taken together, the three systems theories yield four insights described in the next sections.

Reciprocal interdependencies among group members. First, students' management of uncertainty in robotics engineering groups was dependent on interrelationships, ways in which a student (i.e., as a member of a community of practice, or as part of a distributed cognitive system, or as an agent in a complex adaptive system) was connected with his or her group members. Uncertainty management is dialogical, relational, and reciprocally influencing. Students' capacity to perform in these systems was not simply a matter of individual strengths or the quality of the sets of strategies individuals who comprised a group had developed, but also of the interaction among individuals and between individuals and the academic task. From a complex adaptive systems perspective, there is unpredictability in the reciprocal interdependency among agents. This unpredictability is a result of the nonlinear relationships among those agents. What will emerge from the patterns of uncertainty management that develop within a group is dependent on “opportunistic and chance juxtapositions” (Schallert & Martin, 2003). As members of a collaborative robotics engineering group interacted, they provided feedback to one another, feedback from which individual agents learned, adjusting their behaviors on an ongoing basis. As students received supportive or unsupportive response from their peers, that response acted as negative or positive feedback for subsequent attempts to manage uncertainty.

From a community of practice perspective, students gradually came to appropriate the shared practices of their group through varying levels of participation in the activities and discourses of that group, that community of practice. Learning in each group was situated in the specific context of that group (Brown & Duguid, 1991) and was oriented around the goal of building robots successfully. Although the initial physical surroundings were much the same for every group, the social relations were unique to each group. As students participated in and contributed to communal activity, the members of a group co-constructed knowledge of what it means to do robotics and of how to do robotics. Through joint interaction, group members also co-constructed practices for managing uncertainty. Because managing uncertainty was not the goal of these groups, norms for managing uncertainty can be considered a by-product of participation. Particular communities of practice develop norms for how one was “allowed” to manage uncertainty, what is appropriate, and what will be tolerated as response to attempts to manage uncertainty (Lingard et al., 2003). To understand the ways that an individual within a group manages uncertainty, his or her management and the development of that management has be considered in relation to the collective practices of the group within which that management develops (Cobb, 2002; Saxe, 2002; Radinsky, 2008).

The interaction of individuals and objects. Second, uncertainty management depended on the interaction between individuals and objects that together comprised a system. One of the ways this emerged is through the influence of the task structure on students' uncertainty management. Tasks shape how individual agents perform and contribute in a system (Barley, 1988; Orlinkowsky, 1996). In the project with the less structured tasks, a wider range of things were required of students than in the project with the more structured tasks. From a distributed cognition perspective, there was uncertainty about how to make a robot when no one individual makes the robot. In a distributed cognitive system, a robot is made by interactions between people and interactions between people and objects. Cognition was dispersed among individuals in a group and the materials and tools associated with robotics (Greeno, Collins, & Resnick, 1996; Lave, 1991). Uncertainty was dispersed in the system along with information and knowledge.

Diversity of agents. A third insight is that individual differences among students contributed to the "quality" of each group, the way a particular group functioned as a community of practice, distributed cognitive system, or complex adaptive system. Not only were individuals different from one another, but they brought an array of contributions to the system; skills, abilities, and sets of uncertainty management strategies all appropriated from past experience in past communities. Important were the kinds of communication and interaction skills and abilities students had developed from previous participation in the systems in which they had been a part. These sets of skills, abilities, and histories of participation influenced not only the individual's uncertainty management, but also the uncertainty management of group members and how the group could approach its robotics project. Because students in this class often worked in groups on projects across the school curriculum, their uncertainty management was likely influenced by their history of participating with their group members in other academic projects. Additionally, students' responses to their peers' attempts to manage uncertainty were likely influenced by their experiences not only in their current robotics group, but also by their experiences in past groups with the same or different members and in previous robotics projects or in groups associated with other academic disciplines in their class.

Dynamic evolution. Fourth, students enacted uncertainty management within an academic task setting that was constantly unfolding on multiple scales of time (Lemke, 2000a). Complex adaptive systems theory emphasizes the dynamics of how agents shape one another and how they mutually shape the systems they comprise. Robotics engineering tasks evolved over time, changing as students moved from task to task within a project and as they moved from project to project. In addition to its inherent evolutionary properties, in one of the projects, with its design task activities, students had a hand in changing the structure of the task and this act of structuring shaped their uncertainty and the ways they responded to that uncertainty. From a perspective of complex adaptive systems theory, the structure of the task and students' management of uncertainty in the task co-evolved as projects unfolded (McDaniel, 2007).

Not only the task, but also the ongoing social system evolved over time. As students worked with their group members they learned to trust or to distrust their group members' knowledge and goodwill. They learned how to get approval from their group members, how to obtain power in decision making, or how to get along without such power. Their uncertainty about the social system increased or decreased about these things over time, fluctuating to various degrees in different groups throughout a project.

Moving Beyond the Analysis

A systems analysis of uncertainty management must entail not only an examination of the relationships within a group, but also an examination of the environmental forces that likely shaped that system. Considering each group as a complex adaptive system leads us to understand that the group is embedded in the larger system of the classroom, which is embedded in still larger social systems of the school, the district, the community, and so on. When considering a complex adaptive system, each level above the level under consideration can be considered the environment of that level. Here, I limit myself to considering the impact only of the level above the group, the classroom collective. Going somewhat beyond the analysis I conducted in this study, I hypothesize that an individual’s uncertainty management was influenced by at least three environmental factors: the initial task structure, the teacher’s moves, and interactions with classmates working in other groups. These environmental factors are depicted in Figure 5.2.

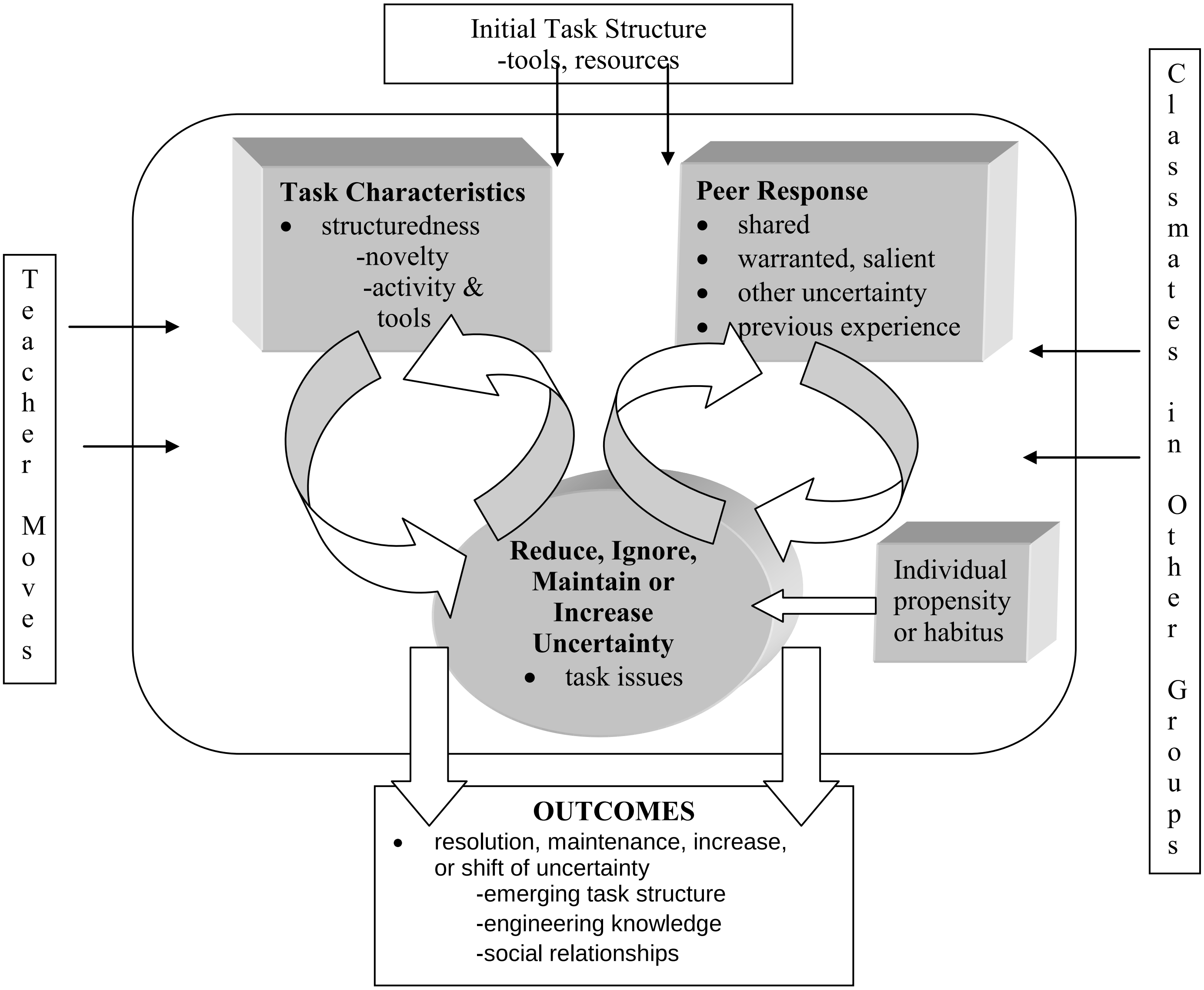

Figure 5.2 A Hypothesized Model of Uncertainty Management in Collaborative Projects

Even though tasks and children co-evolve as an academic project unfolds, the initial structure of a task will bound the direction and range of possible adaptations (Allen & Varga, 2006). Sources of uncertainty are more constrained in a more structured task than in a less structured task, and strategies for managing uncertainty are also more limited in range. To use a metaphor by Weick (2001), a more structured academic task is a task for which students have a map of the territory. It has been covered before. There are few unknown uncertainties. As students navigate more structured tasks, the teacher urges them to consult their map. If the map is a good one and if students have acquired adequate general map-reading skills and map reading skills specific to the type of map they are using, then their learning journey is likely to be successful. A less structured task, on the other hand, is a task for which no map exists. There is more uncertainty about the terrain; students have only a compass to guide their travels (e.g. each other, task framing, tools and materials). Students believe the task can be accomplished; otherwise the teacher would not have assigned it. They know the general direction they should head (e.g., the objective is to create a robotic product to solve an environmental problem), although their final product will evolve and they are uncertain about how to get there or how close they are to arriving.

Although up to this point, the role of the teacher in this instructional context has been treated as background, she was undoubtedly influential in how students' experienced and managed uncertainty as they worked in their robotics groups. Although she did not provide explicit instruction in how one should manage uncertainty in these types of tasks, she did send messages about how students should collaborate, what it means to collaborate, and how engineers and designers behave, think, and talk. These messages carried both subtle and obvious messages related to managing uncertainty. For example, Ms. Billings communicated repeatedly that all decisions had to be made as a group, and these instructions shaped the ways that students interacted as they experienced and managed uncertainty while engaged in the assigned projects.

As the members of each collaborative group interacted with one another to navigate their assigned project successfully, the other groups around them were also engaged in this same goal-directed behavior. As evidenced in the findings reported in Chapter four, students sometimes called on the expertise of classmates outside their groups as one of their strategies for managing uncertainty. In addition to this intentional strategy, interactions between members of different groups were instigated by unsolicited offers of help or advice, and this likely also influenced uncertainty management. In addition, students observed the work of different groups, intentionally and simply as a result of sharing the close quarters of a classroom, and this likely influenced the uncertainty they experienced and how they managed it. For example, in the example in Chapter 4 in which Kim requested scaffolding for participation from her group members, she revealed in an interview that she was motivated to do so when she looked around the room and saw other groups having fun.

An Exploratory Analysis of the Relationship between Managing Uncertainty and Accomplishing Goals in Academic Contexts

This study focused on identifying how students managed uncertainty in collaborative robotics engineering tasks. However, as an educational psychologist, I am always interested ultimately in how any phenomenon relates to learning and academic success. Therefore, I am interested also in how individuals' attempts to manage uncertainty shaped students' abilities to engage successfully in collaborative robotics engineering projects.

My analysis suggests that the students had two goals in this collaborative academic task setting: (1) to design, create, and exhibit a robot that met or exceeded assignment requirements and, (2) to maintain good relationships in the class. Uncertainty is something that is experienced during efforts to achieve these goals, and the way uncertainty is managed is highly influential in terms of achieving these goals in an academic setting. In this section, I explore the relationships between students' uncertainty management and their social and academic goals. This analysis is offered tentatively; its purpose is only to illustrate aspects of the relationship between managing uncertainty and meeting goals in an academic task setting.

