Managing Small Groups to Meet the Social and Psychological Demands of Scientific and Engineering Practices in High School Science.

The new Framework for K-12 Science Education (National Research Council [NRC], 2011) stresses teaching and learning of both scientific and engineering practices in order for students to understand and experience how scientist and engineers work; "how scientific knowledge is produced and how engineering solutions are developed" (p. 3-1). Crucially, the Framework conceptualizes these scientific and engineering practices as overlapping but distinct. Knowledge of both domains, it is argued, will help students to become critical consumers of scientific information, to understand the impact of scientists' and engineers' work on daily life and how this work addresses major societal challenges (e.g., treating of diseases, addressing climate change or generating sufficient and affordable energy), and lead them to consider a career in a STEM field.

This new focus on scientific practices accompanies a call for more sustained emphasis on inquiry and engineering design activities, particularly as part of a constructivist science curriculum centered on class activities done in small groups. Yet, if the Framework correctly posits fundamental differences in the professional practices of scientists compared to engineers, it follows that the nature of productive group work in high school science should vary depending on whether the task involves scientific inquiry or engineering design. The proposed study investigates this claim using a mixed methods approach, addressing the following questions: i) How does students' small group work differ when students are engaged in engineering design tasks versus scientific inquiry tasks? ii) Do students need a different mix of individual resources (cognitive, social and affective resources) in order to engage successfully in an engineering design task vs. a scientific inquiry task? iii) How do small groups collectively cope with the various cognitive, social and affective demands posed by inquiry and engineering design tasks? and iv) how does the quality of a group's joint management of this complex set of demands impact student learning in each type of task?

Scientific and Engineering Practices

The new Framework for K-12 Science Education (NRC, 2011) lists eight scientific and engineering practices that inquiry and engineering design tasks would ideally include. Our proposed study focuses on one key practice: Engaging in arguments from evidence. Figure 1 highlights the similarities and differences in this practice between science and engineering as stated in the Framework (NRC, 2011, p. 3-31). Although some of the processes in the two domains are similar, the goals of these processes are different. While scientists search for the best explanation for a natural phenomenon, engineers search for the best possible solution to a problem. Our proposed study will clarify whether the different goals of engagement demand a different mixture of individual resources and if so, which are more relevant for successful productive task completion and student learning and why.

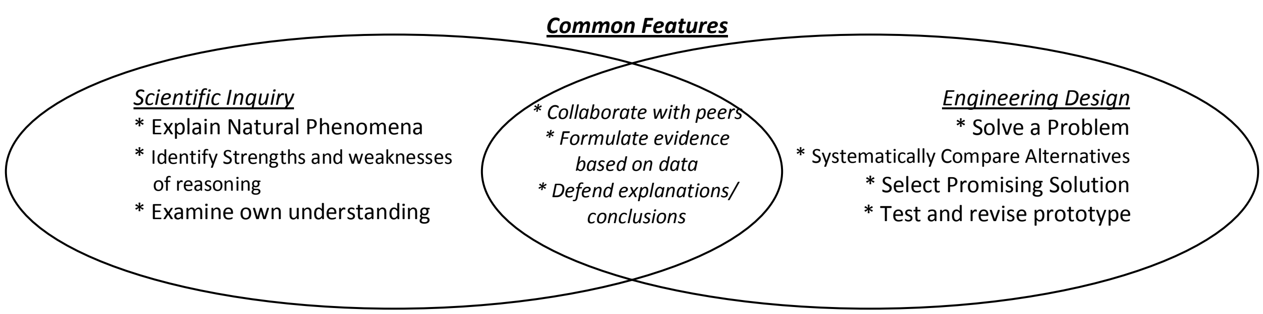

Figure 1: Distinguishing practices in science from those in engineering with respect to engaging in arguments from evidence; adapted from National Resource Council, 2011, p. 3-31.

Small Group Work in the Science Classroom

Classroom activities using an inquiry approach have often featured student work in small groups to reduce teacher-centeredness and reliance on prepackaged material and to maximize the autonomy of students (NRC, 1996). What is the evidence that "group work" works? In an overview of the research on small groups and learning in science, Bennett, Hogarth, Lubben, Campbell and Robinson (2010, p. 86) found that published studies reported positive links between small group discussion and subsequent student understanding, but they caution that authors of these studies were often "advocates" of the small group approach. These authors also note "[t]here is a growing body of evidence … that teachers lack skills and do not feel confident in small group discussion". (2010, p. 71) At the same time, Johnson and Johnson (2009, p. 375) state that one approach to small group work, cooperative learning, is now "a standard and widespread teaching procedure" across the world and "an educational psychology success story." Cooperative learning is based on a clear theoretical foundation (social interdependence theory), and their review of the research validates its positive effects on student achievement, interpersonal relationships and on psychological health across subjects, grades and educational settings.

Proponents claim that collaboration within a group leads to shared goals and values and develops collective and individual responsibility, stronger engagement, interest and motivation. Well-structured and managed group work allows students to develop communication skills by defending their work based on evidence, to learn from other groups, and to engage in problem solving that mirrors future work and life experiences. Asking questions, formulating hypotheses, articulating arguments, using models or analogies to explain concepts, conducting investigations, analyzing and evaluating data, proposing solutions, and creating various ways of communicating results are all aspects of cooperative learning. These processes are also features of both scientific and engineering practices. Small group activities may therefore support learning of such practices.

Scientific Inquiry and Engineering Design in Science Education

A large body of science education research (e.g., Smith, Maclin, Houghton, & Hennessey, 2000; Metz, 2004) as well as international, national, and state science education standards and frameworks (NRC, 2011; 2000; 1996;; Council of Ministers of Education, Canada, 1997) stress the importance of science teachers' use of inquiry teaching for effective and sustained student learning. Yet, even though inquiry is not consistently used in U.S. science classrooms (Davis, 2003; Roehrig & Luft 2004; Rowell, 2004) and more research is needed to guide teachers in managing small group work effectively for student learning, the new Framework spotlights a potentially very different set of pedagogical challenges in its new emphasis on engineering design. Note, the terms "scientific inquiry" and "inquiry teaching or task" refer in our proposed study to student engagement in scientific investigations that demand various skills, knowledge, and affects.

Other research has detailed challenges to inquiry teaching including teachers' lack of experience implementing inquiry activities (Smerdon, Burkam, & Lee, 1999; Luft, 2001); lack of skills to design inquiry projects properly (Quintana, Reiser, Davis, et al., 2004); or lack of motivation and peer and administrative support for the implementation (Wee, Shepardson, Fast, & Harbor, 2007). Yet, other studies pinpoint the kind of intellectual challenges inquiry teaching poses for students (Blumenfeld, Soloway, Marx, et al., 1991; Krajcik, Blumenfeld, Marx, et al., 1998) including student difficulties in designing and learning from authentic inquiry investigations (Fortus, Dershimer, Krajcik, et al., 2004). A common characteristic of all these studies is the focus on *cognitive* aspects of teaching and learning; the social and affective processes (e.g., Pintrich, Marx, & Boyle, 1993; Pintrich & Schrauben, 1992) are only superficially considered, if at all. Although the new Framework mentions the importance of student interest for student engagement and learning (NRC, 2011), it only addresses the cognitive aspect by stressing students' questions about natural phenomena (p. 2-4). Our proposed study systematically examines affective and micro-social dynamics of small group work that hinder or foster the use of inquiry and also engineering design methods, ultimately tracing the effect of these dynamics to subsequent achievement in science.

