Small-group Instruction in Science, Mathematics, Engineering and Technology (SMET) Disciplines: A Status Report and an Agenda for the Future

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Calls for reform in undergraduate mathematics and science education have been made by a number of disciplinary groups and national commissions, including the National Science Foundation (NSF) in 1996, the National Research Council (1996) and the American Association for the Advancement of Science (1990). Though these reports vary in details, all recommend an examination of the learning process in SMET classes and encourage exploration into teaching/learning practices that require active involvement of students via small-group instruction rather than the passive involvement fostered by reliance on the lecture method.

Perhaps the most compelling evidence regarding the power of small-group instruction in SMET disciplines comes from a recent evaluation of over 340 NSF project directors. They were asked to evaluate which of 13 possible innovations in undergraduate teaching were central to effective teaching. Students working in teams was ranked highest of the 13 (Britton, 1997).

Coupled with this call for interactive instruction are significant increases in the number of papers, texts, workshops and professional meetings which concern themselves with cooperative and collaborative small-group instruction. This paper is an attempt to place the recent flurry of activity into context for SMET faculty. It is our "take" on the field after reviewing several hundred studies, reports, books, and other works in preparing an annotated bibliography on small-group instruction in college-level SMET disciplines (Cooper & Robinson, 1997) for the National Institute for Science Education (NISE). The bibliography[1] contains nearly 100 resources which may be useful to researchers, theorists and practitioners in this area. We believe these resources will be particularly useful to those interested in getting started in using small-group instruction or fine-tuning the practices that they have begun using. The present paper and the bibliography were informed by a NISE meta-analysis of work performed by Leonard Springer, Mary Elizabeth Stanne and Samuel Donovan (1997).

We offer our assessment of three issues:

1. What do we know about the impact of small-group instruction on student outcomes in SMET classes?
2. How solid is the research/theory base for small-group instruction in SMET classes?

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[1]The bibliography is available as Occasional Paper No. 6 from the National Institute for Science Education, Wisconsin Center for Education Research, University of Wisconsin-Madison, 1025 West Johnson Street, Madison, WI 53706; tel: (608) 263-9250. It is also available on the NISE Web site: http://144.92.174.191/nise/cl1/clweb/clhome.htm.

3. What questions or issues have yet to be resolved in the research and practice relating to small-group instruction in SMET classes?

Question #1. What do we know about the impact of small-group instruction on student outcomes in SMET classes? The best current source on this topic is the NISE meta-analysis of the effect of small-group instruction by Springer, et al. They have reviewed hundreds of studies dealing with the impact of small-group instruction on a number of student outcomes in SMET classes. They report that small-group instruction has "robust" effects on three broadly-defined student outcome measures: achievement, persistence (attrition) and attitudes. Springer et al. report that small-group instruction produces achievement differences on a variety of student measures, including grades and scores on several types of tests. Student attrition rates (from courses and from institutions) are lower for students exposed to small-group instruction relative to their peers taught by more traditional methods. Student attitudes toward the subject matter and how skilled they feel about their competence in the discipline are also positively effected by their exposure to small-group instruction. The "effect size" for these findings, to use a meta-analysis term, is about .50 for all three outcomes. Effect size is a statistical description of the impact of a treatment on a group of students. An effect size of .50 is considered moderate.

Based on the NISE meta-analysis and the quantitative and qualitative studies we reviewed for the bibliography, we are confident that small-group instruction at the college level has a positive overall or main effect on these three student outcomes. It has been reported that small-group, cooperative instruction has a powerful effect on a variety of additional outcome measures, including higher-order (critical) thinking skills and cognitive development. The evidence in the SMET literature is less clear on this point, though the procedures used in small-group instruction are consistent with the techniques that experts in critical thinking and cognitive development say should be in place in order to foster these outcomes, techniques such as cognitive rehearsal and elaboration, modeling, feedback, and active learning (Brookfield, 1987; Kurfiss, 1988).