Managing uncertainty and academic goals. For students I observed working on the collaborative robotics engineering projects, there was always tension between action and reflection, a tension that impacted learning and project success. The ways that students experienced and managed uncertainty played a large role in how this tension played out for individuals and for groups. An example of this tension follows.

An overarching theme in Demetre's uncertainty management was a desire to collect more information and pause to think before taking action (see Table 4.1). He had no reticence about expressing uncertainty, recognizing and acknowledging it openly. He did not hesitate to say, "*I'm not sure*," and these direct statements of uncertainty were usually preceded or followed by an explanation or idea. He frequently expressed doubt about the ideas of his group members. He often used analogies in his attempts to reduce uncertainty, likening the robotics problem in front of him to a problem with similar characteristics from another context. In response to my inquiry about his group's problems programming the obstacle course for Project 1, Demetre said:

> *We need to have a little more figuring, study more, get more knowledge if it's possible to do that. It's possible to measure distance on kilometers and all that. The only problem is this is a rotation of how far the robot will move. But it is possible to measure, like, the rotations of the earth. So I started thinking on my*

own, trying to think, "Is it possible for the wheel to be like the earth, to be spinning around in a rotation?" [100308]

Demetre's response to his uncertainty about how to program his group's robot was to collect more information before taking action. Demetre managed his uncertainty by recognizing and acknowledging it openly, trying to think of similar problems he had encountered before. Comprehending his problem of robotic motion as pertaining to rotating objects, he drew an analogy based on his previous knowledge, comparing the orbital rotations of earth to the rotations of the wheels on a robotic vehicle.

Contrasted with Demetre's need for reflection is Nathan's need for action. Nathan was a member of Demetre's group during Project 1. Nathan's tendency for managing uncertainty was to continuously take action, rarely consulting with his group about that action. Nathan operated from a model of risk taking in the face of uncertainty. That model is represented well in the following quote in which Nathan expressed uncertainty about how the program his group had written would translate into actions by their robot:

We did this new program that actually worked, but at first I was a little bit unsure that it would work. And it ended up coming through for us when it hit the wall... Well since I wasn't very sure, testing stuff, well, that program was kind of strange. It's stranger than what we had last time…But a scientist needs to take his risks... Well, sometimes when people do experiments and they're not sure, they take a risk and most of the time it comes through. ...I watch the science channel a lot and so there are shows when scientists take risks. So that's where I got the idea of taking risks even though I'm not sure. [100809]

Nathan managed uncertainty during robotics projects by mimicking one way he saw other scientists manage uncertainty, which was to take risks. He recognized the uncertainty of risk taking as an opportunity, feeling confident that risks frequently turn out well. He attributed his group's success not to knowing what to do and doing the right thing, but to their risk taking. His strategies emphasized action in the face of uncertainty; taking risks and benefiting from the risks, taking risks and learning from what happens.

These contrasting strategies for managing uncertainty caused friction throughout the time Demetre and Nathan worked together, with Nathan wanting to take action and Demetre pushing for reflection prior to action. There was little explanation or discussion to create sense together that might have helped them resolve uncertainty, learn, and progress with the project. It seems possible that Nathan's propensity to take action, juxtaposed against Demetre's need to delay decision, could have complemented one another and facilitated learning had either student been more skilled at collaboration. For example, recognition that a good theory might bring together thought and action might have benefited them, as it did in one instance for Satya's group.

Satya described in an interview how having a plausible explanation enabled her and her group members to take action, describing how her group experimented with a new practice of programming distance using portions of rotations. She acknowledged that the group was not sure about what would happen if they used a partial rotation. Prior to testing this programming change they had never tried before, the members of her group took turns "*saying what we thought would happen,*" and each had a different theory. In this way, they took advantage of the multiple perspectives in the group to expand the number of plausible explanations or the range of themes about why they should try a certain course of action and what experiments should be conducted: *"I just told my theory, then Kisha told her theory, and then Kim told her theory."* When she saw the experiment run, she used the results to test her and her group members' theories- not simply to reduce her uncertainty. Satya interpreted the results of their test as indicating that all the theories worked, minimizing the discrepancy between the result and her plausible explanation and also between the three theories: "*It actually, it kind of worked, my theory. The wheel did turn half, but it also worked with Kisha and Kim because the robot did turn, but the wheel turned half way*."

Important was not only the actions and behaviors students took as they navigated their projects and their uncertainties, but also the way they thought of those actions as related to their goals. In an informal interview, I asked Berta why she and her group members were testing a change to their robot as they tried to get it to negotiate a curve in the obstacle course. Berta explained: *"We're axious to see if we do this, will this help us in future things, like in other things that we might have to turn it or something. So even if we're not sure it's going to work, we want to see where it would lead us... so we'll know if we want to use it in the future*." Here, Berta was describing that she acted in the face of uncertainty not only to resolve uncertainty about the problem right in front of her, but also for what it could teach her for the future.

Satya was a poster child for managing uncertainty in a way that facilitated learning for her and for her group members. When I asked her if there was anything she had been uncertain or unsure about during her group's immediately prior robotic session, she replied:

> *I'm unsure about everything with robotics because it's new to me. Whenever we first took the pre-test on robotics, there were only a few questions that I understood. And all the building and programming I didn't understand very well. So that can tell me I'm very new to robotics and that it's different. And whenever we started doing it, our group was lagging behind. So that makes me understand that we need to work harder… and it kind of makes me feel nervous. Because we're wasting time and we have a very short time to make robotics work. And also, it would help if we got the turn done quicker and there's more complex maneuvers at the end.*

When Satya experienced uncertainty, she interpreted it to as likely to change and as impetus to work harder. She thought about the future of the project, predicting more difficulties, preparing for more uncertainty as the task unfolded. She had a goal of "*making robotics work*."

Managing uncertainty and social goals. When students responded to one another's attempts to manage uncertainty, they positioned one another in particular ways, and this could be threatening to students' goals related to maintaining successful relationships with their classmates. Thus, expressing uncertainty in order to manage it was socially risky in this collaborative context, both in terms of participating in decision making and project activities and also in how students were perceived by their group members. For instance, in two of Demetre's collaborative groups, expressing uncertainty led to him being trampled on by others who expressed greater certainty. Isabel's group members interpreted her frequent and persistent pursuit of a satisfactory resolution to her task uncertainty as "*bossy*" or "*not on task.*"

In particular, expressing uncertainty about social relationships put students in a vulnerable position. Ray's frequently expressed uncertainty about his social standing gave his peer collaborators power over him. In particular, Derrick seemed at times to gain social power by resisting Ray's request for information pertaining to how his group members felt about him or even by contributing to that uncertainty. The more social uncertainty Ray expressed, the less empathy and less respect Derrick had for him. Derrick himself rarely expressed uncertainty of any kind, and he frequently "took over" the group decision making and project activity. The students in this group were showing the beginnings of how one learns that expressing uncertainty is not always a good thing. When one expresses uncertainty, one gives power to others over one's feelings and that may cause pain. The way to gain social power may be to express great certainty, even in the face of repeated evidence that all is not certain.

In this setting, where students were working closely over a long period of time, trying to concentrate on a challenging academic task, Ray's social uncertainty produced a socially negative affect about him in his group members. Perhaps the socially negative effects of this social monitoring were produced in part by the fact that their expression kept interrupting the work of the group. Timing is important in this sort of meta-awareness of emotional issues. In a different context, perhaps in a different group, Ray's sensitivity to social cues and trying to address, redress, and repair relationships would be a socially positive attribute.

Even addressing project activity uncertainty was socially risky. Both Demetre and Isabel expressed uncertainty frequently and both received negative social attention for doing so. However, it was different for Satya, also a high expresser of uncertainty, because she had so much power because of her intellect and because of her bearing. The relationships among uncertainty, learning, and social relationships are complicated. Demetre's attempts to manage task uncertainty with his group members was sometimes socially costly. At the same time, his expressions of uncertainty sometimes caused a shift in the action by his group members, action that catalyzed a search for learning resources from his entire group.

Limitations of the Study

Although I acknowledged several limitations of my study in Chapter 3, in this section, I briefly discuss three additional limitations.

First, my data relied on my observations of uncertainty and uncertainty management as revealed in peer discourse and in interviews with students. However, neither of these sources are perfect indicators of uncertainty. Although language, paralinguistic markers, and physical gestures can symbolically represent uncertainty, they cannot index it perfectly. In interviews, I was at the mercy of what students could tell me about their experiences in their groups; however, fifth graders are variable in their metacognitive abilities (Keating, 2004). Achievement motivation theory suggests that some students may be more likely than others to hide their uncertainty and even to lie about it when one of their salient goals is to avoid being perceived as less knowledgeable (Dweck, 2000).

Second, my analysis focused on focal students and may not be representative of every member of the class. My confidence that it adequately represents at least many members of the class is raised because over the course of the year, I observed over half the members of the class for at least one project, and interviewed every student in the class at least two times. However, there may be systematic bias in my study in that I selected as my focal students, members of the class who were forthcoming in early interviews. A few students were reluctant or unable to articulate their thoughts and feelings in early interviews. I ultimately did not select these students as focal students. It is possible that these students, perhaps less metacognitively aware than my focal students, managed uncertainty in ways different than those I identified in this study.

Third, the analysis I conducted for this study was limited to interactions among members of collaborative robotics engineering groups. The teacher in this study unquestionably influenced how students managed uncertainty during the collaborative tasks in the ways she set up the environment; messages she conveyed about collaboration, about learning, about design engineering activity. To more fully understand students' responses to uncertainty in this context, I would need to systematically examine her influence. Furthermore, the relationship system that developed over time within the class as a whole was undoubtedly influential, as was the larger familial and cultural milieu in which each student were also embedded.

The students in this study participated in only one design project. It is an interesting question as to whether they would have managed uncertainty differently if given a second opportunity to attempt to design their own robotics products.

I wish to reiterate that my goal in this study was simply to identify the range of uncertainties and uncertainty management strategies used by these students. Although in attempting to understand my research questions, I did categorize students' preferred strategies, I did not attempt in this study to categorize individual students based on strategies they used. Additionally, I concentrated here on individuals' uncertainty management; but students also managed uncertainty as a group and they helped to manage the uncertainty of their fellow group members. The relationships among these three uncertainty management activities should be explored in future analysis. Related to this issue is the fact that I only dealt with within-group uncertainty management. Students were influenced by classmates outside of their group as they directly asked for help from non-group peers, indirectly sought help by observing classmates or recalling their past words and actions, and as help was offered by classmates without prompting.

The observations made in this study took place in the context of robotics engineering instruction in one fifth grade class as students engaged in collaborative robotics projects. The generalizability of these findings to other academic settings is in question for several reasons. First, engineering is a task entailing certain types of uncertainty and in robotics engineering, uncertainty will eventually be reduced. That is a purpose of engineering. That is not necessarily true in art or literature, for example, where the very end objective may be to introduce or reinforce uncertainty, to leave the task with a sense of wonder, doubt, or amazement. Second, this was a new curricular area. Students have much more prior experience with most curricular areas by the time they reach fifth grade. The novelty of this curricular area is not likely to be encountered in other academic areas.

Implications for Educational Practice

Previous research has established that the ways that students and teachers perceive and frame tasks is influential in how students come to manage uncertainty in these tasks. Teachers across disciplines overwhelmingly assign tasks low in both ambiguity and risk (Doyle, 1983, 1988). In the language they use in the classroom, teachers also tend to offer a stable world free from uncertainty (Feldman & Wertsch, 1976), as is often depicted in the textbooks students are assigned to read (Langer, 1997). Teachers' propensity to reduce uncertainty in academic tasks may impede students' attempts to make sense of school environments and of the open and confusing contexts in which they live.

Children are willing to take social and task risks and teachers can capitalize on this. Uncertainty was a pervasive experience for students collaborating to produce robots, and students were largely not averse to the risks entailed by uncertainty. That students were largely not risk averse in this collaborative setting is explainable in part by the fact that they were not working in isolation but were participating in a community of practice, a distributed system, a complex adaptive system. Children have lots of strategies for managing uncertainty, but there is a lot of difference between students and the ways they have for managing uncertainty tend to be fairly unorganized. Therefore, teachers need to help students develop more and richer strategies for managing uncertainty and help them learn to reason about how to use those strategies.

