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ABSTRACT

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. Research concerns included: potential sources of bias in the methodology; whether the effects of small-group learning differ for various groups of students (majors or nonmajors, first-year or other students, men or women, predominantly white or predominantly underrepresented groups); and whether the characteristics of different small-group learning procedures (time spent working in groups) are related to the outcome measures. Using 39 studies from 1980 or later, the study demonstrated that various forms of small-group learning are effective in promoting greater academic achievement, more favorable attitudes toward learning, and increased persistence. 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)

EFFECTS OF SMALL-GROUP LEARNING ON UNDERGRADUATES IN SCIENCE, MATHEMATICS, ENGINEERING, AND TECHNOLOGY: A META-ANALYSIS

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EFFECTS OF SMALL-GROUP LEARNING ON UNDERGRADUATES IN SCIENCE, MATHEMATICS, ENGINEERING, AND TECHNOLOGY: A META-ANALYSIS

ABSTRACT

Recent calls for instructional innovation in undergraduate science, mathematics, engineering, and technology (SMET) courses and programs highlight the need for a solid foundation of education research at the undergraduate level on which to base policy and practice. We report herein the results of a meta-analysis that integrates research on undergraduate SMET education since 1980. The meta-analysis demonstrates that various forms of small-group learning are effective in promoting greater academic achievement, more favorable attitudes toward learning, and increased persistence through SMET courses and programs. The magnitude of the effects reported in this study exceeds most findings in comparable reviews of research on educational innovations and supports more widespread implementation of small-group learning in undergraduate SMET.

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EFFECTS OF SMALL-GROUP LEARNING ON UNDERGRADUATES IN SCIENCE, MATHEMATICS, ENGINEERING, AND TECHNOLOGY: A META-ANALYSIS

The need to strengthen science and mathematics education in the U.S. was repeatedly emphasized in education studies conducted during the 1980s (e.g., National Commission on Excellence in Education, 1983; National Science Foundation & U.S. Department of Education, 1980). More recently, reports from national commissions, disciplinary groups, researchers, employers, faculty, and students call for instructional innovations in science, mathematics, engineering, and technology (SMET) education (American Association for the Advancement of Science, 1989, 1990; National Research Council, 1995, 1996; National Science Foundation, 1996). A consistent recommendation advanced in recent reports is the need for a shift in emphasis from teaching to learning. The message is clear: What students learn is greatly influenced by how they learn, and many students learn best through active, collaborative, small-group work inside and outside the classroom (American Association for the Advancement of Science, 1989, 1990; National Research Council, 1995, 1996; National Science Foundation, 1996). The National Science Foundation (1996), for example, recommends that students have frequent access to active learning experiences in class and outside of class (as through study groups).

Collaboration in SMET courses and programs is aimed at enhancing the preparation of students for collaboration in SMET professions and at giving all students a better sense of how scientists and engineers work. An American Association for the Advancement of Science (1989) report advises that "the collaborative nature of scientific and technological work should be strongly reinforced by frequent group activity in the classroom. Scientists and engineers work mostly in groups and less often as isolated investigators. Similarly, students should gain experience sharing responsibility for learning with each other" (p. 148).

Cooperation in SMET courses and programs may offer benefits apart from promoting an understanding of how scientists and engineers work. The American Association for the Advancement of Science (1989) also suggests that "overemphasis on competition among students for high grades distorts what ought to be the prime motive for studying science: to find things out. Competition among students in the science classroom may result in many of them developing a dislike of science and losing their confidence in their ability to learn science" (p. 151). Excessively competitive classroom environments have particularly impeded the opportunity of women and members of underrepresented groups to participate equally in SMET (*Science,* 1992; Seymour, 1992, 1995; Seymour & Hewitt, 1994; Tobias, 1990). Consequently, educational equity remains an elusive goal amid calls for scientific literacy for all (National Science Foundation, 1996).