It is often reported that small-group, cooperative procedures have particularly powerful impacts on women and minority students. Once again, it appears that these techniques should have a particularly powerful impact on these groups according theory and some research (Belenky et al., 1990; Tobias, 1990; Treisman, 1985). It is not clear to us that there is a sufficient quantity of evidence in SMET higher-education settings to unambiguously "document" this claim, although the qualitative data and our own experiences suggest that well-planned small-group instruction does have powerful effects on these groups. The NISE meta-analysis group recently reported that minority students may be particularly effected by small-group SMET instruction when achievement is assessed. They also reported that women may be particularly affected by small-group instruction when attitudinal measures are taken. However, these findings are based on a very small number of studies, many having methodological problems. This research appears to be both important in terms of social-policy implications and promising in its likelihood of yielding positive results. We urge researchers and funding agencies to encourage careful examination of these issues using more carefully controlled studies than are currently in the literature.

There are several theoretical positions regarding why small-group instruction has the impact that it appears to have. From the cognitive perspective, small-group instruction allows students to cognitively rehearse and relate course material into existing schema or conceptual frameworks, thus producing a deeper, contextualized level of understanding of content (Kurfiss, 1988). When peers work together there is a great deal of modeling, cognitive disequilibrium, feedback and perspective taking that emerge as students explain and receive explanations from their colleagues.

More humanistically-oriented theorists point to the intrinsically rewarding nature of small-group interaction based on the assumption that students have a natural potential for learning that is best fostered in non-threatening groups. These theorists tend to focus on the learning process which they believe is best developed without excessive teacher intervention and control, thus allowing students to find their "voices" via democratic, student-centered learning environments (Belenky, et al., 1986; Bruffee, 1985; Cohen, 1994). The humanistic theorists stress the causal link between conversation and thinking with thought being a product of verbal interaction. Conversation characterized by a diversity of perspectives results in "richer, deeper, more comprehensive and more complex thinking" (Cuseo, 1996, p. 6). Although social interaction is important in all small-group theories, it plays a fundamental role in humanistic theory, which is based on constructivist assumptions of how knowledge is acquired. Constructivism is described further in the next section of this paper.

Motivational theorists often stress the role of rewards in explaining the effects of small-group instruction. They tend to stress the importance of grades and other incentives as the causal agents responsible for the power of small-group learning. Such theorists tend to emphasize individual accountability and rewards for appropriate group functioning in small-group learning and to be critical of undifferentiated group grading for team work, where all team members receive the same grade regardless of differences in contributions to the total-team effort (Slavin, 1980).

Few researchers in small-group instruction in SMET have directly addressed which of these explanations or what combination of causal agents is responsible for the impact of small-group learning on college students. Identification of these factors would appear to be a productive, though complicated, area for future research. The precollegiate small-group work is at least a decade ahead of the collegiate work in both the quality of the research and the understanding of how to implement the research findings in classrooms.

Question #2. How solid is the research/theory base for small-group instruction in SMET classes? Although studies have been conducted on small-group instruction for many years, there has been a dramatic increase recently. For example, a preliminary report of the NISE meta-analysis group indicated a doubling of research reports from the 1987-89 period to the 1990-1992 period in both engineering and science, and another doubling from 1990-1992 to 1993-1995. For the years prior to 1987, there was very little work reported in the data bases utilized.

Despite the *relative* increases in the number of reports of small-group instruction in SMET disciplines in the last 5-7 years, the absolute numbers are still small. The studies which meet traditional standards of quantitative research control are very limited, particularly in fields such as physics, chemistry, biology and engineering. The quantity and quality of research reports in mathematics is generally better, perhaps due to the early and powerful influence of Uri Treisman and the various math reform movements. In a recent search of the ERIC data base the number of reports listed under the descriptors *cooperative learning* and *higher education* was 699. The time period covered in the search was 1992 through August, 1996. Of these 699 reports, covering a nearly five-year span, only 11 were in chemistry, 12 in physics, 13 in biology and 19 in engineering. In contrast, 58 citations were found in mathematics.

Thus, the field of research on small-group instruction in SMET disciplines in higher education can be characterized as promising, but relatively immature. As indicated above, the number of studies done in many SMET fields in higher education is relatively small and the quality of those studies is often less than rigorous.