Teachers should perhaps be more explicit in their instruction regarding uncertainty management, helping students recognize that different strategies might be helpful in different situations, depending on the nature of a task, the source of a particular uncertainty (e.g., is this an uncertainty that can be reduced?), and features of the social context (e.g., can I get help with my uncertainty in this group?). Individuals in most contexts rely extensively on tactics for reducing uncertainty, and this is helpful at many times and in many ways. However, it is also dangerous because it is our fallback position; we overuse it, and our heuristics and biases lead us to over-rely on it (Khaneman, Slovic,

& Tversky, 1982). Ignoring uncertainty may enable us at times to take action and avoid becoming paralyzed by uncertainty (Anderson, 2003) or to save social face and protect social power. Maintaining uncertainty may enable us to think longer, and in this there may be more potential for accommodating rather than assimilating new knowledge. Finally, increasing uncertainty helps us see differently. It can increase the likelihood of gaining from multiple perspectives and is instrumental for creativity, scientific progress, and designing.

We know that the nature of an academic task makes a difference in what students can learn. But it turns out that helping students learn to manage uncertainty may require that we give them open tasks to work on and that we develop ways to help them learn from those tasks without our structuring those tasks for them. Less structured tasks presented students with opportunities to structure their own problems and make meaning of them. Open structure presented opportunities to struggle and struggle may facilitate learning (Rohmkemper & Corno, 1988), particularly opportunities to struggle in a collaborative context (Kapur, 2008). If a teacher wrings many of the sources of uncertainty from an academic task before she or he gives it to the students, then s/he has wrung much of the learning potential out. Rather than structuring tasks to elicit as little student uncertainty as possible, teachers need to help students learn new ways to respond to their own uncertainty and their peers' uncertainty in open tasks. Teachers may believe that increasing task structure helps students be more successful and experience less anxiety and that it reduces unproductive time. Assigning less structured, open tasks likely to elicit more student uncertainty from multiple sources may induce uncertainty in the teacher as well, and this may create anxiety in themselves that teachers wish to avoid. At the same time, teachers likely value the potential for learning, engagement, and self direction that such tasks encourage. Increasing the frequency and effectiveness of less structured, more open tasks may require that teachers learn how to manage their own uncertainty better and to consider how the ways they currently conceive of students' uncertainty may be problematic (Kapur, 2008).

Socially supportive response is influential. What an individual can accomplish in a collaborative setting is not entirely up to that individual. Managing uncertainty is a social task. Just like learning, it requires the development of relationship systems that enable individuals to implement the strategies they have and to leverage the strategies other people have. Students in this study relied on their peer collaborators to implement many of their strategies for managing uncertainty. This speaks to the importance of social cognition, meta-collaborative awareness, social regulation, and co-regulation of learning as important aspects of learning to which teachers need to attend (e.g., Hadwin & Oshige, 2006; Jackson, Mackenzie, & Hobfoll, 2000). Uncertainty management is part of learning environments, part of the discourse that goes on in collaborative academic tasks. Therefore, we need to help students learn to communicate with each other about uncertainty and under conditions of uncertainty, to help them use the people around them to manage that uncertainty, and to help them respond effectively to the uncertainty of their peer collaborators in ways that may positively impact learning.

It may be convenient to think of educational systems as closed systems and to teach mainly through more structured or closed tasks. However, almost all the systems students will face in school and in the rest of their lives are open systems and the problems they will face are less structured and open ended. Teachers should consider including more design tasks in their instruction because design tasks provide opportunities for students to develop their capacities to manage and express uncertainty in collaborative settings. As we try to move forward toward ways of dealing with uncertainty in our environment, more and more of what we have to do are design functions. If we want children to be flexible, adaptive individuals who are responsive to the world as it unfolds, we need to teach in ways that help them learn to manage the psychological experience of uncertainty. In a dynamic world, especially in societies that are knowledge-intensive and innovation-driven, schools need to prepare students to "learn new things, collaborate in the solution of novel problems, and produce innovations in areas that presently may not even exist" (Berieter & Scardamalia, 2003, p. 56). Design tasks present opportunities for students not only to grapple with uncertainty about what they believe and what they ought to believe, but also to grapple with uncertainty about how an idea or product can be improved, about its developmental potential, its usefulness (Berieter & Scardamalia, 2003). Design tasks also present opportunities for students to think of collaboration not just as an act of adding or pooling our strengths together or of partitioning tasks into pieces to be collected at the end of a project, but also as an act of truly distributed cognition in which ideas and products emerge from the reciprocal interdependencies among group members. It is in these types of distributed cognitive systems that uncertainty seems the most prevalent and the most fruitful for generating innovation and creativity.

Theoretical Implications and Future Research

Previous systematic observations of students engaged in collaborative projects associated with the STEM disciplines have conceptualized the practice of students engaged in such tasks as a process of learning to engage productively in argumentation (Andriessen, 2006; Radinsky, 2008), reasoning (Cobb, 2002), problem solving, inquiry (Pertrosino, 1997), or a lever for cognitive change (Chan, Burtis, & Berieter, 1999). These conceptions are useful for helping us think about individuals' change in conceptions of the world and how individuals in groups influence one another's thinking about disciplinary content. However, studying a collaborative academic project in terms of what it affords for learning to manage uncertainty changes our perspective on what is happening in that project as well as what is occurring in other collaborative academic tasks. Attending to uncertainty management focuses attention directly on what the experience of learning about science-related curriculum is like for students and on how they respond to that experience. Conceptualizing project-based tasks as a process of negotiating uncertainties and understanding better the uncertainties students face in academic tasks of all kinds as well as the ways they manage uncertainty in learning tasks could help us shape tasks and social contexts in academic settings in ways that will enable us to help them do it better.

My study has implications for educational theory in that there were two surprises that contradicted previous literature. First, uncertainty was the norm as students engaged in collaborative robotics engineering projects. Although past research has found that students try to limit uncertainty in academic tasks (Doyle, 1988) or fail to become uncertain altogether when uncertainty is warranted (Sieber, 1969), I found little evidence that this was true for these students in these tasks. When students successfully reduced uncertainty about one thing, their attention shifted to a new uncertainty. The second surprise was that students expressed little uncertainty about task parameters or evaluation criteria. This too contradicts previous findings by Doyle and Carter (1984) that students avoid the risk and ambiguity of evaluation. The discrepancy may be because the students in my study were younger than the students in Doyle's study. Or it might have been due to the way the teacher in this study framed the task. Had a different teacher assigned the same task, students may have experienced more uncertainty related to the teacher's expectation of the assignment. It could also indicate that these issues are less salient to students when tasks are challenging, engaging and have real-world connections.

My findings suggest that uncertainty management is an important aspect of learning in educational contexts. As of yet, theories that explicate the relationship between learning and uncertainty are underdeveloped. Educational philosophers the likes of Dewey and Bruner have long asserted that uncertainty is endemic to learning. However, there has to date been little integration of empirical and theoretical work on uncertainty and uncertainty management in academic contexts. I assert that educational researchers should attend more directly to the experience of uncertainty in academic contexts and to the ways that students manage the psychological experience of uncertainty and that investigating the place of uncertainty in learning may lead us to question many of our implicit assumptions about learning.

We often conceptualize learning as an act of moving as quickly as possible from a state of not knowing to a state of knowing, but we may spend most of our time and make most of our decisions in life from places of uncertainty. We often assume that students are motivated to reduce uncertainty, but my analysis suggests this may be a faulty assumption. Furthermore, our acting on such an assumption may lead students to take up this motivation, as motivational structures in classrooms are powerful forces. We often assume that educational goals should be to reduce uncertainty, but this may not always be a good goal. Educational researchers need to explore the possibility that *the conservation of uncertainty*, a different way to approach learning than the usual equilibrium (or near equilibrium) approaches, could be beneficial. We tend to think of competence and expertise as going hand in hand with certainty. However, expertise can be seen as a process of *progressive problem solving* and *reinvestment* (Berieter & Scardamalia, 1993a) that require the cultivation of uncertainty in addition to the reduction of uncertainty. In an unknowable, unpredictable, dynamic world, knowing should be thought of as a springboard for learning; and learning is an act rife with uncertainty. A worthy educational goal could be to pursue uncertainty because through this pursuit, learning can occur.

In order to help students learn to manage uncertainty adaptively and effectively, we need to understand the variety of ways that they currently manage uncertainty. Current understandings of how students manage uncertainty in learning situations are limited, particularly for less structured tasks. There is need for more documentation of how uncertainty management is influenced by the immediate social context and how it plays out over time. Further work is warranted in understanding how students increase their capacity to successfully manage uncertainty during academic tasks. Better appreciation of students' responses to and management of uncertainty in different types of academic tasks could help increase the use of academic tasks that elicit high levels and multiple forms of uncertainty. Future research needs to explore the relationships among the cognitive, affective, and behavioral responses to uncertainty by concentrating on uncertainty management, as researchers have found these to be mutually influencing in non-academic settings.

The three systems theories used in this study call our attention in various ways to the interaction of context and individual propensity. Not only does the influence of contextual variables need to be considered, but also the interaction of project activity uncertainty and social system uncertainty needs to be attended to in future research because social and intellectual issues are intertwined in academic contexts. Educational researchers need to attend to the self organization that occurs in different contexts and how self organization influences the ways individuals enact the orientations, attributions, and affect that they bring with them from their interactions in past groups. We need to understand how students perceive of each other as uncertain and how those perceptions shape interactions around academic tasks.

Managing uncertainty in collaborative settings entails more than managing one's own uncertainty; it involves also addressing the uncertainty experienced by one's group members and by the group as a collective. I observed instances of students' responding to group member's uncertainty by ignoring, explicitly offering help, dismissing, encouraging, explaining/showing, entertaining ideas, participating in idea sharing. I also noticed that an important function students can play for one another is to purposefully *introduce uncertainty* in order to try to cause others to become uncertain when you think they are not uncertain but they should be. Future research should examine the influence of individual students on uncertainty management in a group.

Clearly in the 21st century, uncertainty management is a topic which needs to be carefully considered. Educators and educational researchers have a responsibility for helping students learn to manage uncertainty effectively. This study helps us see ways in which students presently manage uncertainly and suggests ideas for teachers and researchers as we continue to pursue this issue. It is hoped that eventually, this line of research will lead to insights that may add to our understanding of how to help students learn multiple strategies for managing uncertainty, successfully match strategies and situations, and flexibly implement chosen strategies over a large range of academic tasks and life circumstances.

Appendix A
Reflection Questions Assigned by the Teacher

Project 1 Reflection Questions
100808
1. Explain how your group worked together to build the vehicle. What were some challenges you experienced?
2. Explain how your group is working together on the programming. What exactly do you need to do to accomplish at the next work session? How can you be successful?

121508
1. Explain how your robot performed on the course. What went wrong? What went right
2.Explain in detail what you would have done different to make your robot complete the course more effectively.
3. Explain what you would learned about robotics yourself and working with your team.

Project 3 Reflection Questions
050709
1. How has your thinking about your design changed and why?
2. What is frustrating you and how are you dealing with it?

051209
1. Explain how your robot is changing and why.
2. How does your original drawing compare to your robot?
3. What do you need to do at your next session?

051509
1. What did you accomplish today>
2. Explain how your project is changing.
3. What are you still frustrated by or concerned about?

052709
1. What are you working on right now?
2. What do you still need to do?
3. What are you worried or concerned about?

052909
1. How did your robot perform? If you could have changed anything, what would you do differently?
2. What did you learn about yourself from working in a group?

Appendix B
Student Interview Protocol

The following statements and questions are examples of the kinds of questions and prompts that were used in semi-structured interviews.

Group Process and Decision Making

- *Tell me about what was happening here.*
- What were you trying to do here?
- That was an interesting decision.
- Why do you think your group was having so much difficulty making this decision?
- Why do you think that decision was so easy for your group?
- What was the hardest part/your biggest problem/challenge today?
- How many ideas did you try?
- How often does it happen that you __________?
- Was there ever a time when your group didn't know what to do next?
- What do you think is the reason you didn't know what to do next?
- How did you decide what to do when __________?
- What happens in a group when you don't know what to do next?
- What problems is your group still having?

What interviewee said or didn't say

- What did you mean by what you said there?
- Why did you say it like that?
- Could you have said it like this, "______________"? Why/why not?
- Can you remember a time you thought something but didn't say it? [to your group members]
- You didn't say anything to your group members about that – why not?
- Did you think about saying something to them about your idea/what you were thinking/feeling?