The complex and indeterminate nature of engineering design offers both great potential and challenge for teaching/learning. Engineering design tasks in particular provide a rich learning context addressing cognitive and affective aspects of learning because they "engage a natural desire to make something and they tap into the curiosity that comes from wanting to learn how things work" (Brophy et al., 2008). Realistic engineering design problems are open-ended and often ill-defined; the first (and often recurring) step for an engineer is to carefully define the problem. Overly simplified or canned design problems may miss the important problem definition phase, including the identification of a wide range of stakeholders, and articulation of governing constraints and technical requirements (Bucchiarelli, 1994). Engineering design is an iterative process, characterized by cycles of divergent and convergent thinking (concept generation and selection), design development, refinement, and evaluation (Dym et al., 2005). Providing students opportunities to iterate - to generate, test, and refine ideas in a cycle of continuous improvement - is essential for optimal design solutions; finding time for such iteration can be challenging in the classroom setting. Providing students with an outline of a problem retains the iterative process but allows for more time working on the other steps of the engineering design process. Additional important engineering design skills that can be addressed through classroom activities include decision-making based on data from analysis, design verification, and documentation; these, like iteration, require time. Not surprisingly, teacher preparation also impacts the effectiveness of engineering design learning, given that many K-12 teachers do not have extensive training in engineering design (Nadelson et al., 2012, Cejka & Rogers, 2005).

Additional challenges associated with teaching engineering design in K-12 settings stem from the fact that although scientific inquiry and engineering design inform each other, the two are truly distinct. One common implementation of engineering design in primary and secondary education is as a mechanism to reinforce scientific concepts; students pursue a design task that necessitates investigation into or application of a given science topic. Although the design task provides an interactive approach to learning, students often need assistance making the connections between the scientific knowledge and the design task at hand (Puntambekar & Kolodner, 2005; Roth, 2001; Crismond, 2001). Moreover, realistic design tasks usually incorporate multiple scientific topics/disciplines (Layton 1993), requiring that the design task be simplified or additional scaffolding be provided. Most importantly, however, through the implementation of the "design tasks to reinforce science" approach, students experience engineering design only as a tool to better understand science and not as a field unto itself (Leonard & Derry, 2011). These distinctive features of teaching and learning engineering design in school settings suggest that the optimal small group learning process may vary substantially from that involved in science inquiry group work.

One way to view the state of research regarding the challenges of inquiry and engineering design teaching and learning, at least as it pertains to collaboration in small groups, is to consider what group members must *collectively construct* as they work on a task. Most of the research has focused on the need for groups to construct a "joint problem-solving space" (Roschelle, 1992; Teasley & Roschelle, 1993) that involves coming to a collective cognitive understanding of the task. Barron (2003) usefully demonstrates that the nature of the cognitive challenges faced by sixth grade math groups does not, on its own, explain the variability of group outcomes. To address this gap, Barron proposes a "dual-space" model of collaboration in which groups must attend to and develop the "content space" (the problem to be solved) as well as the "relational space" (the challenges based on social interactions within the group). Both content and relational spaces may be deeply shaped by the language abilities of group members, and for English language learners, science may well represent a second foreign language (Rosebery & Warren, 2008).

A few studies support Barron's dual space model by highlighting the social dimension of small group work during inquiry by focusing on intra-group interaction and discourse patterns (Engle & Conant, 2002; Keys 1997; Jiménez-Aleixandre, Rodriguez, & Duschl, 2000). Such relational space work may benefit from the interpersonal social competency of group members (Ten Dam &Volman 2005), such as respect for others and insight into others' perspectives. Nonetheless, most of the research focuses only on interactions pertaining to the task. To fully understand group work, all interactions, task-related and non-task-related, must be considered.

In our proposed study, we posit that the role of the affective domain in group work is under-theorized, and so we will investigate how the demands of inquiry vs. engineering design tasks necessitate collective construction of a "triple problem-solving space" in which content, social/relational, and affective components are developed on a moment-by-moment basis. Affect, whether positive or negative, activated or not, has been shown to impact small group interaction in upper-elementary math tasks (Linnenbrink-Garcia, Rogat, & Koskey, 2011). Moreover, Cartney and Rouse (1996, p. 85), emphasize the importance of the "emotional life of the group" which is distinct from the affective states of individual members, thereby suggesting that the group itself must be understood as co-constructing affect, just as Barron (2003) takes the group as the unit of analysis from a relational standpoint.

If groups fail to manage any of these three aspects of the collective space, group collaboration will be unsuccessful, and learning – even from a well-designed task – is likely to be minimal. While our focus is on collective construction of the group's "triple space," we recognize that students bring various kinds of individual resources to the demands of cooperative inquiry and engineering design work, such as prior knowledge and skills, social competencies, and interest. Tracing the way these kinds of individual student resources influence group construction of the triple problem-solving space will allow us to take an analytical perspective to identify dynamics driving group work rather than the more typical descriptive approach of most research on small group work in an inquiry context (Bennett, et al. 2010, p. 91). We want to stress that our participating teachers will be trained in and use of specifically selected and/or modified inquiry as well as engineering design group tasks to control conditions across all tasks and classes.

Research questions

Our proposed study will focus on five research questions:

RQ1: How do levels of student *affective resources* (interest and motivation) affect the quality of group construction of the problem solving space (PSS) during inquiry vs. engineering design tasks?

RQ2: What types of social competencies help students manage their interactions in ways that support construction of a collective problem solving space (PSS) during inquiry vs. engineering design tasks? (*social resources*)

RQ3: How do students' scientific knowledge (task-specific prior knowledge) and skills (for developing arguments) affect the quality of group construction of the problem-solving space (PSS) during inquiry vs. engineering design tasks? (*cognitive resources*)

RQ4: What cognitive, social and affective demands do students face when working in small groups on inquiry vs. engineering design tasks, and in what ways do students collectively cope with them?

RQ5: How does the quality of group construction of the problem-solving space affect student achievement?

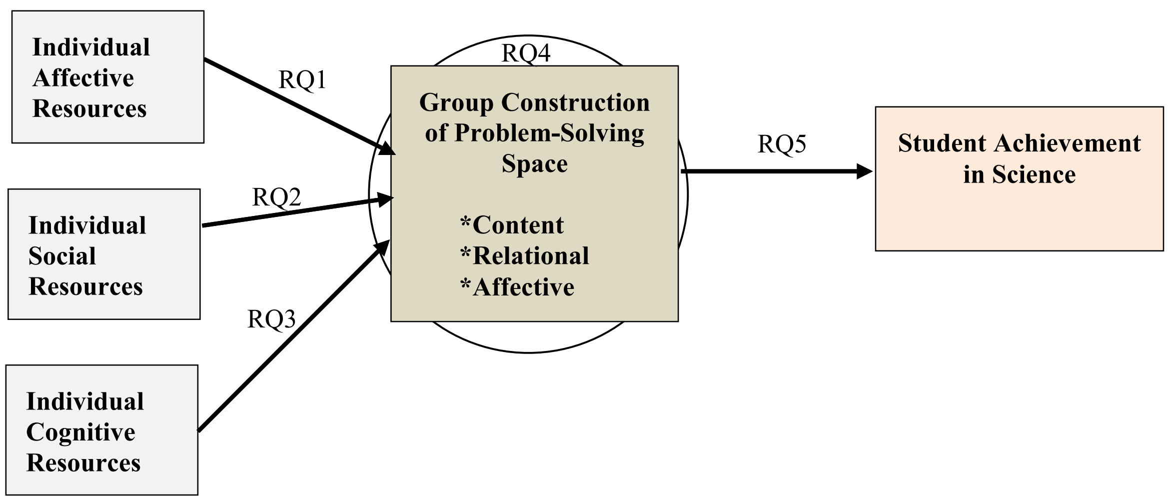

Figure 2: Individual resources for group inquiry work, the triple problem-solving space, and science learning