As was suggested earlier, there is a fairly extensive body of knowledge on principles of cognitive development, affective/humanistic education, and motivational theory which can lend coherence to small-group instruction and provide a framework to guide additional research and theory. Unfortunately, many authors contributing to small-group literature do not relate their work to existing theoretical positions. Many do not link their contributions with prior research that would set their work in a historical context. As research and theory in collegiate SMET disciplines matures and becomes a more cumulative and coherent field, these links will (hopefully) be made more explicit.

We are also encouraged by the recent increase in teaching-methods courses offered by graduate programs. We believe that this may increase the skill of future SMET researchers with regard to both pedagogy and research methods.

Although we acknowledge that small-group work performed at the K-12 level may deal with different challenges and student populations, that work is empirically and theoretically mature and useful to college-level researchers and practitioners, if only to serve as rough guides to possible rich areas of work at the college level. Many of the findings reported recently by college-level SMET researchers and practitioners were initially reported many years before by David and Roger Johnson, Robert Slavin, Shlomo Sharan, Elizabeth Cohen and others working with precollegiate populations. SMET researchers/practitioners such as Richard Felder in engineering, Patricia and Kenneth Heller in physics, and Susan Nurrenbern and Melanie Cooper in chemistry, clearly document the influence of these early contributors. Authors working with precollegiate populations have also generated a number of workbooks and other applied materials which can be useful to the collegiate SMET teacher. The Cooper and Robinson (1997) annotated bibliography describes these works and includes both precollegiate and collegiate resources.

Another challenge that we perceive with collegiate research on small-group instruction has to do with the lack of integrative research. There has been little work with an attempt to integrate the knowledge base such as the meta-analysis performed by the NISE group. Precollegiate cooperative learning has several contributors including the Johnson brothers at Minnesota and Robert Slavin at Johns Hopkins who have committed themselves to years of systematic study of research, theory and practice. There are no comparable researchers in college-level SMET disciplines addressing field-based (classroom-based) small-group work. The collegiate SMET integrative works could include either quantitative analyses, qualitative summaries or a combination of both methodologies. It is interesting to note that the research programs of the Johnsons and Slavin have also yielded a huge amount of applied work which has been adopted by K-

12 practitioners in significant numbers. These scholars document the importance of sound research and theory as a basis for good practice.

One reason for the lack of integrative work may be the issue of vocabulary. There are a host of different procedures subsumed within the rubric of small-group instruction. Among these are cooperative learning, collaborative learning, team learning, problem-based learning, peer-assisted instruction, Supplemental Instruction, and lab work. Attempts have been made to distinguish these terms (Cuseo, 1992; Smith & MacGregor, 1992). Some authors in the small-group literature argue that, for their types of small-group instruction to work, the techniques must be faithfully executed in every detail. Other contributors suggest that any movement in the direction of getting students more actively involved should be commended, not faulted, if one or more elements of a certain technique are not executed according to dogma. It does appear that all forms of small-group instruction are not created equal; some appear to be better than others in fostering specific outcomes. Not all techniques work better than the lecture method. For example, badly-structured small-group instruction leaves strong negative feelings among students regarding the fairness of grading systems, the feeling of unequal distribution of labor and other issues (Feichtner & Davis, 1984-85; Laws, Rosborough, & Poory, 1995). Examples of effective and less effective small-group techniques are identified in the Cooper and Robinson (1997) bibliography.

There are a number of divisions within the field of small-group instruction in college-level SMET work that sometimes lead to problems in taking an inclusionary approach to addressing important issues. Much of the collaborative- and cooperative-learning literature is based on the principle of constructivism. Constructivist approaches have a jaundiced view of what they term "received knowledge" imparted by the lecture method and other forms of teacher-centered instruction. Rather than having the teacher serve as a dispenser of facts and lower-level cognitive information, constructivists believe that the teacher should serve as a facilitator who attempts to structure an environment in which the learner organizes meaning on a personal level; students and teachers should work in a collegial mode, often using small-group procedures. Those opposed to the constructivist position argue that there is a body of knowledge that is fundamental or foundational and that such content is best presented in more traditional-instructional formats, such as the lecture. It occurs to us that some combination of lecture or lecture-discussion can co-exist with more experiential forms of small-group learning (and other instructional procedures), thus giving students with different learning styles exposure to preferred teaching/learning methods for at least part of the time. It can further be argued that over-reliance on any single mode of instruction can be deleterious. Strong feelings exist on these issues and often divide faculty.