Interviewees thoughts about group members

- Was there ever a time you wondered what another group member was thinking?
- Was there ever a time when you thought one of your group members was unsure about something?
- Can you remember any times you were really unsure about what to say to another group member/ unsure what other group members were doing/thinking?
- Was there ever a time you were unsure what other group members would think about your idea/something you said?
-

Interviewees thoughts about the project, product, and the process

- How is creating your own robot different than following directions to make a robot?
- What made you think of that idea?
- What made you decide to do that? What else might you have done?
- How confident or sure were you that the idea would work? Would you say you were really confident, kind of confident, or not confident?
- Why were you so confident?
- Was there anything you were uncertain about?
- Oh, here's where you start to ____________________. What were you thinking when you first started ____________________?
- Were you ever afraid it was not going to work?
- Was there anything you were worried/nervous about?
- Were you curious about...?
- Did you think about other ways to do that?
- How do you decide what to do when________?
- How often do you get frustrated when you first start?
- Why do you think that happened?
- Can you remember any times you were really uncertain about what to do?
- Did you never think to yourself...?
- What was going on here?
- How did it happen that you ______________?
- Could you think of any other ways to fix it?
- I noticed you had problems_________________. Can you tell me about what you were thinking and feeling then?
- How sure were you that you didn't need to ______________?
- What was the hardest decision to make?
- How did you feel about that decision?
- Did you think that was the best way to do it?
- Do you think it would be different creating a robot by yourself instead of working in a group? How would it be different?
- Can you tell me more about that?
- Is there anything else you want to say about that?
- What do you mean when you say "_________________"?

Appendix C
Questions for Final Student Interviews

1. How much do you feel like your last project changed from time you first had the idea? Follow up questions: Why do you think it changed so much? What do you think about that? What other ways could it have looked? Where did you get your ideas for the changes?

2. Can you remember any time during this project when you felt really unsure about something?
   Follow up questions: Can you tell me more about that? What did you think about that? How did you feel? What did you do?

3. How was this last project different than the other two robotics projects you did this year?

4. Of the three projects you did this year, which was your favorite? Least favorite? Why?

   How much experience did you have building things with LEGOS before you started doing robotics in this class?

5. Ms. Billings is going to be teaching robotics again next year. Is there anything you want Ms. Billings to know about doing robotics in a group that you think she might not know?

6. Would you mind looking at your program and explaining it to me?

Appendix D
Teacher Interview Protocol

1. Please describe your use of robotics. What would you like me to understand about robotics instruction in your classroom?

2. How long have you been teaching robotics? How long have you been including collaborative design tasks in your instruction? How has your instruction around collaborative design tasks changed over time?

3. What are your objectives for collaborative design assignments? What do you think your students are learning from participating in collaborative design tasks?

4. What problems do your students experience during collaborative design activity? How do you support and scaffold their participation in this kind of work?

5. Is there anything else you would like me to know about this activity that I have not thought to ask you?

Other questions will be asked to follow-up on the teacher's responses.

Appendix E
Uncertainty Markers

Type of Uncertainty Marker	**Description**	**Examples**
Paralinguistic Markers		
rising prosody/intonation (Barr, 2003)		
Errors		
Disfluencies		
Hesitations, 5 types (Maclay & Osgood,1959)	unfilled pauses	silent pauses
	sounds of hesitation	"um", "er"
	filled pauses	"well"
	Repeats	
	false starts	
Hedges*		
Frequency	adverbs that refer to the probability of occurrence	often, seldom, never
Psychological	parenthetical adverbs that convey psychological uncertainty	expect, doubt
Ambiguous	modal verbs and auxiliaries that convey referentially ambiguous uncertainty	might, perhaps
Other Markers		
Questions: basic vs. wonderment (Berieter & Scardamalia, 1991)		"What do we do here?"
Approximators (Meaney, 2006)		"It's pretty long"
Statements of inability (Meaney, 2006)		"I don't know what to do"
Qualifiers (McFayden, 1996)		
Rephrasings (McFayden, 1996		
Self-reports of mental states that reflect metacognitive awareness (Anderson et al., 2001).		"I'm not sure" "I'm confused"

Appendix F
Uncertainty Management Strategies and Tactics

Frequencies should be read as representing occurrence *in the data* rather than in the students' project sessions for two reasons. First, some categories are much easier to observe than others. For example, many instances of ignoring or avoiding uncertainty may have been unobservable with my data collection methods. Second, evidence was collected from transcripts of collaborative design sessions, field notes, and interviews and so single instances of the phenomena may be represented more than one time.

Uncertainty Management Codes	Definition and Description	Freq. Project 1	Freq. Project 3	Social and Task Examples from Transcripts
Tactics for Reducing Uncertainty				
Analyze the issues	-break down components into smaller pieces -examine steps or sequences -identify cause and effect linkages This is done prior to taking action; thinking through the issues	*14*	*24*	*Satya: [We were wondering] Is the sound going to work? And we were like, that might not work because we're already going to have to use all the motors for the car, so we won't' be able to put another NXT or another motor, especially in that spot for the sound.*
Systematic testing or experimentation	Take action based on analysis and check the results – analyze the results. As opposed to analyze the issues, this is doing, not thinking, but is often accompanies by analysis. Includes backtracking and re-checking	*23*	*22*	*Berta: Is anything around here metal? Let's see if it can pick up a water bottle. [activates the robot and picks up a water bottle]* *Berta: Ok, it can pick up the water bottle.* *Shamitra: No, without water, remember?* *Berta: Yeah, it's not going to have water in it so it's not going to be so heavy. I need something metal.*
Trial and error experimentation	Could also be called, "try something to see what happens"	*7*	*7*	*Shamitra: Want to give it a shot?* *Berta: Maybe. It goes this way and then, perhaps you put it there..*
Scenario plan	I wonders here but not I wonder why – those are cause-effect wonderings and are different; not wonder about what, but about what could be	*2*	*20*	*Isabel: I was thinking, what is the worst thing they can say, like, I'd think they would say, so like how is it going to do this, and, why is it going to do that, and keep asking more and more questions, things like that.*

Refer to past experience to identify a correct course of action, support a decision, or reduce options	-create analogies -suggest strategies that have worked before	*10*	*26*	*Shamitra: You take that one and I'll take this one. You know how they groove and move and jog? It's hard, once you notice it, You have to…(inaudible) .. So, we want it to be perfectly straight once we do everything. It's like algebra. If it's here, it's there. [speaking to Sam about problems they are having stabilizing the legs of their robot and making them symmetrical.]*
Request information or explanation from members	- understanding of you, the task, their ideas, reflect back – did you say... (none in A)how do you do this?	*20*	*95*	*Isabel: I still don't understand; how are we going to get it to float?*
Ask for confirmation		*8*	*47*	*Shamitra: Okay, so this would be, so we really need to stabilize it. It still moves, which we don't want, right?*
Explain clearly/show	Used only to manage social uncertainty, trying to increase one's chance of being understood by one's group members	*0*	*19*	*Berta: I tried to make sure I was very detailed and I drew pictures of it. [because she wasn't sure if group members would understand her idea]*
Directly ask for help from group members		*3*	*2*	*Sam: Ok, I might need some help with this one.*
Seek out an expert-outsider (e.g., teacher, classmate)	This is usually the teacher or members of other groups who are perceived as more expert	*39*	*9*	*Luis just asked Lydia [member of another group] to come over and show him how they programmed the light.*
Seek information from textual resources	Examples include Internet, Mindstorms help section, building manual	*5*	*29*	*Luis: You should look up claw machines. [on the NXT website to help you decide how to structure your robot]*
Refer to authority source or figure	Usually refers to teacher or group leader (project manager). This code applies when authority is sought, not information	*7*	*14*	*Shamitra: Ms. Davis says it has to be realistic.* *Derrick: Ms. Davis isn't going to like it.*
Observe others [group members, other groups]	There may be more evidence of this obtainable in video recordings that were not used for this analysis	*4*	*6*	*Sam is cutting his eyes over to where Shamitra is building the same [robot] leg. [field notes from a group building session after Sam had struggled for a while with building the leg]*

Seek agreement	-combine ideas -compromise -obtain consensus -vote	*2*	*61*	*Ray: Does that sound good to you? Derrick: Yeah Isabel: Bobby, that sound okay to you? [Bobby nods] So we all agree? This is what we're doing?*
Think aloud	Talk one's self through an activity in the presence of group members and gain support from their presence	*2*	*13*	
Tactics for Ignoring Uncertainty				
Avoid	-hide the truth -hedge -drop consideration of an idea -minimize problems	6	11	*Berta: That's going to be complicated. [responding to Shamitra's description of an idea] Shamitra: Well, never mind. Luis didn't' tell Derrick that he liked Xavier's idea better because he wasn't sure if it would hurt Derrick's feelings.*
Pass task off to a group member	Turning the task over to a group member may indicate many things, one of which is uncertainty	6	5	*Shamitra: Can you do it? [after struggling for several minutes to interpret on-line building directions]*
Dismiss or fail to consider an uncertainty	This is a response to uncertainty expressed by others, but can be seen as a way of ignoring one's own potential uncertainty. It is easier to observe students dismissing others uncertainty.	3	19	
Blame/justify uncertainty on an external source		3	7	*Derrick interrupted and dismissed Isabel's expression of doubt about the design of their robot's paddles Isabel: Yeah, but isn't that going to make it// Derrick: It's going to work! Bobby with controller*
Keep going, persist, bluff		1	2	*H: I was just kind of, like, kept presenting and I was acting like I really wasn't stressed out.*

Tactics for Maintaining Uncertainty				
Acknowledge	-use hedges (e.g., maybe, might, probably) -directly state (I'm not sure…) -identify a problem	14	*26*	*Isabel: I figured it out, I think, I hope.* *Xavier: We got to try to find something to let this out…* *Shamitra: It's not working out so good, Julio; it's just not happening.*
Share ideas to socially construct actions, decisions, or solutions (sensemaking)	discourse moves made to generate ideas, alternatives, perspectives within a group	*7*	*54*	*Shamitra: See, I think...Then you skip one, I think.. then it - would still be .. right? because it's got the little reach there.* *Sam: Well, mind if turn it with that?* *Berta: See if that's the problem.* *Shamitra: What do you see Luis?* *Luis: I know the problem… Oh, yeah, I see now.* *Berta: Yeah, It doesn't match that.* *Shamitra: Yeah, it doesn't.* *ALL: This is supposed to be the other way.*
Delay decisions	-wait ,hold off, reflect -make several drafts -draw on the past for multiple options -try to be open	*4*	*20*	*Berta: maybe we should like draw how we <u>think</u> it will look and then do that so we don't'//* *Shamitra: Like, so we can draw it on this paper, and then do our final on this paper, right?* *Berta: We didn't' know who was in our group yet, so I didn't' know what maybe they would like so I tried to be open…* *Isabel: But I like the net, too. I don't' know, but I like the box too, cause you can just tape it to the box…*
Express doubt	-resist closing options quickly	*4*	*32*	*Sam: But wouldn't that be the same thing?*
Hedge your bets,	-recognize and maintain multiple options -choose robust options - gather information and	*6*	*31*	*Julio: But I think we need the hard stuff in case there're rocks in the pool.*

	keep open, not plan out the whole thing, go step by step.			*Berta suggested to her group that they draw it for now, but come back…* *Isabel: …so we might try like some other… but if it doesn't work, we're probably going to make it just go straight or do something.*
Tactics for Purposely Increasing Uncertainty				
Open the problem space		0	7	*Shamitra suggested that her group members all draw independent sketches of their conception of the design idea they had agreed on so that they could take advantage of their diverse perspectives (synopsis of field notes)*

Appendix G
Description of Focal Students

Berta was an African-American girl. Identified as gifted and talented, Berta was a talented writer and spent much of her free time journaling and writing fiction, even publishing her work in online fan clubs. In one assignment of three paragraphs to write a story about being a rock, she wrote eleven pages. Berta was a careful thinker. Berta lived with her mother and father and her older brother, who attended a school for autistic children. Although a quiet person, who was easily overwhelmed by too much movement and loud noise, one of my first field notes about her was that she seemed, “very willing to engage her two male partners” during robotic Project 1. She was not demanding or commanding in her presence, she garnered a certain level of respect in the classroom for her intellectual capacity. However, she was not looked on by her classmates as a leader. Berta tended to manage uncertainty by collecting information, even at night on the computer. She also checked in with friends about social uncertainties, and she got overwhelmed, she cried and wrote in her journal as a way to calm herself. She often attributed to uncertainty to, “I’m new to robotics.”