Social-Psychological Demands of Inquiry and Engineering Design: Key Variables

Figure 2 outlines the major constructs of our project, which highlights the social-psychological demands of small group-based inquiry and engineering design while acknowledging the importance of content demands. Levels of individual students' affective, social and cognitive resources can be brought to bear on co-construction of an effective problem-solving space that has collective components that we believe work in concert: content, relational, and affective. In turn, the degree to which the group successfully constructs this problem-solving space influences student achievement in science. In this section, we describe in more detail the key variables in this model.

Individual Affective Resources: Interest and Motivation

The role of interest. Interest is an individual psychological state and an emotion and plays a key role in students' cognitive engagement and learning (Eccles, Wigfield & Schiefele, 1998; Ainley, Hidi & Berndorff, 2002; Renninger, 2000). Researchers distinguish between two main types of interest: *individual interest* and *situational interest*. We will consider both types of interest and investigate how they influence students' interaction with the different tasks during small group activity. *Individual interest* is defined as a relatively enduring predisposition to reengage in particular domains such as school subjects, and activities such as sport or music (Ainley et al., 2002).

Learners expressing individual interest reengage independently in content, have curiosity, self-regulate easily to reframe questions and seek answers, actively seek feedback, recognize other's contributions to the discipline, and express positive feelings towards the content (Hidi & Renninger, 2006). *Situational interest* is defined as a short term psychological state and emotion that facilitates students' motivation to act, to pay more attention, and persist at a task, or to enhance further interest in the content, which then in turn may result in increasing interest over a longer period of time (Renninger, 2000). Thus, certain features of a learning situation (e.g., working in small groups) or specific tasks (e.g., inquiry and engineering design tasks) may arouse a student's interest regardless of personal preferences (Krapp, 2002) or individual interest in a science discipline in general. When situational interest is triggered, students demonstrate more focused attention to a task (Hidi, 2001; McDaniel et al., 2000), better integrate new information with prior knowledge (Miller & Kintsch, 1980), and develop content knowledge and a sense of value of the content (Hidi & Renninger, 2006).

Interest researchers have found that both situational interest and individual interest are motivating for students (Hidi & Renninger, 2006). A prior experience with a topic or familiarity with inquiry tasks may result in students becoming interested in engineering design tasks, although they may never have worked at such tasks (Renninger & Shumar, 2002, 2004). If students see the relevance of asking questions and developing arguments in order to defend their design plans during engineering design tasks, then these students can be said to have an individual interest in such tasks. Students who hold individual interest express intrinsic motivation (Deci & Ryan, 1985) to understand the task at hand combined with a surge of excitement for adding to their knowledge (Hidi & Renninger, 2006). A widely-respected theory linking individual interest, motivational influences, and achievement is Self-Determination Theory (Deci & Ryan, 1985, 2000; Deci, Vallerand, Pelletier & Ryan, 1991).

Self-Determination Theory (SDT). The foundation of Deci and Ryan's theory (1985, 1991, 2000) is that individuals have three basic psychological needs: *competence*, *autonomy*, and *relatedness*. The need for competence incorporates a need to experience personal control in predictable ways in order to master challenges in the environment. The need for autonomy includes the freedom to regulate one's behavior, and relatedness pertains to the need for positive interpersonal relationships – to care for others and experience others' care. In learning environments, when students' basic needs for competence, autonomy, and relatedness are met, their learning behaviors are *intrinsically* motivated. Deci and colleagues state that for students to become highly engaged in and intrinsically motivated for school learning, academic environments must connect with and facilitate students' needs for developing competence through perceptions of autonomy (Deci, Spiegel, Ryan, Koester & Kauffman, 1982; Rigby, Deci, Patrick & Ryan, 1992). For example, in a case study of an 11th-grade general science course, Nieswandt and Shanahan (2008) found a strong relationship between the teacher's pedagogical approach (focusing on the connections of science to everyday life using guided inquiry) and students' shift from extrinsic motivation (e.g., focusing on grades) to intrinsic motivation. Other research suggests that when science teachers give students opportunities to learn autonomously (Akey, 2006; Grolnick & Ryan, 1987; Hardre & Reeve, 2003), their motivation for learning will more likely be experienced as an internal, student-owned initiative (i.e., self-determined motivation) instead of an external, coercive imperative (Hidi & Harackiewicz, 2000; Reeve, 1996). The relationship between SDT and situational interest has also been demonstrated. Boekaertz and Minnaert (2006) and Minnaert, Boekaertz, and DeBrabander (2007) found that vocational students' feeling of competence during early stages of group work in project-based learning predicted situational interest and students' need for autonomy predicted situational interest during execution and closing of the project.

The range of studies on interest and SDT suggests not only that individual affective resources influence small group learning behavior during inquiry and engineering design tasks (see RQ1), but also that characteristics of the tasks influence individual affective resources. Our set of inquiry and engineering design tasks will reflect this by allowing student autonomy (e.g., with respect to experimental design, and data collection and interpretation) and at the same time provide elements of scaffolding to support students' perception of competence.

Individual Social Resources: Interpersonal Social Competence

We hypothesize that the degree of social competence of individual group members is likely to influence the collectively constructed group work. While an individual's social development is essential for adulthood and citizenship, Zwaans, van der Veen, Volman & ten Dam (2008, p. 2119) point out that social competence, the "totality of knowledge, skills, and attributes which students need to fulfill developmental tasks, such as making friends or cooperation with peers" is also a central educational goal. Zwaans, et al. (2008) and Zwaans, ten Dam and Volman (2006) operationalize social competence as having three components, intrapersonal, interpersonal and societal. As a resource available for small group work in an inquiry and engineering design context, the interpersonal aspect of social competency (i.e., having confidence and respect for other people, applying insight into the wishes and motives of others) is most germane. Lane, Pierson and Givner (2004, p. 182) also support the notion that social competence is an educational goal in itself, particularly in the areas of self-control (e.g., receives criticism well, responds appropriately to teasing) and cooperation (e.g., ignores peer distractions when doing class work). However, neither line of research has evaluated whether high levels of social competence are associated with more effective group learning strategies or subsequent higher academic achievement on the part of individual students. In the proposed study, RQ 2 will address this issue, by considering whether the overall level of social resources in the form of interpersonal social competency brought to the group by individual members is associated with group learning behavior.