Question #3. What questions or issues have yet to be resolved in research and practice in small-group instruction? The answer to this question appears to be that there is much more that we don't know than that we do. We noted earlier that there appears to be a significant body of knowledge documenting that small-group instruction is generally superior to traditional forms of instruction on broadly-defined outcome measures such as achievement, attrition and attitude. There are very few other issues that have been "resolved" at an empirical level. Some would argue that none of these questions can be empirically resolved, that the tools for measuring effects on students are such poor assessments of important educational outcomes that attempts to do this kind of research is doomed to find only trivial answers. Our position is that, when one combines the qualitative and quantitative work on small-group instruction, important information can be obtained and that it can be applied to a wide range of contexts, as has been demonstrated with precollegiate work in cooperative learning.

Although practitioners have strong feelings on these matters, issues which have yet to be resolved in small-group instruction include: how groups should be formed, how large they should be and how long they should stay together. What to do about the freeloader/dominator issue and how to grade when using small-groups also do not have generalizable empirical answers at this time. When to use a specific small-group procedure to achieve a given educational outcome has not been formally assessed in detail in the higher-education SMET literature. Although the research base addressing these questions is not well developed, there is a great deal of wisdom of practical experience concerning how to address these issues (as can be found in many of the workbooks and other sources identified in the Cooper and Robinson bibliography).

Nor is there detailed information on how to overcome faculty resistance to small-group instruction. It requires a kind of personal paradigm shift in thinking about the teaching/learning process to fully commit to cooperative, small-group instruction. Many SMET faculty have to come to grips with such fundamental issues as their values toward how knowledge is acquired, what relationship they should have with their students, how to grade, and content-coverage issues. In most cases, commitment to cooperative, small-group instruction is at odds with the prior experiences of SMET faculty. Many small-group adherents in

SMET disciplines have come to the realization that such traditional-instructional procedures were dysfunctional for a large percentage of students (Hagelgans et al., 1995; Treisman, 1985).

The Future. It seems to us that small-group instruction can have a powerful impact on a host of outcomes (for professors, students and institutions). When one looks at the data concerning how much students retain when taught using the lecture method, it seems hard to believe we could do much worse in arguing for more interactive learning methods.

One area that future researchers may wish to pursue is using small-group instruction to foster higher-order thinking in SMET classes. Despite the focus put on this student outcome by the National Science Foundation, the National Research Council, the National Council of Teachers of Mathematics and others, the amount of research on it is very limited in higher-education SMET literature. Most cognitive measures described in SMET reports are grades, exam scores and other testing procedures, with little documentation that these measures assess critical-thinking. Use of more real-world, "authentic" assessment instruments in studies of SMET small-group techniques should be encouraged by publishers, funding agencies, researchers and other interested parties.

A trend that we find encouraging is the recent increase in workbooks and materials related to discipline-specific applications of small-group instruction in SMET, such as Susan Nurrenbern's 1995 workbook on cooperative learning in chemistry, the 1995 Mathematics Association of American sourcebook titled " A Practical Guide to Cooperative Learning in Mathematics" (MAA Notes #37) and McNeill and Bellamy's 1995 workbook for the core engineering program at Arizona State. We hope that NSF, the disciplinary societies and other SMET-related groups will play a significant role in encouraging the publication and dissemination of such material.

We recently conducted an informal poll of a number of leading researchers and practitioners in small-group instruction. We asked them to identify the most important issues relating to the future of small-group work at the college level. Virtually all responded that the role of technology in small-group work was the most important issue. Groups such as the American Association for Higher Education Technology Roundtable are pushing for the integration of technology and interactive instruction. The very recent technology literature is filled with examples of how technology-based instruction can use interactive formats to put a human face on a variety of otherwise passive instructional formats such as televised learning and computer-assisted instruction. We believe the technology-based instruction that will have the most impact on student outcomes will be characterized by methods which foster learner engagement with content, including techniques which encourage greater student-student and student-teacher interaction.