Demetre was an African American boy, identified by his teacher as an average student. In terms of academics, the teacher described Demetre as an average student. Although he said he identified himself as someone who did not know much about technology, he also gave the impression he was interested in technology and science, saying. I often saw library books on science and technology on his desk. Demetre’s social standing in his fifth grade class was probably the lowest of his classmates. It was difficult for me to pinpoint from where his social difficulties arose. He had a few mannerisms that annoyed his classmates and the teacher; he made small noises and had difficulties sitting still. Additionally, he sometimes made inappropriate, out of place remarks in classroom conversation and in response to teacher inquiries. All in all, students in this class got along well; however, Demetre was the biggest “scapegoat” in the class. The other boys did not seem to accept him in their group. Father worked as a car wash attendant. From several stories Demetre related in class, I got the impression that the family members were close. Both parents came to back-to-school night, bringing along Demetre’s two younger brothers. In terms of robotics engineering, Demetre struggled with his participation. During the first two projects, he was in groups of all boys and he was not well-respected in either group.

Luis was a Hispanic boy, an average student, quiet and a bit shy around his classmates. Like many of the students in this class, he had attended Midtown Elementary School since kindergarten. Luis continued to received ESL services, though his command of English was [close to being on grade level]. His parents had emigrated from Mexico and the family made frequent trips there. Luis’s mother spoke little English; neither parent attended back-to-school night or robofair, the two school functions at which I was present. Nor did I ever see either of them at the school at other times. Although quiet, Luis got along well with his classmates, and was not above having a little fun. Luis wrote the following limerick, which was well-received by his classmates, a fact that seemed to please him immensely:

There once was a boy named Lou,
Who had a girlfriend named Sue.
They kissed 'til they were missed
And then they got the flu.

In terms of his participation in robotics engineering projects, Luis had fairly good intuitions about building, however, he identified himself as a person who did not understand the programming, an assessment further testified to in interviews with him in which I asked him to describe his group's programming. Luis tended to manage uncertainty primarily by avoiding or ignoring it. He was quick to blame his peer collaborators for problems, rather than puzzle over the problem. He made quick claims often, "I know what to do", rather than mitigate his claims with uncertainty markers. Because of these behaviors, it might have been easy to get the idea that Luis did not experience uncertainty, if not for two other frequent behaviors. Luis tended to begin a sentence and trail off at the end without finishing it when he was unsure or doubtful about an issue. He also seemed to try to prepare himself for failure, for instance with comments such as, "It's not going to work." Altogether, Luis's behaviors point to a boy who tends to manage uncertainty by trying to minimize or avoid acknowledging its existence.

Isabel was a White girl. A special education student, Isabel had to leave the class during part of robotics instruction across the year and this put her at a disadvantage in terms of knowledge and skills acquisition. It also placed her at the mercy of her group members in terms of acquisition of practices. During both Project 1 and Project 2 she was a member of a group that struggled to keep up with the progress the rest of the class was making. Although she usually managed to keep her sunny, hopeful disposition, Isabel sometimes expressed anxiety about being behind.

Ray was a White boy of average academic standing. His mother was a teacher, actively and visibly involved in his schooling. He loved soccer. He got along fairly well with his classmates, was outgoing and friendly, even if a little intimidated by some of the boys in his class. Although an average student, Ray was identified by his teacher as being a bit immature in his problem solving capacity. In terms of his participation in robotics, Ray seemed to struggle with understanding concepts and procedures. This was especially true for programming.

Satya was a female of East Indian decent. Identified as gifted and talented, she was pulled out of class on Tuesday and Friday mornings for 45 minutes to attend a district-initiated program designed to provide differentiation for gifted students. The teacher put a lot of thought in to how to differentiate and extend the curriculum for Satya, partly this was due to Satya's behavior of asking Ms. Billings about books she should read, and things she should do over breaks. The two exchanged emails often on the weekends. Satya was well respected in the classroom, noted by other students for her intelligence and her kindness. Satya was an only child. Her parents were quite involved in her education, as signified by Satya's mother's attendance at back to school night, and occasional "stopping by' the class to drop off things, and by the fact that the year after the observations made in this dissertation, Satya's parents enrolled her in a private middle school. It is also represented by a limerick Satya composed and read aloud to her classmates as part of a class assignment:

The rules of school I obey,
And I still go out of my way,
But as hard as I try, my parents will cry
If I don't bring home all As.

As in most collaborative academic situations in which the class participated, Satya was recognized and deferred to as a leader in all three of the collaborative robotics groups in which she participated across the year. She herself felt handicapped by the fact that she missed parts of robotics to attend a gifted and talented program. However, she still seemed to keep up with the rest of the class in terms of her understanding of robotics engineering concepts and practices.

References

Adams, R. S. (2001). *Cognitive processes in iterative design behavior*. Unpublished doctoral research: University of Washington.

Adorno, T. W., Frenkel-Brunswik, E., Levinson, D. J., & Sanford, R. N. (1950). *The authoritarian personality*. New York: Harper.

Allen, P., & Varga, L. (2007). Complexity: The co-evolution of epistemology, axiology, and ontology. *Nonlinear Dynamics, Psychology, and Life Sciences*, *11*(1), 19-501.

Almasi, J. F. (1995). The nature of fourth graders' sociocognitive conflicts in peer-led and teacher-led discussions of literature. *Reading Research Quarterly, 30 (3),* 314-351.

Alibali , M. W. & Goldin-Meadow, S. (1993); Gesture-speech mismatch and mechanisms of learning: What the hands reveal about a child's state of mind. *Cognitive Psychology, 25*, 468-523.

Alabali, M. W., Kita, S., & Young, A. J. (2000). Gesture and the process of speech production: We think, therefore we gesture. *Language and Cognitive Processes, 15(6),* 593-613.

Anderson, C.J. (2003). The psychology of doing nothing: Forms of decision avoidance result from reason and emotion. *Psychological Bulletin, 129 (1),* 139-167.

Anderson, R. C., Nyuyen-Jahiel, K., McNurlen, B., Archodidou, A., Kim, S., Reznetskaya, A., et al. (2001). The snowball phenomenon: Spread of ways of talking and ways of thinking across groups of children. *Cognition and Instruction, 19(1),* 1-46.

Anderson; L. M., Stevens; D. D., Prawat; R., & Nickerson, J. (1988). Classroom task environments and students' task-related beliefs. *The Elementary School Journal*, *88 (3),* Special Issue: Schoolwork and Academic Tasks, 281-295.

Andriessen, J. (2006). Arguing to learn. In K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 79–96). New York: Cambridge University Press.

Arias, E., Eden, H., Fischer, G., Gorman, A., & Scharff, E. (2000). Transcending the individual human mind—creating shared understanding through collaborative design. *ACM Transactions on Computer-Human Interaction (TOCHI), 7*(1), 84-113.

Arrow, H., McGrath, J. E., & Berdahl, J. L. (2000). *Small groups as complex systems: Formation, coordination, development, and adaptation*. Thousand Oaks, CA: Sage Publications.

Arthur, B.W. (1999). Complexity and the economy. *Science, 284*, 107-109.

Ary, D., Jacobs, L. C., & Razavieh, A. (2002). *Introduction to research in education* (6th ed.). Belmont, CA: Wadsworth/Thomson Learning.

Babrow, A. (1992). Communication and problematic integration: Understanding diverging probability and value, ambiguity, ambivalence, and impossibility. *Communication Theory*, *2,* 95-130.

Babrow, A. S., Kasch, C. R., & Ford, L. A. (1998). The many meanings of uncertainty in illness: Toward a systematic accounting. *Health Communication*, *10*, 1–23.

Babrow, A.S., & Mathias,M. S. (2009). Generally unseen challenges in uncertainty management. In T. D. Afifi & W. A. Afifi (Eds.), *Uncertainty, information management, and disclosure decisions* (pp. 9-25). New York: Routledge.

Baker-Sennett, J., Matusov, E. & Rogoff, B. (2008). Children's planning of classroom plays with adult or child direction. *Social Development, 17(4),* 998-1018.

Barab, S. A., Cherkes-Julkowski, M., Swenson, R., Garrett. S., Shaw, R. E., & Young, M. (1999). Principles of self-organization: Ecologizing the learner-facilitator system. *Journal of the Learning Sciences*, *8,* 349-390.

Barnes, D. (1975). *From communication to curriculum*. London: Penguin.

Barr, D. J. (2003). Paralinguistic correlates of conceptual structure. *Psychonomic Bulletin & Review*, 10 (2), 462-467.

Bennett, N. & Desforges C. (1988). Matching classroom tasks to students' attainments. The *Elementary School Journal*, *88*(3), 220 – 236.

Bereiter, C. (1994). Implication of postmodernism for science, or, science as progressive discourse. *Educational Psychologist*, *29*(1), 3-12.

Bereiter, C., & Scardamalia, M. (1993a). Chapter four: Expertise as process. In *Surpassing ourselves: An inquiry into the nature and implications of expertise* (pp. 77-120). Chicago: Open Court.

Bereiter, C., & Scardamalia, M. (1993b). Chapter five: Creative expertise. In *Surpassing ourselves: An inquiry into the nature and implications of expertise* (pp. 121-152). Chicago: Open Court.

Bereiter, C. & Scardamalia, M. (2003). Learning to work creatively with knowledge. In E. De Corte, L. Verschaffel, N. Entwistle, & J. van Merriënboer (Eds.), *Unravelling basic components and dimensions of powerful learning environments.* EARLI Advances in Learning and Instruction Series. (pp. 55-68). New York: Pergamon.

Bernstein, B. (1962). Social class, linguistic codes and grammatical elements. *Language and Speech*, *5*, 221-240.

Beyth-marom, R., & Dekel, S. (1983). A curriculum to improve thinking under uncertainty. *Instructional Science*, *12*, 67-82.

Beyth-Marom, R., Novik, R., & Sloan, M. (1987). Enhancing children's thinking skills: an instructional model for decision-making under certainty. *Instructional Science*, *16*, 215-231.

Bloom, P. (2002). Mindreading, communication, and the learning of names for things. *Mind & Language*, *17*, 37-54.

Blumenfeld, P. & Meece, J. L (1988). Task factors, teacher behavior, and students' involvement and use of learning strategies in science *The Elementary School Journal*, *88* (3), 235-250.

Blumenfeld, P., Mergendoller, J., & Swarthout, D. (1987). Cumulative experience of task form: Its impact on students as thinkers and workers. *Journal of Curriculum Studies*, *19*, 135-148.

Bogdan, R. & Bilken, S. (1992). *Qualitative research for education: An introduction to* theory *and methods.* Nedham Heights, MA: Allyn & Bacon.

Bohm, D. (2002). *Wholeness and the implicate order*. New York: Routledge Classics

Boiset, M. & Child, J. (1999). Organizations as adaptive systems in complex environments: The case of China. *Organization Science*, *10* (3), 237-252.

Brashers, D. (2001). Communication and uncertainty management. *Journal of Communication*, *51* (3), 477-498.

Brereton, M. F., Cannon, D. M., Mabogunje, A., & Leifer, L. J. (1996). Collaboration in Design Teams: How Social Interaction Shapes the Product. In N. G. Cross, H. H. C. M. Christiaans & K. Dorst (Eds.), *Analysing Design Activity* (pp. 319-341). Chichester: Wiley.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18 (1), 32-42.

Brown, J. S., & Duguid, P. (1991). Organizational learning and communities-or-practice: Toward a unified view of working, learning, and innovation. *Organization Science*, 2 (1), 40-57.

Brown, A. L. (1993). Distributed expertise in the classroom. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 188-228). New York: Cambridge University Press.

Brown, P. and Levinson, S. (1978) Universals in language usage: Politeness phenomena. In E.N. Goody (Ed.) *Questions and Politeness: Strategies in Social Interactions* (pp. 56–289). Cambridge: Cambridge University Press.

Bruner, J. (1981). The pragmatics of Language Acquisition. In W. Deutsch (Ed.), *The child's construction of language* (pp. 39-55). New York: Academic Press.

Bruner, J. (1986). The language of education (Chap 9, pp. 121-133). *Actual minds, possible worlds.* Cambridge, MA: Harvard University Press.