Individual Cognitive Resources: Prior Science Knowledge and Inquiry and Engineering Design Skills

The importance of prior knowledge for learning science concepts is well-established in science education research that builds on constructivist learning theories (Dochy, Segers, & Buehl, 1999; Crippen & Brooks, 2009; Serry, 2009). Prior knowledge of a topic may also have a positive effect on interest (Schraw & Lehman, 2001; Alexander, Jetton, & Kulikowich, 1995; Schiefele, 1999). Consequently, we will assess student prior knowledge that is closely related to the particular science content being studied in the classroom and that will be necessary for students to engage in small group inquiry and engineering design tasks. While our students will be given a question/problem, they need to decide in their group how to best approach the problem, what type of investigations to design and conduct and what data to collect. All these phases demand discussions among group members and articulating of arguments pro or con a particular approach.

A unique feature of our analysis is that for each of the three types of individual resources described above, we also will consider whether the *distribution* of resources influences group learning behavior. For example, it may be sufficient for effective group functioning to have only one member with exceptionally strong interpersonal social competence as opposed to a more equitable distribution of the stock of social resources in the group.

Group Construction of Triple Problem-Solving Space (PSS)

Barron (2003) urges researchers of collaborative learning to preserve the primacy of the group as a unit of analysis, cautioning that "[q]uantitative studies of collaboration frequently focus on the measurement of variables at the level of the individual and their effect on collaborative outcomes." After considering the individual resources students bring to the table as they begin small group work, we will shift into observing how the group as a social unit functions when faced with an inquiry or engineering design activity. The three aspects of the collectively constructed problem solving space – the content, social/relational and affective – overlap and influence the development of each other; however, we expect these components to be positively correlated, that is, successful group work will require all three components. Prior research allows us to characterize the cardinal aspects of each.

Content Space. There is a vast body of research that examines how type, quality, and frequency of interactions within groups of students support collective access to the science content. Research in "knowledge building" processes (Woodruff & Meyer, 1997; Micari, Pazos, Streitweiser, & Light, 2010) and argumentation (Duschl & Osborne, 2002) takes the content of the science problem as the focal point of interaction. Roschelle (1992) and Teasley and Roschelle (1993) highlight the strictly cognitive aspect of the task in their conception of a collectively constructed, uni-dimensional "problem space." Other studies have sought to specify the necessary steps for adequate reasoning to develop during group discussions (Keys, 1997). Inquiry and engineering design learning requires particular behaviors and skills (e.g., collaboration with peers, deep thinking, making connections between new science concepts and everyday life phenomena; Blumenfeld et al., 1991; Krajcik et al., 1998; Roth, 1995), which as Lee (2002) points out can be intimidating for students, particularly for low performing students. A three-part measure assessing the quality of learning-oriented interactions in problem-based learning correlated strongly with subjective reports of group productivity (Visschers-Pleijers, et al. 2005), while Veermans and Järvelä (2004) found distinct coping strategies in group learning contexts for "learning-focused" and "non-learning focused" students. Learning-focused students' coping strategies were progressive and very task-oriented. Students worked in a self-regulative manner, asked very specific questions relating to the task, knew how to proceed, and could ask for specific help. In contrast, for "non-learning focused" students, coping strategies were regressive and less task-oriented. They had difficulties to find and persist with a research question and sometimes exhibited work-avoidance behavior. These students also had difficulty externalizing their own thinking processes, challenging their ability to ask for specific help, and responded negatively to the teacher's support, tending to devalue the task. Building on these results, our proposed study will explore whether students demonstrate such collective coping strategies during inquiry small group work, whether they can apply them to engineering design tasks, and how the different tasks affect co-construction of the problem-solving space.

Relational Space. A number of studies have considered group composition as a factor influencing interactional patterns, including status markers such as gender and race (Tolmie & Howe, 1993; Parsons, Tran, & Gomillion, 2008). Following Cohen and colleagues work in complex instruction (Cohen 1994a, 1994b; Cohen & Lotan, 1995), Kurth (2002) found that teacher assignment of specific roles to group members tended to have a positive effect on the quality of group discussion in science. Other research has investigated the emergence of relatively stable role structure during the course of the group's work, such as leadership/facilitator roles and division of labor (Richmond & Striley, 1996; Micari, et al., 2010). Notable here for guidance on both quantitative and qualitative ways to investigate emergent group structure is Hogan's (1999) elaboration of 8 "sociocognitive roles" that may develop independently of roles formally assigned by the teacher, such as "promoter of reflection" and "mediator of social interaction," as well as counterproductive roles such as "promoter of acrimony" and "reticent participant."

Building on Engle and Conant's (2002) work that details some of the social, rather than content-based, interactions and structures that sustained group engagement in an elementary science task, Barron (2003) found that success on a group math task was predicated on how peers *responded* to proposed ideas, not the number of ideas. The social cohesion of a group seems to play a role in group efficacy, allowing group diversity to have benefits (Sargent & Sue-Chang, 2001). Thus, in Barron's view of the relational space, all interactions in the group are seen as potential opportunities or challenges for moving academic thinking forward. Related research suggests a strong tendency for small groups working on inquiry tasks to avoid the intellectual task-related conflict that promotes deeper learning (Tolmie & Howe 1993; Jiménez-Aleixandre, et al. 2000). Oppositional cultures also may develop in small groups, as they do in student-centered classrooms (McFarland, 2001, 2004). Functional relational spaces can be characterized by positive interactions that support, rather than undermine, broad participation, and by the absence of "social loafing," i.e., disengagement due to the nature of the collective work process (Linnenbrink-Garcia, et al. 2011). These studies highlight the need to consider the relational forces that shape the final group work product, as opposed to looking only at the demands of the task content and subsequent collective cognitive processing.

Affective Space. As introduced previously, consideration of the affective space during inquiry and engineering design group work promises to add a new layer of complexity to our understanding of small group process, in particular, as seen in connection to the content and relational spaces. Research on first-year teacher education students by Järvenoja & Järvelä (2009) found variation in the socio-emotional demands of group work, but that research participants used both self- and shared emotional regulation in response, and that "emotions can be regulated collaboratively as well as individually." Cartney and Rouse (1996) also find strong emotional effects on undergraduate group members that are results of group process. A key set of shared beliefs that impact group functioning and learning is a sense of psychological safety, the notion that the group is a safe space for interpersonal risk taking (Edmondson, 1999). Conceptualizing affect in terms of valence (positive or negative) and activation (high or low), Linnenbrink-Garcia, Rogat and Koskey (2011) found links between affect and quality of group interaction in the form of "socio-behavioral engagement" (p. 13). Assuming that activation is relatively constant during the small group task, affect valence toward the group can be validly assessed using a "feeling thermometer" (Alwin, 1997). In sum, these recent research results underscore our decision to view affect as not only an individual resource but also a dynamic characteristic of the group itself.

Student Achievement in Science

Ultimately, a major aim of understanding the social, psychological and cognitive demands of small group work is to improve meaningful learning in science. In their systematic review of the literature on small group discussion in science, Bennett, et al. (2010, p. 86) found that methodologically strong studies reported positive but conditional links between small group discussion and subsequent student understanding. Tolmie and Howe (1993) conclude that small group discussion most likely promotes better learning when conflict about the problem engenders diversity in predictions and explanations within the group, although DeDreu and Weingart's meta-analysis (2003) finds mixed support regarding the impact of task-related conflict, while relationship conflict within groups had negative impacts on group outcomes.