There is a least preliminary evidence that cooperative, small-group procedures can impact a wide range of outcome measures such as achievement, liking for science and math, critical thinking and retention. There is evidence that this technique may be particularly effective for women and minority students. There is also evidence that cooperative techniques may increase the likelihood that bright students who historically avoid SMET disciplines may be attracted to cooperatively-taught SMET courses (Tobias, 1992). There is considerable empirical evidence at the precollegiate level and some evidence at the collegiate level that cooperative procedures can have significant impacts on such prosocial outcomes as active listening, altruism and teamwork, skills in large demand in the market place and in the society at large. Thus cooperative small-group procedures provide more "bang for the buck" relative to other instructional and curricular programs available in the college experience (Astin, 1994). In an era of diminishing support for colleges, cooperative learning can supply some of the benefits historically associated with counseling centers, student services, social organizations and other programs thought to be "extracurricular" to formal instruction.

In reading some of the literature on small-group instruction, one gets a feeling that this procedure is destined to cure all societal ills and save democracy. We believe that cooperative, small-group instruction can have a powerful impact on a large number of educational outcomes for many students. But the data on the impact of this method is far from complete and the findings are not close to unanimous. This paper is an attempt to put the field in some kind of context so that we may set a reasoned agenda for the future. The last thing we need in this era of public mistrust of institutions and diminished spending for higher education is another educational fad that fails to live up to unrealistic expectations.

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STEM Ä°ngilizce Science, Technology, Engineering, Mathematics kelimelerin baÅŸ harflerinin birleÅŸmesiyle oluÅŸmuÅŸ olup (Dugger, 2010;Sanders, 2009), literatÃ¼rÃ¼mÃ¼zde FeTeMM (Fen, Teknoloji, MÃ¼hendislik, Matematik) olarak da rastlanÄ±lmaktadÄ±r (Ã‡orlu, 2014).Â Numerical mathematics, as an applied discipline, should be taught on real world examples. By using inexpensive Arduino hardware, we can create simple experiments that are easily reproduced by students.Â One of the main reasons for the disparities between these groups in physical science jobs is the academic achievement gaps leading to different percentages being served in programs at higher levels of education (Carter & Darling-Hammond, 2016;Duncan & Murnane, 2014;Gonzalez & Kuenzi, 2012). Center for Science Mathematics and Engineering Education, Committee on. Undergraduate Science Education 1999). The recent workshops sponsored by the.Â engineering coalition and the Center for the Integration of Research, Teaching and. Learning (CIRTL) show that many other factors affect the adoption of instructional. innovations.Â teaching effectiveness lies in â€œgray literatureâ€ such as evaluation reports to the. NSF, which has a limited distribution. Any replication of effective teaching in. See more of Science, Technology, Engineering and Mathematics - STEM on Facebook. Log In. or. Create New Account. See more of Science, Technology, Engineering and Mathematics - STEM on Facebook. Log In. Forgot account?Â Mystery Mathematics in Universe Discovery Documentary 2015 math Documentary Mathematics Documentary Science Documentary 2015 In physics and cosmology, the ma Mystery Mathematics in Universe Discovery Documentary 2015 math Documentary Mathematics Documentary Science Documentary 2015 In physics and cosmology, the ma Science, Technology, Engineering and Mathematics - STEM. May 8, 2016 Â·. Seeing is believing. Science, technology, engineering, and mathematics (STEM), previously science, mathematics, engineering, and technology (SMET), is a broad term used to group together these academic disciplines. This term is typically used when addressing education policy and curriculum choices in schools to improve competitiveness in science and technology development. It has implications for workforce development, national security concerns and immigration policy. The science in STEM typically refers to two out of A meta-analysis of research on college students in science, mathematics, engineering, and technology (SMET) was undertaken to clarify the effects of small-group learning at the undergraduate level. The focus was three broad categories of outcomes among SMET undergraduates: achievement, persistence, and attitudes.Â The magnitude of effects reported in this study exceeded most findings in comparable reviews of research on educational innovations and supports more widespread implementation of small-group learning in undergraduate SMET. Three figures and five data tables are appended. Also appended is a bibliography of the characteristics of various meta-analyses studies. (Contains 86 references.) (SW).