Bruner, J. (1996). *The culture of education*. MA: Harvard University Press.

Budner, S. (1962). Intolerance of ambiguity as a personality variable. *Journal of Personality*, 31, 29-50.

Cacioppo, J. T., Petty, R. E., & Kao, C. (1984). The efficient assessment of need for cognition. *Journal of Personality Assessment*, *48*, 306–307.

Cadella, M. E. & Atman, C. J. (2005). A qualitative study of the role of mathematics in engineering capstone design projects: initial insights. In W. Aung, R. W. King, J. Moscinski, S. Ou, & L. Ruiz (Eds.), *Innovations 2005: World innovations in engineering education and research* (pp. 247-362). Arlington, VA: International Network of Engineering Education and Research.

Capra, F. (1996). *The web of life.* New York: Doubleday**.**

Cazden, C. B., (2001). *Classroom discourse: The language of teaching and learning*. (2nd edition) Portsmouth, NH: Heinemann.

Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction, 15*, 1-40.

Chapman, A. (1997) Towards a model of language shifts in mathematics learning. *Mathematics Education Research Journal 9* (2), 152–72.

Clore, G. L. (1992). Cognitive phenomenology: The role of feelings in the construction of social judgment. In A. Tesser & L. L. Martin (Eds.), *The construction of social judgments* (pp. 133-164). Hillsdale, N.J.: Erlbaum.

Cobb, P. (2002). Reasoning with tools and inscriptions. *Journal of the Learning Sciences*. *11*(2/3), 187–216.

Corbin, J. M. & Strauss, A. L. (2008). *Basics of qualitative research.* UK: Sage.

Corsaro, W. (1982). *Friendship and peer culture in the early years*. Norwood, NJ: Ablex.

Covino, W. A. (1988). *The art of wondering: A revisionist return to the history of rhetoric*. Portsmouth, New Hampshire: Boynton/Cook Heinemann.

Cross, N., & Cross, A. C. (1996). Winning by design: the methods of Gordon Murray, racing car designer. *Design Studies, 17*(1), 91-107.

Cross, N., & Cross, A. C. (1998). Expertise in engineering design. *Research in Engineering Design, 10*(3), 141-149.

Cross, N. G., Christiaans, H. H. C. M., & Dorst, K. (1996). *Analysing design activity*. Chichester: John Wiley & Son.

Davis, B., & Sumara, D. (2006). *Complexity and education: Inquiries into learning, teaching, and research*. Mahwah, New Jersey: Erlbaum.

DeBacker, T. K., & Crowson, H. M., (in press) Measuring need for closure in classroom learners, *Contemporary Educational Psychology*.

Delisle, R. (1997). *How to use problem-based learning in the classroom.* Alexandria, Va.: Association for Supervision and Curriculum Development.

Derry, S. J., DuRussel, L. A., & O'Donnel, A. M. (1998). Individual and distributed cognitions in interdisciplinary teamwork: A developing case study and emerging theory. *Educational Psychology Review*, 10, 25 -56.

Dewey, J. (1910). *How we think*. Boston: Heath.

Dewey, J. (1929). *The quest for certainty*. New York: Minton, Balch, & Company.

Dewey, J. (1981). Experience and nature. In J. A. Boydston (Ed.), *The later works, 1925-1953* (Vol. 1). Carbondale, IL: Southern Illinois University Press.

Do, S. L., & Schallert, D. L. (2004). Emotions and classroom talk: Toward a model of the role of affect in students' experiences of classroom discussion. *Journal of Educational Psychology*, *96*, 619-634.

Dorst, K. (2003). The Problem of Design Problems. *Design Thinking Research Symposium, Sydney, 17*(19.11).

Doyle, W. (1983). Academic work. *Review of Educational Research*, 53, 159-199.

Doyle, W. (1988). Work in mathematics classes: The context of students' thinking during instruction. *Educational Psychologist*, *23 (2),* 167-180.

Doyle, W., & Carter, K. (1984). Academic tasks in classrooms. *Curriculum Inquiry*, *14,* 129-149.

Dror, I. E. & Harnad, S. (eds.) (2008). *Cognition Distributed: How Cognitive Technology Extends Our Minds*. (258 pp.) John Benjamins, Amsterdam.

Duch, B. J. (2001). Writing problems for deeper understanding. In B. J. Duch, S. E. Groh, and D. E. Allen (Eds.), *The power of problem-based learning: A practical "how to" for teaching Undergraduate Courses in Any Discipline* (pp. 47–58). Sterling, Va.: Stylus.

Duckworth, E. (1996). *The having of wonderful ideas* (2nd ed.). New York: Teachers College Press.

Duff, P. (2007). Second language socialization as sociocultural theory: Insights and issues. *Language Teaching* 40, 309–319.

Dweck, C. (2000). *Self-theories.* New York: Psychology Press.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design Thinking, teaching, and learning. *Journal of Engineering Education*, *94(1),* 103-120.

Edwards, A. D., & Mercer, N. (1987). (Chapter 3). New York: Routledge. Einhorn, H. J. & Hogarth, R. M. (1986). Decision making under ambiguity. *The Journal of Business,* 59 (4), S225-S250.

Edwards, E. D., & Westgate, D. P. G. (1984). *Investigating classroom talk* (2nd edition). London: Falmer Press.

Einhorn, H. J. & Hogarth, R. M. (1986). Decision making under ambiguity. *The Journal of Business,* 59 (4), S225-S250.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition & Instruction, 20,* 399-483.

Emmer, E. T. (1986).Academic activities and tasks in first-year teachers' classes. *Teaching and Teacher Education*, 2, 229-244.

Erickson, F. (1992). Ethnographic microanalysis of interaction. *In The Handbook of Qualitative Research in Education: Academic Press*. Chapter 5.

Erickson, F. (1996). Going for the zone: The social and cognitive ecology of teacher-student interaction in classroom conversations. In D. Hicks (Ed.), *Discourse, Learning, and schooling* (pp. 29-62). New York: Cambridge University Press.

Erickson, F. (2004). *Talk and social theory*. Malden, MA: Polity Press.

Feldman, C. F. & Wertsch, J. V., (1976). Context dependent properties of teachers' speech. *Youth & Society*, *7 (3),* 227-258.

Fischhoff, B. (1977). Perceived informativeness of facts. *Journal of Experimental Psychology: Human Perception and Performanc*e, *3,* 349-358.

Florio-Ruane, S. (1987). Sociolinguistics for Educational Researchers. *American Educational Research Journal, 24* (2), 185-197.

Folkman, S, Schaefer, C, & Lazarus, R. S. (1979). Cognitive processes as mediators of stress and coping. In V. Hamilton & D. M. Warburton (Eds.), *Human stress and cognition. An information processing approach* (pp. 265-298) New York Wiley.

Fontana, A. & Frey, J. H. (2000) The Interview: From structured questions to negotiated text', in N.K. Denzin and Y.S. Lincoln (Eds.), *Handbook of Qualitative Research*, 2nd edn. (pp. 61-106) Thousand Oaks, CA: Sage.

Ford. L. A., Babrow, A S. & Stohl. C. (1996). Social support messages and the management of uncertainty in the experience of breast cancer: An application of problematic integration theory. *Communication Monographs,* 63, 189-207.

Fortus, D., Dershimer, R. C., Krajcik, J. S., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching*, *41*(10), 1081-1110.

Gee, J. (1996). *Social linguistics and literacies* (2nd edition). London: Routledge Farmer.

Gee, P. (2005). Semiotic social spaces and affinity spaces: From the Age of Mythology to today's schools. In Barton & Tusting (eds.), 214–232.

Giere, D. (1999). *Science without laws*. Chicago: University of Chicago Press.

Giddens, A. (1990). *The Consequences of modernity,* Stanford, CA: Stanford University Press.

Giddens, A. (1991) *Modernity and self identity*, Stanford, CA: Stanford University Press.

Gill, E. A. & Babrow, A. S. (2007). To hope or to know: Coping with uncertainty and ambivalence in women's magazine breast cancer articles. *Journal of Applied Communication Research, 35* (2), 133-155.

Gilovich, T., Vallone, R.,& Tversky, A. (1995). The hot hand in basketball: On the misperception of random sequences. *Cognitive Psychology, 17, 295-314.*

Gilvry, D. & Roth, W-M. (2004). Toward a new conception of conceptions: Interplay of talk, gestures, and structures in the setting. *Journal of Research in Science Teaching, 43*(10), 1086-1109.

Glanville, R. (2007). Designing complexity. *Performance Improvement Quarterly,* 20 (2), 75-96.

Goel, V., & Pirolli, P. (1992). Design Problem Spaces. *Cognitive Science, 15,* 395-426.

Goetz, J. R**,** & LeCompte, M. D. (1984). *Ethnography and qualitative design in educational research*. New York: Academic Press.

Goldsmith, D. J. (2001). A normative approach to the study of uncertainty and communication. *Journal of Communication*, 514-533.

Goldstone, R. & Janssen, M. (2005) Computational models of collective behavior. Trends in Cognitive Sciences vol. 9 no 9 pp. 424 – 430.

Graff, G. (2003). Clueless in academe: How schooling obscures the life of the mind.

Granic, I. & Lamey, A V. (2000) The self-organization of the Internet and changing modes of thought. New ideas in psychology 18, 93-107.

Gray. E. M. & Tall, D. D. (1993). Duality. ambiguity, and flexibility: A "proceptual" view of simple arithmetic. *Journal for Research in Mathematics Education.* 25. 116-146.

Green, M. (1984). Cognitive stage differences in types of speaker uncertainty markers. *Language and Speech, 27*(4), 323-

Greeno, J. G. (2006). Learning in Activity. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences (pp. 79-96).* New York, Cambridge University Press**.**

Greeno, J.G., Collins, A.M. & Resnick, L. B. (1996). Cognition and learning. In D. Berline, and R. Calfee (Eds.), *Handbook of educational psychology* (pp. 15-46). New York: Macmillan.

Grice, H. P. (1975). Logic and conversation. In P. Cole & J. L. Morgan (Eds.), *Syntax and semantics: Speech acts* (vol. 3). New York: Academic Press.

Gumperz, J. (1982). *Discourse strategies*. London: Cambridge University Press.

Hadwin, A. F., & Oshige, M. (2006). Self-regulation, co-regulation and shared regulation: Examining the many faces of social in models of SRL. Paper submitted as part of a symposium organized by A. F. Hadwin, & S. Järvelä titled: *Socially constructed self-regulated learning: Where social and self meet in the strategic regulation of learning* for the Annual meeting of the American Educational Research Association, San Francisco, CA (April, 2006).

Hall, R. (1999). The organization and development of discursive practices for "having a theory." *Discourse Processes, 27*(2), 187–218.

Hammer, D. (1995). Student inquiry in a physics class discussion. *Cognition & Instruction, 13,* 401-430.

Harnad, S. (2005). Distributed processes, distributed cognizers, and collaborative cognition. *Pragmatics & Cognition, 13*(3), 501-514.

Haslam, A., S. & McGarty, C. (2001). 100 years of certitude? Social psychology, the experimental method and the management of scientific uncertainty. *British Journal of Social Psychology, 40*, 1-21.

Hatch, M. J. (1999). Exploring the empty spaces of organizing: how improvisational jazz helps redescribe organizational structure. Organization Studies, *20*(1), 75-100.

Herbst, P. G. (2003). Using Novel Tasks in Teaching Mathematics: Three tensions affecting the work of the teacher. *American Educational Research Journal*, *40*(1), 197-238.

Hewitt, J., & Scardamalia, M. (1998). Design principles for distributed knowledge building processes. Educational Psychology Review, *10*, 75-96.

Hiebert, J. & Wearne, D. (1993). Instructional tasks, classroom discourse, and students' learning in second-grade arithmetic. *American Educational Research Journal*, *30*(2), 393-425.

Hiebert, J., Carpenter, T. P., Fennema, E., Fuson, K., Human, P., Muray, H., Olivier, A., & Wearne, D. (1996). Problem solving as a basis for reform in curriculum and instruction: The case of mathematics. *Educational Researcher, 25* (4), 12 -21.

Hills, T., Stroup, W., & Wilensky, U. (2005, April). *Patterns of risk seeking and aversion among pre-service teachers: Mathematical decisions, preference, efficacy, and participation*. Paper presented at the Annual Meeting of the American Educational Research Association, Montreal.