Methodology

Research Design

Our proposed study is divided into four phases over three years. Each phase has distinct tasks as seen in Figure 3, which shows the proposed timeline.

Phase	Task	Year 1	Year 2	Year 3
1	Identify inquiry and engineering design tasks from existing tasks			
	Pilot tasks in one class			
	Revise tasks based on pilot			
	Provide professional development for teachers on implementing tasks			
2	Implement inquiry and engineering design tasks each in series of three			
	Collect qualitative and quantitative data in 12 classes			
3	Analyze data from Phase 2			
	Conduct teacher focus group			
	Disseminate preliminary results (i.e., conferences, publications)			
4	Disseminate final results			
	Present mini-conference with science teachers and pre-service science teachers – focus on implications for teaching			

Figure 3: Timeline and phases of project and major activities in each phase

The study will utilize a "parallel mixed analysis" (Tashakkori & Teddlie, 1998, p. 128), piloting some inquiry and engineering design tasks in *phase 1* and collecting and analyzing a combination of qualitative and quantitative data in *phase 2*. Data collection will include self-reports and process-oriented data (group observations and focus group interviews). We will administer an ***Individual Resources Questionnaire*** addressing individual affective, social and cognitive resources to all participating high school science students (*N*=230 across 11 to 12 classes) using Survey Monkey© or as a paper-pencil survey depending on teachers' preference prior to the first set of small group observations (3 inquiry tasks) and prior to the second set of small group observations (3 engineering design tasks). A paper-and-pencil ***Group Learning Behavior Questionnaire*** (group construction of the problem-solving space) will be administered to all students after each observation (6 observations total per class). Two student groups per class will be videotaped for process-oriented data collection during the six group tasks. Field notes will be taken during the group activities including how the teacher introduced the task; copies of lesson plans, handouts and any other written materials distributed for the task will be collected. Two focus group interviews will be conducted and videotaped with each videotaped student group to draw out student perspectives on how their individual affective, social and cognitive resources factored into their collective work as a group. The first focus group interview will be conducted after the final inquiry task is completed, and the second focus group interview after the last engineering design task. Following implementation of all tasks, a teacher focus group will be conducted emphasizing perceptions of the tasks and student group dynamics (*phase 3*). The focus group will be videotaped.

Participants

The proposed study will recruit high school science students in Western Massachusetts (*N*=230) whose teachers volunteered to participate, representing diverse school contexts in terms of race/ethnicity, socioeconomic status and urbanicity. Teachers who have indicated interest in the project include those from high and middle SES, suburban districts with majority Caucasian students as well as rural, low SES districts. Urban, low SES districts likely to be included in the study are majority Hispanic and mixed Hispanic/African American.

To determine the number of individual subjects needed to achieve a power of .80 for the models we describe in the data analysis section, we conducted a power analysis with the utility developed by Preacher and Coffman (2006) that uses the R program and is available at www.quantpsy.org. A minimum sample size of 104 is necessary to achieve a power of .80 when the alpha level is .05, for a close-fit test of null hypothesis for the fit index RMSEA (Root Mean Square Error Approximation) equal to .05, and the alternative null hypothesis for RMSEA is .08, and

230 degrees of freedom[1]. In order to achieve a sample size of at least 208 students over the course of the school year (allowing for split-half validation of instruments), we will aim to recruit 230 students (or approximately 11-12 classes at 20 students per class).

Sampling and Human Subject Consent Procedure

After IRB approval has been given (UMass Amherst and various school districts), invitation and consent letters explaining the study, the nature of teacher and student involvement, and the process of securing consent will be sent by email to all teachers who had shown initial interest. After teachers consent to participation, information and consent letters for parents and students will be distributed during science class time; only students whose parents/guardians consent to their child's participation will receive questionnaires, and be interviewed and observed. During administration of surveys students not participating in the study will receive content-related seatwork or work on homework assignments. Selection of groups of 4-5 students for videotaped observations will be based on whether all members of a group have parental/guardian consent. Of these groups, two groups per class will be randomly selected for videotaped observations and focus group interview.

Inquiry and Engineering Design Tasks

In collaboration with participating high school science teachers ($n = 4$), we will in *phase 1* identify a series of scientific inquiry tasks and a series of engineering design tasks from tasks available on the Internet or in major textbooks. Tasks will be modified if necessary, to align with Massachusetts' high school science curriculum and to reflect a common format: Question/problem given; open (student-designed) procedure and solution; selection of materials given; and if necessary prompts for different steps given (e.g., for note taking/drawings of experimental design or engineering design, for argument development). Table 1 shows brief sketches of possible inquiry and engineering design tasks. Additionally, we will work with and prepare teachers on how best to implement these tasks based on cooperative learning, inquiry and engineering design principles, and to ensure similar conditions to allow comparison across classes.

Table 1: Example of an inquiry and engineering design task for groups of 4 students

Inquiry task	*Engineering design task*
For your next party you are planning to make Rainbow Soda cocktails from a variety of soda "pops" and some energy drinks. But how can you layer 6 different kinds of soda pops and energy drink so that the different sodas will not mix? Does the type of glass influence the layering? In your group, discuss possible procedures to answer the questions using your knowledge of the principles of liquids that we learned in class last week. Identify strengths and weaknesses of the different procedures that you discuss and follow procedures that are likely to help you understand the phenomenon of layering liquids, collecting data to support your argument. Use the materials provided. Be prepared to defend your procedures and show your results to your peers in class.	Your local university's Engineers Without Borders program has asked you to help on a sanitation project in Rwanda, Africa. The project aims to improve the health of children as young as 4, and as old as 20 who live in an orphanage in the community of Mugonero. According to the World Health Organization, about 38 percent of the world lacks access to improved sanitation, which makes it unlikely that people wash their hands after bathroom use or before meals. Research has shown that washing hands with soap and water has been shown to reduce the risk of diarrheal disease by almost half. Thus, many people in underdeveloped countries suffer from diseases that could be prevented if they had a way to wash their hands regularly. To solve this problem, we ask you to design a prototype of a hand washing station that enables hand washing without plumbing and with a fraction of the water used by a conventional/modern faucet with plumbing. In your group, discuss possible designs; select the best solution based on the given criteria, test and if necessary revise your prototype. Use the materials provided. Be prepared to defend your prototype to your peers in class.

[1] An analogous power analysis conducted using the online program developed by Soper (2010) suggested a minimum sample size of 118 would yield power of .80 to detect medium effect sizes (f^2=.15) for a multiple regression with 10 predictor variables. Since this is an exploratory study, we seek sufficient power to make statistical inferences about individuals, but not groups, which would necessitate a much larger sample.

Adopted from: Minnesota Science Teachers Education Project, 2012. Retrieved July 12, 2012 from http://serc.carleton.edu/sp/mnstep/activities/20127.html

Adopted from: American Society for Engineering Education, 2012. Retrieved June 29, 2012 from teachers.egfi-k12.org/tippy-tap-hand-washer/

Instruments

Almost all quantitative instruments have been used in previous studies but not necessarily with similar populations as the one in this study, which may necessitate modification of some items. Table 2 provides an overview of all quantitative instruments.

In order to answer RQ1 (effect of student *affective resources* on group construction of the problem solving space), we will use quantitative and qualitative methods. *Students' individual interest* will be assessed with the Class-Specific Interest and Domain-Specific Interest scales (Marsh, Köller, Trautwein, Lüdtke, & Baumert, 2005). Items will be modified to reflect the specific science content in the participating classes. Because no measure exists for students' *situational interest* of specific tasks, we will develop a measure following Renninger's and Su's (2012) summary of learner characteristics and task environment during development of situational interest. *Students' motivation* is assessed with three subscales (perceived competence, perceived task choice and relatedness to group) of the Intrinsic Motivation Inventory (IMI; McAuley, Duncan, & Tammen, 1987), which assesses participants' subjective experiences in various contexts.

The three dimensions of the *Group Problem-Solving Space* will be assessed separately. The level of co-construction of the *cognitive space* will be measured with the Group Interaction Questionnaire (Visschers-Pleijers, et al., 2005). Co-construction of the *relational space* will be assessed using Sargent & Sue-Chang's (2001) Social Cohesion scale and the Social Loafing and Positive Group Interaction scales (Linnenbrink-Garcia, et al. 2011). The *affective* component of the problem-solving space will be measured using Edmondson's (1999) Psychological Safety scale and the Group Feeling Thermometer (Wilcox, Sigelman & Cook, 1987; Alwin 1997). Group means will be calculated to quantitatively characterize each group's level of co-construction. It is expected that the means of scales across all three aspects of the problem-solving space will be positively correlated; i.e., groups with strong co-construction of a cognitive space will tend to have strong relational and affective spaces as well. We hypothesize that individual interest, situational interest and motivation will be positively associated with group construction of the triple space.

We will address RQ2 (effect of student *social resources* on group construction of the problem solving space*)* with two scales measuring the individual student's interpersonal social competence. The first scale, the Objectives of Social Competence Scale (OSCS; ten Dam & Volman, 2007) addresses interpersonal skills necessary for effective interactions and will be modified based on the original Dutch version. Our second scale, the Social Skills Improvement System Rating Scale (SSISRS; Gresham & Elliott, 1990) focuses on interactions skills such as self-control, co-operation, and assertion. We expect that both of these scales will be positively associated with *Group Construction of Problem-Solving Space*, as described above.

Our third research question (RQ3) refers to the effect of student *cognitive resources* on group construction of the problem solving space. We will measure student *task-specific prior knowledge* and s*kills for developing arguments*. In order to assess knowledge and skills*,* in collaboration with the teachers we will develop four content related questions that also demand students to engage in arguments. These questions will use a format familiar to students in each class. To account for high variability across participating classes with respect to science subject and the specific content within the science subject, we will adjust by taking z-scores around the class mean. We hypothesize that cognitive resources, both prior content knowledge and level of skills for engaging in arguments will be positively related to group construction of the problem-solving space.

RQ4 focuses descriptively on the dynamics within the group (*which cognitive, social and affective demands are present during inquiry vs. engineering design group tasks, and how do students collectively cope with them).* We will first appraise patterns in the quantitative measures of the problem-solving space to understand the balance between the demands of each component of the triple space. Second, we will code videotaped group *observations* (2 groups per class) focusing on students' engagement in arguments during the six inquiry and engineering design tasks and how these interactions construct the problem-solving space. Third, after both the last observed inquiry group work and the last observed engineering design group work we will conduct *student focus group interviews* (*N*=20 to 24) on students' perceptions of how the group worked, individual contributions during group work and group task management issues within the triple problem-solving space. Fourth, after all group tasks are finished we will conduct a *teacher focus group* centering on teachers' perceptions of students' engagement during group work, and possible differences in student engagement between inquiry and engineering design tasks.

Table 2: Overview of quantitative instruments (including Cronbach's Alphas and sample items)

Questionnaire		Instrument (Cronbach's Alphas if published)	Description or Sample Items
Individual Resources Questionnaire	Cognitive Resources	Task-specific prior knowledge (4 items, to be developed by teachers) Skills for inquiry- and engineering design-based tasks (5 items)	Science subject-specific and science content-specific multiple choice or short answer Selected items focusing on Scientific Inquiry (SI; from MOSART test, PISA and TIMSS)
Individual Resources Questionnaire	Affective Resources	Class-Specific Interest (Marsh, et al. 2005) (4 items, α>.8) Domain-Specific Interest (Marsh, et al. 2005) (5 items, α>.8 Individual task-specific Interest (to be developed)	• I enjoy working on engineering design problems. • How important is it for you to learn a lot in science classes? • How much to you look forward to science class?
Individual Resources Questionnaire	Affective Resources	Intrinsic Motivation Inventory (IMI; McAuley, Duncan, & Tammen, 1987), total of 21 items Subscales: Perceived competence (α≥.6)* Perceived choice (α≥.6)* Relatedness (α≥.6)* * Cronbach's alphas are reported as general criteria for inclusion of items	• I think I am pretty good at doing this task. • I believe I had some choice about doing this task. • I felt like I could really trust my science teacher.
Individual Resources Questionnaire	Social Resources	Social Skills Improvement System Rating Scale (based on Gresham & Elliott, 1990) (37 items, α for total =.86) Subscales: (α's from DiPerna & Volpe 2005, p. 349-350) Self-Control (α=.67) Cooperation (α=.68) Assertion (α=.56)	• Receives criticism well • Responds appropriately to peer pressure • Ignores peer distractions • Questions rules that may be unfair
Individual Resources Questionnaire	Social Resources	Objectives of Social Competence -- Interpersonal Scale (Zwaans, et al., 2006; Zwaans, et al. 2008), 13 items (α in original not reported)	• Has confidence in other people • Has respect for other people • Willing to enter into dialogue • Insight into the wishes and motives of other people
Group Learning Behavior Questionnaire (Construction of Problem-Solving Space)	Content Space	Group Interaction Questionnaire (Visschers-Pleijers, et al., 2005) Subscales: Handling Conflict (3 items, α=.63) Cumulative Reasoning (4 items, α=.70) Exploratory Questions (4 items, α=.56)	• One or more group members was/were contradicted by the others. • We drew conclusions from the information that was discussed in the group. • One explanation did not suffice for the group members; alternative explanations were also mentioned.
Group Learning Behavior Questionnaire (Construction of Problem-Solving Space)	Relational Space	Social Cohesion (Sargent & Sue-Chang, 2001; 4 items, α=.91) Social Loafing (Linnenbrink-Garcia, et al., 2011; 4 items, α=.71) Positive Group Interaction Loafing (Linnenbrink-Garcia, et al., 2011; 4 items, α=.83)	• I get along with members of my group. • I stopped listening to what others in my group were saying. • My group cared about what each person thought.
Group Learning Behavior Questionnaire (Construction of Problem-Solving Space)	Affective Space	Psychological Safety (Edmondson, 1999; 7 items, α=.82) Group Feeling Thermometer (Wilcox, et al., 1989; 1 item)	• It is safe to take a risk on this team. • On a scale of 0-100, how did you feel about your group today?