Hjalmarson, M., Cardella, M., & Adams, R. (2007). Uncertainty and iteration in design tasks for engineering students. In R. Lesh, E. Hamilton, & J. J. Kaput (Eds.), *Foundations for the future of mathematics education* (pp. 409-429). Mahwah, NJ:

Erlbaum.

Hmelo-Silver, C. E. & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive Science* 28, 127-138.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. Review of Educational Research, 67(1), 88-140.

Hogan, K., Nastasi, B. K., & Pressley, M. (1999). Discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. *Cognition and Instruction*, 17(4).

Hogan, K., & Fisherkeller, J. (1999). Dialogue as data: Assessing students' scientific reasoning with interactive protocols. In J. J. Mintzes, J. H. Wandersee, & J. D. Novak (Eds.), *Assessing science understanding: A human constructivist view*. San Diego, CA: Academic.

Holland, J.H. (1998). *Emergence: from chaos to order*. Reading, MA: Addison-Wesley.

Huber, G. L., Sorrentino, R. M., Davidson, M., Eppler, R., & Roth, J. W. H. (1992). Uncertainty orientation and cooperative learning: Individual differences within and across cultures. *Learning and Individual Differences*, 4, 1-24.

Hutchins, E. (1995a). How a Cockpit Remembers Its Speed. *Cognitive Science* 19, 265-288.

Hutchins, E. (1995b). *Cognition in the Wid*. Cambridge, MA: MIT Press.

Hyland, K. (1996). Writing without conviction? Hedging in scientific research articles. *Applied Linguistics* 17 (4): 433-454.

Hymes, D. (1974). *Foundations in sociolinguistics: An ethnographic approach*. Philadelphia: University of Pennsylvania Press.

Jackson, T. Mackenzie, J. & Hobfoll, S. (2000). Communal aspects of self-regulation. 275-296. In M. Boekaerts, P.R. Pintrich, & M. Zeidner, *Handbook of self-regulation* (Chap.13). San Diego, CA: Academic Press.

Jacobson, M. J. (2001). Problem solving, cognition, and complex systems: Differences between experts and novices. *Complexity*, 6(3), 41–49.

Johnson, B. B. & Covello, V. T. (1987).*The Social and Cultural Construction of Risk*, Dordrecht: D. Reidel.

Jones, D., & Christensen, C. A. (1999). Relationship between automaticity in handwriting and students' ability to generate written text. *Journal of Educational Psychology*, 91, 44-49.

Jonassen, D. H. (2000). Towards a design theory of problem solving. *Educational Technology, Research and Development*, 48(4), 63-85.

Jordan, M. E., Schallert, D. L., Cheng, A., Park, Y., Lee, H., Chen, Y., Yang, M. Chu, R., & Chang, Y. (2007). Seeking self organization in classroom computer mediated discussion through a complex adaptive systems lens. *Yearbook of the National Reading Conference, 56*, 39-53.

Jordan, M. E., Lanham, H. J., & Anderson, R. A. & McDaniel, R. R. (2010). Implications of complex adaptive systems theory for interpreting research about health care organizations. *Journal of Evaluation in Clinical Practice (International Journal of Public Health Policy and Health Services Research) 16*(1), 228-231.

Kagan, J. (1972). Motives and development. *Journal of Personality and* Social *Psychology, 22,* 51-66.

Kahneman D., Slovic, P., & Tversky, A. (Eds) (1982). *Judgement under uncertainty: Heuristics and biases,* Cambridge, Cambridge University Press.

Kahneman D. & Tversky, A. (1982). Variants of uncertainty D. Khaneman., P. Slovic, & A. Tversky (Eds.). *Judgement under uncertainty: Heuristics and biases,* (pp. 509-520). Cambridge, Cambridge University Press.

Kapur, M. (2008). Productive failure. *Cognition and Instruction, 26*(3), 379-424.

Kapur, M., & Kinzer, C. (2008). Sensitivities to early exchange in synchronous computer-supported collaborative learning (CSCL) groups. *Computers in Education, 54*(1), 54-66.

Kapur, M., & Kinzer, C. (2007). Examining the effect of problem type in a synchronous computer-supported collaborative learning (CSCL) environment. *Educational Technology, Research & Development, 55*(5), 439-459.

Kauffman, S. (1995). *At home in the universe*. Ne w York: Oxford University Press.

Keating, D. P. (2004). Cognitive and brain development. In R. M. Lerner, *Handbook of adolescent psychology* (pp. 45-84). New York: John Wiley & Sons.

Kempler, T., Linnenbrink, E., A., (2006). Helping Behaviors in Collaborative Groups in Math: A descriptive Analysis. In S.Karabenic & R. Newman (Eds.). *Helpseeking in Academic settings: Goals, groups, and contexts* (pp. 89-115). NJ: Erlbaum.

Kendon, A. (1994). Do gestures communicate? A review. *Research on Language and Social Interaction, 27,* 175–200.

Kennedy, M. (2005). *Inside teaching: How classroom life undermines reform*. Cambridge: Harvard University Press.

Kilduff, M, Angelmar, R., & Mehra, A. (2000). Top management-team diversity and firm performance: Examining the role of cognitions. *Organization Science*, 11(1), 21-34.

Kitchener, K. S. & King, P. M. (1994). *Developing reflective judgments: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco: Jossey-Bass.

Koestler, A. (1964). *The act of creation*. London: Hutchinson.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., et al. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning-by-design into practice. *Journal of the Learning Sciences*, *12*(4), 495-547.

Kress, G. (1989). *Linguistic processes in sociocultural practice*. Oxford, England: Oxford University Press.

Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: The rhetorics of the science classroom.* London: Continuum.

Kruglanski, A. W., & Webster, D. M. (1996). Motivated closing of the mind: Seizing and freezing. *Psychological Review*, *103*, 263–283.

Lakoff, G. (1973) Hedges: A study in meaning criteria and the logic of fuzzy concepts. *Journal of Philosophical Logic*, *2*, 458–508.

Langer, E. (1975). The illusion of control. *Journal of Personality and Social Psychology,* *32*(2), 311-328.

Langer, E. (1997). *The power of mindful learning*. Cambridge, MA: Da Capo Press.

Lankshear, C., & Knobel, M. (2004). *A Handbook for Teacher Research*. England: Open University Press, pp. 266-300 (Chapter 13).

Lave, J. (1991). Situating Learning in Communities of Practice. In Resnick, L. B., Levine, J. M., & Teasley, S. D. (Eds), Perspectives on Socially Shared Cognition, Washington D. C.: American Psychological Association, pp. 63-84.

Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: University of Cambridge Press.

Lazarus, R S. (1983). The costs and benefits of denial. In S. Breznitz (Ed.), *The denial of stress* (pp. 1-30) New York. International Universities Press.

Lebeau, R. (1998). Cognitive tools in a clinical encounter in medicine: Supporting empathy and expertise in distributed systems. *Educational Psychology Review, 10*, 2-24.

Lemke, J. J. (2000a). Across the scales of time: Artifacts, activities, and meanings in ecosocial systems. *Mind, Culture, and Activity*, *3*(4), 273-290.

Lemke, J. (2000b). Multimedia literacy demands of the scientific curriculum. *Linguistics and Education, 10*(3), 247-271.

Lesh, R. (2003). Models and modeling in mathematics education. Monograph for *International Journal of Mathematical Thinking & Learning*. Mahwah, NJ: Erlbaum.

Levitt, E. E. (1953). Studies in intolerance of ambiguity. *Child Development,* 24, 263-268.

Lewis, C. (1997). The social drama of literature discussions in a fifth/sixth-grade classroom. *Research in the Teaching of English, 31* (2), pp. 163-204.

Liebovitch, L. S. (1998). *Fractals and Chaos Simplified for the Life Sciences*. New York: Oxford University Press.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage Publications.

Lingard, L, Garwood, K, Schryer, C. F., & Spafford, M. M. (2003). A certain art of uncertainty: case presentation and the development of professional identity. *Social Science & Medicine*, 56, 603-616.

Lipshitz, R., & Strauss, O. (1997). Coping with uncertainty: A naturalistic Decision-making analysis. *Organizational Behavior and Human Decision Processes*. 69 (2), 149-163.

Lodewyk, K.R., & Winne, P. H. (2005). Relations among the structure of learning tasks, achievement, and changes in self-efficacy in secondary students. *Journal of Educational Psychology*, 97 (1), 3-12.

Lorenzi, P. (1980). Applied behavior under uncertainty. In S. Fiddle (Ed.) *Uncertainty: Behavioral and social dimensions*. (pp. 284-304).New York: Praeger Publishers.

Luhmann, N. (1993). Risk: *A sociological theory*. Berlin: de Gruyter.

McDaniel, R.R. Jr. (2007). Management strategies for complex adaptive systems: Sensemaking, learning and improvisation. *Performance Improvement Quarterly*, 20(2), 2142.

McDaniel, R. R., Jr., Jordan, M. E., & Fleeman, B. (2003). Surprise, surprise, surprise!: A complexity science view of the unexpected. *Health Care Management Review, 28*, 266-278.

McDaniel, M. A., Waddill, P. J., Finstad, K., & Bourg, T. (2000). The effects of text-based interest on attention and recall. *Journal of Educational Psychology*, 92, 492-502

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought.* Chicago: University of Chicago Press.

Maclay, H., & Osgood, C. E. (1959). Hesitation phenomena in spontaneous speech. *Word*, 15, 19-44.

Mahlke, V. B. (1993) Design technology in the elementary school, *The Technology Teacher*, 53, pp. 6–7.

Major, D. (1974). *The Acquisition of modal auxiliaries in the language of children* (The Hague).

Maloch, B. (2005). Becoming a "WOW Reader": Context and continuity in a second grade classroom. *Journal of Classroom Interaction, 40 (1)*, 5-17.

Maloch, B. (2004). One teacher's journey: Transitioning into literature discussion groups. *Language Arts, 81*, 312-322.

March, J. G. (1991). How decisions happen in organizations. *Human-computer Interaction*, 1991, 6, 95-1 17.

Mathieu, J., Heffner, T., Goodwin, G., Salas, E. & Cannon-Bowers, J. (2000). The Influence of Shared Mental Models on Team Process and Performance. *Journal of Applied Psychology, 85* (2), 273-283.

Meaney, T. (2006). Really that's probably about roughly what goes down: Hesitancies and uncertainties in mathematics assessment interactions. *Language and Education*, 20 (5), 374 – 390.

Meijers, A. W. M. (2000). The relational Ontology of Technical Artifacts. In P. A. Kroes & A. W. M. Meijers (Eds.), *The Empirical Turn in the Philosophy of Technology, Research in Philosophy and Technology* (Vol. 20). Oxford: Elseviers Science

Mercer, N. (2000) *Words and Minds: How We Use Language to Think Together*. London: Routledge.

Mercer, N. (1995). *Guiding the construction of knowledge*. Multilingual Matters, Ltd.

Metz, K. (2004). Children's' understanding of scientific inquiry: Their conceptualizations of uncertainty in investigations of their own design. *Cognition and Instruction*, *22*(2), 219-290.

Milliken, F. C. (1987). Three types of perceived uncertainty about the environment: State, effect, and response uncertainty. *Academy of Management Review*, *12*(1), 133-143.

Mishel, M. H. (1990). Reconceptualization of the uncertainty in illness theory. *Image:* Journal *of Nursing Scholarship*, *22*, 256–262.

Mishel, M. H., & Braden, C. J. (1988). Finding meaning: Antecedents of uncertainty in illness. *Nursing Research, 37*, 98–103, 127.

Moore, J & Rocklin, T. (1998). The distribution of distributed cognition: Multiple interpretations and uses. *Educational Psychology Review, 10* (1), 97-113.

Munthe, E. (2003). *Teachers' Professional Certainty*. Research presented to the University of Oslo, Faculty of Education Norway. Unipus As: Oslo.

Neuberg, S., & Newsom, J. (1993). Personal need for structure: Individual differences in the desire for simple structure. *Journal of Personality and Social Psychology*, *65*, 113-131.

Noica, C. (1987). Questioning and being. (trans.) Rodica Miut. *Questioning Exchange*, *1*(2), 143-149.

Nystrand, M., Wu, L. L., & Gamoran, A. (2003). Questions in time: Investigating the structure and dynamics of unfolding classroom discourse. *Discourse processes, 35*(2), 135-198.

Ochs, E. (1998, originally published in 1979). Transcription as theory. In A. Jaworski and N. Coupland (Eds.) *The Discourse Reader* (pp. 167-182). London: Routledge.