RQ5 (*How does the quality of group learning behavior affect student achievement?)* is addressed with a final ***Science Content and Skills Test*** four teacher-developed science content-related items and five items reflecting inquiry and engineering design principles, particularly engaging in arguments, and drawn from MOSART tests (http://www.cfa.harvard.edu/smgphp/ mosart/ aboutmosart_2.html), which are comprised of multiple-choice items linked to the K–12 physical science and earth science content, and K–8 life science content in the NRC National Science Education Standards; or from tests such as PISA (http://www.oecd.org/statisticsdata/ 0,3381,en_2649_35845621_1_119656_1_1_1,00.html) and TIMSS (http://timss.bc.edu/TIMSS2007/items.html). This test will be administered to all participating students after the last group observation as a paper-and-pencil test.

Timeline of data collection and analysis

Phase 1 (Jan. 1, 2013 to Fall 2013) will comprise selection of inquiry- and engineering design-based tasks and piloting of some of these tasks with one teacher followed by task revision, if necessary. Quantitative and qualitative data will be collected during the 2013/2014 school year (*phase 2* – classroom based, and beginning of *phase 3* – teacher focused). Data analysis (throughout *phase 3*; see section below) and dissemination of results (*phase 4*; see section below) will follow during 2014 and 2015. See Figure 3 for overview and Table 3 on data collection plan.

Table 3: Timeline for Data Collection During Phase 2

Time	Classroom Activities	Quantitative Data Collected	Qualitative Data Collected
Sept 2013		Indiv. Resources Questionnaire 1	
	Inquiry Task 1		Videotaping, Field Notes
		Group Learning Behavior Q 1	
Oct. 2013	Inquiry Task 2		Videotaping, Field Notes
		Group Learning Behavior Q 2	
Nov. 2013	Inquiry Task 3		Videotaping, Field Notes
		Group Learning Behavior Q 3	Student Focus Groups
		Indiv. Resources Questionnaire 2	
Jan. 2014	Engineering Task 1		Videotaping, Field Notes
		Group Learning Behavior Q 4	
Feb. 2014	Engineering Task 2		Videotaping, Field Notes
		Group Learning Behavior Q 1	
Mar. 2014	Engineering Task 3		Videotaping, Field Notes
		Group Learning Behavior Q 1	Student, Teacher Focus Groups
		Science Content/Skills Test	

Data analysis

Quantitative analyses during *phase 3* will be conducted on data gathered from the Individual Resources Questionnaire, Group Learning Behavior Questionnaires, and final Science Content/Skills Test, answering the above research questions by evaluating how student affective, social and cognitive resources affect the quality of student group work (RQ1, 2 and 3) and in turn, how quality of group work impacts student learning (RQ5). Preliminary data cleaning and descriptive statistics will be conducted using SPSS, with initial hypothesis testing completed using hierarchical linear modeling (HLM), since measures are collected at two levels of analysis. Final estimation will be completed using more robust two-level structural equation models in AMOS. Qualitative data collected during student group work observations and focus group interviews addressing RQ4 will be analyzed using Chi's (1997) eight-step protocol, which includes revealing major themes, organizing major themes, and listing data to illustrate patterns. Using a mixed methods approach, the analysis of these sources of data will follow themes isolated through the analysis of quantitative measures (Tashakkori & Teddlie, 1998), as well as themes highlighted in prior qualitative research on group work, i.e., the role of task and relationship conflict; emergence of sociocognitive roles; responses to correct proposals; construction of opposition to emerging authority figures in the group; possible broadening-and-building of affect in the group, influence of concurrent processes of English language acquisition, and students' ability to engage in arguments (e.g., articulating and answering product-related questions, articulating an argument; using evidence to support an argument). Using NVivo software, themes generated through this procedure will be quantified. NVivo allows both quantitative and qualitative comparisons based on the frequency of themes. Thus, qualitative and quantitative data collected through the interviews and videotaped group work observations will be triangulated with quantitative data from the surveys in order to seek convergence of results across both methods, with the multiple data sources complementing each other in order for one method to explicate the results of the other (Greene, Caracelli, & Graham, 1989).

Project Evaluation

The advisory board for our study will conduct the project evaluation, which is closely coordinated with, but distinct from the research questions of our study. In accordance with best practice, the evaluation will use qualitative and quantitative methods to obtain multiple perspectives on the effectiveness of the project throughout the funding period. During the first two years of the project, formative evaluation will provide feedback on research design feasibility, ethics and implementation, with appropriate changes made as needed. Summative evaluation at the end of the project will also suggest future research questions. Specifically, the focus of the formative evaluation will be on monitoring (i) how challenges encountered during the selection and piloting of inquiry and engineering design tasks and teacher training on implementation of tasks were resolved (*phase 1;* process evaluation); (ii) the effectiveness of the research design for answering the research questions (*phase 1 and 2*; process evaluation), and (iii) teachers' implementation of the tasks as intended (*phase 2*; implementation evaluation). The summative evaluation will also investigate (iv) whether data collection and analysis have fully addressed research questions (*phase 4*; outcome evaluation). Evaluation data will be collected by one of the advisory board members (John Kudukey) through semi-structured interviews with teachers (*phase 1)*; a teacher focus group and a teacher questionnaire after the implementation of all tasks (*phase 2*); semi-structured interviews with PI, Co-PI and Engineering Consultant (*phase 1 and 2*); and review of preliminary and final project results after data analysis (*phase 3 and 4*). Feedback to the research team will be given during annual advisory board meeting and phone conferences in between annual advisory board meetings.

Broader Impact and Intellectual Merit

Our proposed study addresses several puzzles facing science education in theory and practice. First, the study promises to break new ground in the research community's understanding of small group work. The literature is equivocal on how best to implement small group work in a school science inquiry context, and virtually non-existent when it comes to group work on engineering design tasks. The project fully integrates the affective as well as social components with the more thoroughly studied cognitive component of group dynamics, as represented by our concept of the co-construction of the triple problem-solving space. It draws substantially from and integrates social psychological and organizational theory literature that is not well known in the science education community.

Second, the study fills a gap in the literature identified by Bennett, et al. (2010) regarding small group learning in science by taking an *analytical* view of small group work, rather than merely descriptive, empirically tracing the impact of the specific individual resources to the co-construction of an effective problem-solving space and assessing subsequent effects on student learning. Methodologically, as well, the study shores up some weakness in the research in this area by using a mixed methods approach on a relatively large number of classrooms in order to begin to generalize beyond the research base that has relied heavily on qualitative case studies (Bennett, et al. 2010).

This naturalistic investigation in actual classrooms will have particularly practical value by developing new forms of science teacher professional development (PD) about how to scaffold students' cognitive, affective and social resources through appropriate instructional designs. Results also promise to flesh out ways to facilitate students' productive participation in small groups while at the same time "providing opportunities for students to negotiate ways of participating that are meaningful to who they are and want to become" (Hand, 2010, p. 126). The President's Council of Advisors on Science and Technology (2010) recently concluded that STEM education must both prepare and inspire all students. However, inspiring students to learn and to pursue STEM careers will quite likely fail, if their desires, interests, and competencies are not explicitly taken into account when creating and managing group learning opportunities. The project resonates with The Committee on Defining Deeper Learning and 21st Century Skills (NRC, 2012, p. Sum-3) call for domains of competence reflecting 21st century skills: cognitive (e.g., critical thinking, information literacy, reasoning and argumentation, and innovation); intrapersonal (e.g., flexibility, initiative, appreciation for diversity, and metacognition); and interpersonal (e.g., communication, collaboration, responsibility, and conflict resolution). Quality group work in science focusing on scientific and engineering practices will promote the learning and practice of these 21st century skills.