O'Day, J. (2002). Complexity, accountability, and school improvement. *Harvard Educational Review, 72*, 293-329.

O'Neill, D. K., & Atances, C. M. (2000). 'Maybe my daddy give me a big piano': The development of children's use of modals to express uncertainty. *First Language*, *20*, 29-52.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York : Basic Books.

Penner, D. E., Lehrer, R., & Schauble, L. (1998). From physical models to biomechanics: A design-based modeling approach. *Journal of the Learning Sciences, 7*,429-450.

Perry, N., Phillips, P, & Dowler, M (2004). Examining features of tasks and their potential to promote self-regulated learning. *Teachers College Record, 106*(9), 1854–1878.

Petrosino, A. J. (March, 1997). *Authentic experience within investigation activities: The role of reflection in the learning environment*. Paper presented at the Annual Conference of the American Educational Research Association, Chicago, Il.

Piaget, J. (1972). Intellectual evolution from adolescence to adulthood. *Human Development, 15,*1-12.

Piaget, J., & Inhelder, B. (1975). *The origin of the idea of chance in children.* New York: Norton, 1975.

Plummer, K. (2001). *Documents of life 2: An invitation to a critical humanism*. Long, UK: Sage Publications.

Prigogine, I, & Sengers, I. (1997). *The End of Certainty: time, chaos, and the new laws of nature*. New York: The Free Press.

Prince, E. F., Frader, J.. & Bosk, C. (1982). On hedging in physician-physician discourse In R J DiPieuo (Ed.), *Linguistics and the professions* (pp 83-97) Norwood, NJ Ablex

Polanyi, M. (1958). *Personal Knowledge: towards a post-critical theory.* Chicago: University of Chicago Press.

Radinsky, J. (2008). Students' roles in group-work with visual data: A site of science learning. *Cognition & Instruction, 26*, 145-194.

Rohrkemper, M. & Corno, L. (1988). Success and failure on classroom tasks: Adaptive learning and classroom teaching. *The Elementary School Journal, 88*(3), 296-312.

Rokeach, M. (1960). *The open and closed mind*. New York: Basic Books.

Roseman, I. J. (1984). Cognitive determinants of emotion: A structural theory. *Review of* Personality *& Social Psychology, 5,* 11-36.

Roth, W.-M. (2003). Gesture-speech phenomena, learning, and development. *Educational Psychologist*, *38*(4), 249-263.

Roth, W.-M. (1995). Inventors, copycats, and everyone else: The emergence of shared resources and practices as defining aspects of classroom communities. *Science Education*, *79*,475-502.

Rowland, T. (2000). *The pragmatics of mathematics education: Vagueness in mathematical discourse*. London: Falmer.

Rowell, P. M. (2002). Peer interactions in shared technological activity: A study of participation. *International Journal of Technology and Design Education 12*, 1-22.

Sadler, P. M., Coyle, H. P., & Schwartz, M. (2000). Engineering Competitions in the Middle School Classroom: Key Elements in Developing Effective Design Challenges. *Journal of the Learning Sciences, 9*(3), 299-327.

Salomon, G. (ed.), (1993). *Distributed cognitions: Psychological and educational* considerations (pp. 139-163). Cambridge: Cambridge University Press.

Salomon, G. & Sieber, J. E. (1970). Relevant subjective response uncertainty as a function of stimulus-task interaction. A*merican Educational Research Journal*, 7, 337-50.

Sawyer, R. K. (2003). *Improvised dialogues: Emergence and creativity in conversation*. Westport, Conn.: Greenwood.

Scardamalia, M. & Bereiter, C. (1991). High levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *The Journal of the Learning Sciences, 1*(1), 37-68.

Schallert, D. L., & Martin, D. B. (2003). A psychological analysis of what teachers and students do in the language arts classroom. In J. Flood, D. Lapp, J. R. Squire, & J. M. Jensen (Eds.), *Handbook of research on teaching the English language arts* (2nd ed., pp. 31-45). New York: Macmillan.

Schauble, L. Klopfer, L. E., & Raghavan, K. (1991). Students' transition from an engineering model to a science model of experimentation. *Journal of Research in Science Teaching, 28*(9), 859-882.

Schiffrin, D. (1994). *Approaches to discourse*. Malden, MA: Blackwell.

Seitz, J. (2003). A communitarian Approach to creativity. *Mind, Culture, and Activity, 10*(3), 245-249.

Sheer, V. C., & Cline, R. J (1995). Testing a model of perceived information adequacy and uncertainty reduction in physician-patient interactions *Journal of Applied Communication Research, 23*, 44-59.

Shiller, R. J. (1995). Conversation, information, and herd behavior. *The American Economic Review, 85*(2), 181-185.

Sieber, J. E. (1969). Lessons in uncertainty. *The Elementary School Journal, 69*(6), 304-312.

Sieber, J. E. (1974). Effects of decision importance on ability to generate warranted subjective uncertainty. *Journal of Personality and Social Psychology, 30*(5), 688-694.

Sieber, J. E., Clark, R. E., Smith, H. H. & Sanders, N. (1978). The effects of learning when to be uncertain on children's knowledge and use of drugs. *Contemporary Educational Psychology, 3*, 246-64.

Sieber, J. E. Epstein, M. & Petty, C. (1970). Effectiveness of modeling and concept learning procedures in teaching children to indicate uncertainty. *Irish Journal of Education*, *4*, 90-106.

Singer, M., Radinsky, J. & Goldman, S. R. (2008). The Role of Gesture in Meaning Construction, *Discourse Processes*, *45* (4) 365-386.

Slavin, R. E. (1995). *Cooperative learning: Theory, research and practice* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Slavin, R. E. (1983). *Cooperative learning*. New York: Longman.

Smith, C. A., & Ellsworth, P. C. (1985). Patterns of cognitive appraisal in emotion. *Journal of Personality and Social Psychology, 48*, 813-838.

Smithson, M. (1989). *Ignorance and uncertainty: emerging paradigms*. New York: Springer Verlag.

Sorrentino, R. M., & Roney, C. R. (1990). Uncertainty orientation: Individual differences in the self-inference process. In J. M. Olson & M. P. Zanna (Eds.), *Self-inference processes: The Ontario Symposium* (Vol.6, pp. 239-257). Hillsdale, N.J.: LEA.

Sorrentino, R. M. & Roney, C. J. R. (2000). *The uncertain mind: individual differences in facing the unknown*. Philidelphia, PA: Psychology Press.

Squire, J. R. (1964). *The responses of adolescents while reading four short stories*. Champaign, Illinois. National Council of Teachers of English.

Spradley, J. P. (1979). *The ethnographic interview*. NY: Holt Reinhart.

Spiro, R.J., Feltovich, P.J., Jacobson, M.J., & Coulson, R.L. (1991).Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. *Educational Technology*, 24-33.

Stacey, R. D. (1992). *Managing the unknowable: strategic boundaries between order and chaos in organizations*. San Francisco, CA: Josey-Bass Publishers.

Swann, J. (1993). Observing and recording talk in educational settings. In D Graddol, J. Maybin, & B. Stierer, (Eds.), *Researching Language and Literacy in a Social Context* (pp. 26-48). Clevedon, UK: Multilingual Matters.

Taleb, N. N. (2001). *Fooled by randomness: The hidden role of chance in the markets and in life*. NY: TEXERE.

Taylor. S. E (1983) Adjustment to threatening events. A theory of cognitive adaptation. *American Psychologist, 38,* 1161-1173.

Thelen E. & Smith, L. B. (1994). *A Dynamic Systems Approach to the Development of Cognition and Action,* Cambridge, MA: MIT Press.

Thomas, J. B., & McDaniel, R. R. Jr. (1990). Interpreting strategic issues: Effects of strategy and the information-processing structure of top management teams. *Academy of Management Journal*, *33*, 286-306.

Thompson, J. D. (1967). *Organizations in Action*. New York: McGraw Hill.

Thorne, S.L. (2009), 'Community', semiotic flows, and mediated contribution to activity. *Language Teaching*, *42*(1), 81–94

Tiedens, L. Z. & Linton, S. (2001). Judgment under emotional certainty and uncertainty : The effects of specific emotions on information processing. *Journal of Personality and Social Psychology*, 81 (6), 973-988.

Tobin, K. G. (1984). Student task involvement in activity-oriented science. *Journal of Research* on *Science Teaching, 21,* 469-482.

Turner, G. J. & Pickvance, R. E. (1973). Social class differences in the expression of uncertainty in five-year-old children. In B. Bernstein (Ed.), *Class, codes, and control.* vs. 2. London: Routledge.

van den Boss, K. (2001). Uncertainty management: The influence of uncertainty salience on reactions to perceived procedural fairness. *Journal of Personality and Social Psychology*, *80,* 931–941.

Verhoeven, C. (1967). *The philosophy of wonder* (M. Foran, Trans.). New York: Macmillan.

Vygotsky, L.S. (1978). *Mind in society*. London: Harvard University Press.

Waldrop, M. M. (1992). *Complexity-the emerging science at the edge of order and chaos*. New York, NY: Touchstone/Simon & Schuster.

Walker, C. H. (1987). Relative importance of domain knowledge and overall aptitude on acquisition of domain-related information. *Cognition and Instruction*, *4*, 25-42.

Weary, G., Marsh, K.L., Gleicher, F., & Edwards, J.A. (1993). Depression, control motivation, and the processing of information about others. In G. Weary, Gleicher, F., & Marsh, K.L. (Eds.) *Control motivation and social cognition* (pp. 255-287). New York: Springer-Verlag.

Webb, N. (1982). Student interaction and learning in small groups. *Review of Educational Research*, *52*, 421-445.

Webb, N. M., &Palincsar, A. S. (1996). Group processes in the classroom. In D. C. Berliner &R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 841-873). New York: Simon & Schuster.

Webb, N. M., Ing, M., Kersting, N., & Nemer, K. K., (2006). Help seeking in cooperative learning Groups. In S. Karbenic & R. Newman (Eds) *Help seeking in academic settings: Goals, groups, and contexts* (pp. 45-88). Mahwah, NJ: Lawrence Erlbaum.

Webb, N. M., Nemer, K. M., & Ing, M. (2006). Small-group reflections: Parallels between teacher discourse and student behavior in peer-directed groups. *The Journal of the Learning Sciences*, 15 (1), 63-119.

Webster, D. M., & Kruglanski, A. W. (1994). Individual differences in need for cognitive closure. *Journal of Personality and Social Psychology*, 76(6), 1049–1062.

Weick, K. E. (1979). *The social psychology of organizing*. Reading, MA: Addison Wesley.

Weick, K. E. (1995). *Sensemaking in organizations*. Thousand Oaks, CA: Sage.

Weick, K. E. (2001). Leadership as the legitimation of doubt. In W. Bennis, G. M. Spreitzer, T. G. Cummings (Eds.), *The Future of Leadership. (pp. 91-103)* San Francisco, CA: Jossey-Bass.

Weick, K. (2005). Collective Sensemaking. In McDaniel, R., & Driebe, D. (Eds.), *Uncertainty and Surprise in Complex Systems: Questions on Working with the Unexpected* (pp. 31-50). Berlin Heidelberg: Springer-Verlag.

Weiss, R. S. (1994). *Learning from strangers: The art and method of qualitative interview studies.* New York: Free Press.

Wells, G. (2000). Modes of meaning in a science activity. *Linguistics and Education*, 1*0*(3), 307-334.

Wertsch, J. V. (1991). A sociocultural approach to socially shared cognition. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 85-100). Washington, DC: American Psychological Association.

Wildavsky, A. (1988). *Searching for safety*. New Brunskwick (USA): Transactions Publishers.

Wilensky, U. & Resnick, M. (1999). Thinking in levels: a dynamic systems approach to making sense of the world. *Journal of Science Education and Technology*, *8*(1), 3-18.

Wilson, T. D., Centerbar, D. B., Kermer, D.A., & Gilbert, D.T. (2005). The pleasures of uncertainty: prolonging positive moods in ways people do not anticipate. *Journal of Personality and Social Psychology*, *88*, 5-21.

Wilson, T. D, Centerbar, D. B., Kermer, D. A., & Gilbert, D. T. (2005). The pleasures of uncertainty: Prolonging positive moods in ways people do not anticipate. *Journal of Personality and Social Psychology*, *88*(1), 5-21.

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This dissertation was typed by the author.