Finally, this project is likely to be fruitful in generating future research to foster quality science teaching, such as investigating specific strategies about how to construct groups to address students' socio-psychological weaknesses to support effective small group work. Such work in combination with results from this project will inform the development of empirically grounded professional development courses. A diagnostic tool can be also be developed to assess relevant resources individual students possess prior to group work to help teachers organize groups optimally, while creating a small group process checklist could allow teachers to evaluate group dynamics in real time. These tools will help practicing teachers find the missing piece of the puzzle that too often hinders inquiry and maybe engineering design – how to construct and manage small groups in ways that maximize science learning. Advancing our understanding of the micro-level dynamics of group work in inquiry and engineering design, with sensitivity to differences in scientific practices in the two types of tasks, is "use-inspired basic research" (Pintrich, 2003, p. 699) that derives intellectual merit from both its theoretical and practical implications.

Dissemination

With graduate research assistants and participating teachers, we will present results at national science education and education conferences throughout the project's duration. In addition, we will publish results in leading, peer-reviewed journals in various disciplines (e.g., *Journal of Research in Science Teaching*, *Science Education*, *Journal of Educational Psychology*, *Measurement: Interdisciplinary Research and Perspectives*, *Educational and Psychological Measurement*). Results will also be presented locally at science department meetings and UMass STEM Institute's lecture series, distributed through participating high schools' e-newsletters and made available on our department's publicly accessible website. Furthermore, we will organize a mini conference at which our team of researchers and teachers presents our results and implications for practice to science teachers in Western Massachusetts and preservice science teachers from UMass Amherst and Smith College.

Key Personnel

PI, Martina Nieswandt (University of Massachusetts Amherst; *50% FET*), is an Associate Professor of Science Education in the Department of Teacher Education and Curriculum Studies in the School of Education. Her research focuses on the relationship between motivation, affect and learning associated with high school science concepts utilizing mixed-methods approaches. Recently, she explored the role of interest and self-concept on 9th graders' learning of chemistry, the impact of motivation on 12th graders' learning of evolutionary theory, and factors influencing students' and teachers' motivation to engage in inquiry teaching (see C.V.). Nieswandt will direct the proposed research study and provide overall project management. Tasks include: coordinate and manage personnel at UMass (graduate research assistants); direct, in collaboration with the Co-PI, research design, data collection instruments, and data analysis; communicate with the engineering design consultant and advisory/evaluator board; lead advisory board meetings; introduce teachers/students to the research; and in collaboration with the Co-PI and graduate student research assistants write conference papers to be presented and articles for journal publication.

Co-PI, *Elizabeth McEneaney* (University of Massachusetts Amherst; *50% FET*) is an Assistant Professor in the Department of Teacher Education and Curriculum Studies in the School of Education, specializing in sociology of education, with particular emphasis on inequality in science and math education. Recent research includes an AERA-funded project to evaluate the impact of state-level language acquisition policy on ELL science and mathematics achievement using NAEP. She has extensive experience designing and implementing data management and analysis procedures and program evaluation systems, and using advanced statistical modeling, including latent class analysis and multilevel modeling. She has taught both quantitative and qualitative research methods courses in graduate education programs. This expertise will support her role in this project, which is to assist in any needed revisions of the instruments, oversee sampling of teachers and timing of classroom observations, advise on qualitative analysis strategies, and lead the statistical analyses. In collaboration with the PI, she will write papers to be presented at conferences and articles to be submitted to journals for publication.

Training and Education of Graduate Student Research Assistants (GSRA)

The training and education of our GSRA are based on our strong belief that they are equal members of the research team. As such, they will have the opportunity to experience educational research in natural settings (science classrooms) utilizing mixed methods. Participating in this apprenticeship model, the students will engage in planning, implementing, and revising our empirical research. They will also be trained in multiple research methods (e.g., interviews, observations, questionnaires) and data analysis methods (e.g., statistical models, qualitative analysis methods). They will have the opportunity to use data collected during this project and/or collect additional data in project sites for their dissertation projects. Finally, they will be invited to participate in writing conference proposals and manuscripts for publication and to present at national conferences.

Engineering Design Consultant

As the Design Clinic Director in the Picker Engineering Program at Smith College, Prof. Susannah Howe coordinates and teaches the capstone engineering design course in which senior engineering students collaborate in teams on real-world design projects sponsored by industry and government. In the past nine years she has supervised 57 student teams on design projects. Her current research focuses on innovations in engineering design education. She is also involved with efforts to foster design learning in primary and secondary schools. She worked for two years with teachers to coordinate after school engineering clubs for students in grades 4-8 and she has conducted multiple outreach sessions on engineering design for middle and high school students. We will draw on her expertise in engineering design throughout the project and particularly during *phase 1* for the task selection and refinement as well as guidelines for instructional support.

Advisory/Evaluation Board

The advisory/evaluation board is comprised of three leading researchers, one in Science Education (Prof. Michael E. Beeth, University of Wisconsin, Oshkosh) and two in Educational Psychology (Prof. Ann Renninger, Swarthmore College and Prof. Richard Ryan, University of Rochester); one Science Education practitioner (Dr. John Kudukey, University of Massachusetts) and a K-12 Science and Engineering Curriculum Specialist (Thomas Gralinski, Smith College) whose research areas and expertise are within the scope of our study. Kudukey and Gralinski are long time residents and former science/technology teachers in Western Massachusetts and familiar with its different school districts. If necessary, they will support us with recruiting teachers beyond those who have already expressed strong interest in our proposed project. Kudukey will also collect evaluation data as outlined above and analyze these data in conjunction with other board members. Besides providing their research expertise in specific areas (conceptual understanding, motivation, affect, implementation of inquiry and engineering design tasks) these experts will have formative and summative evaluation roles (see Project Evaluation section above).

Results of Prior Support from PI

Martina Nieswandt has received various institutional grants from the Social Sciences and Humanities Research Council of Canada (2005: US$3,300; 2004: $3,270; 2003: $3,320; 2002: $2,200), the Imperial Oil Centre for Studies in Science, Mathematics and Technology Education at OISE/UT (2003: US$8,100; 2002: $9,900), and UMass School of Education (2012: $11,689), which were used for small scale studies investigating relationships between motivational and affective variables and their effects on science learning in different science classrooms (Nieswandt & Shanahan, 2008); the influence of affect variables (interest, self-concept) on students' meaningful understanding of science concepts (Nieswandt, 2007); and the development and analysis of extended response questions to measure meaningful understanding of science concepts (Nieswandt & Bellomo, 2009). In addition, as a Co-PI (funded by the U.S. Dept. of Education; 2007-2011; $550,000), she investigated identity development among K-8 teachers enrolled in a three year program leading to a M.S. and a middle school physical science endorsement at the Illinois Institute of Technology (Nieswandt, 2012; Meyer, Nieswandt, Race, et al., 2012).

Budget

University of Massachusetts Amherst requests $892,630 of funding over three years for this research and the dissemination of the results.