For the most part, college and university educators have yet to respond to calls for greater opportunities for collaboration and cooperation in SMET courses and programs (National Science Foundation, 1996). Regrettably, the unintended consequences of this focus on teaching rather than learning include unfavorable attitudes toward SMET among students, unacceptably high attrition from SMET fields of study, inadequate preparation for teaching science and mathematics at the precollege level, and graduates who "go out into the workforce ill-prepared to solve real problems in a cooperative way, lacking the skills and motivation to continue learning" (p. iii).

In contrast to instructors at postsecondary institutions, most instructors at the presecondary level have adopted small-group learning. In a recent national survey (Puma et al., 1993), 79% of elementary school teachers and 62% of middle school teachers reported that they employ cooperative learning (a type of small-group learning that encompasses several practices) in their classrooms on a sustained basis. The widespread practice of cooperative learning at the presecondary level seems to be based largely on the influence of more than 25 years of research, primarily within a social-psychological framework employing quantitative methods, that contrasts the effects of cooperative learning with the effects of competitive or individual instruction. Indeed, links between cooperative learning theory, research, and practice have been characterized as "one of the greatest success stories in the history of educational research" (Slavin, 1996, p. 43).

The substantial number of primary studies on cooperative learning has precipitated several meta-analyses of its effects on various outcomes. Analysts who include postsecondary samples in their quantitative research syntheses (e.g., Johnson & Johnson, 1989; Johnson, Johnson, & Smith, 1991a; Johnson, Johnson, & Smith, 1991b; Johnson et al., 1981; Qin, Johnson, & Johnson, 1995) have integrated the statistical results of hundreds of empirical investigations that contrast cooperative interactions with competitive or individual ones. These meta-analyses have consistently reported that cooperation has favorable effects on achievement and productivity, psychological health and self-esteem, intergroup attitudes, and attitudes toward learning.

The large body of theory and research at the presecondary level (e.g., Cohen, 1994; Johnson & Johnson, 1989; Sharan, 1990; Slavin, 1995), based primarily on grades two through nine, suggests that it is no longer necessary to establish cooperative learning as a "legitimate method of instruction that can help students to learn" (Cohen, 1994, p. 30). Yet despite the volume of research on cooperative learning, few investigations have focused on college students outside the psychology laboratory. To our knowledge, no meta-analysis of small-group learning focuses exclusively on undergraduates.

This meta-analysis of research on college students in SMET is intended to facilitate a greater understanding of the effects of small-group learning at the postsecondary level. We address the learning outcomes most frequently noted in the national reports cited above: academic achievement, persistence (or retention), and a broad range of attitudes (self-esteem, motivation to achieve, and attitudes toward learning SMET material). We choose to use meta-analysis because the procedure has considerable utility in informing policy and practice (cf., Mann, 1994; National Research Council, 1992).

Conceptual framework

A growing literature on small-group learning at the postsecondary level distinguishes between cooperative and collaborative learning (e.g., Matthews et al., 1995). These small-group practices do not follow from a single theoretical perspective, rather, they are "more like an arbor of vines growing in parallel, crossing, or intertwined" (MacGregor, 1992, p. 37). Conceptual frameworks for small-group learning are rooted in such disparate fields as philosophy of education (Dewey, 1943), cognitive psychology (Piaget, 1926; Vygotsky, 1978), social psychology (Deutsch, 1949; Lewin, 1935), and humanist and feminist pedagogy (Belenky et al., 1986). We describe three broad, interrelated theoretical perspectives on the effects of small-group learning on academic achievement as motivational, affective, and cognitive.

Motivational perspective

From a motivational perspective, competitive grading and reward systems lead to peer norms that oppose academic effort and academic support. Because one student's success decreases the chances that others will succeed, students may express norms reflecting that "high achievement is for 'nerds'" (Slavin, 1992, pp. 157-158), or may interfere with one another's success. The rationale for implementing group goals is that if students value the success of the group, they will encourage and help one another to achieve, in contrast to competitive learning environments.

Motivationalist theories also tend to emphasize the importance of individual accountability. An underlying assumption is that students might readily interact with and help one another, but without appropriate structure, their help might merely consist of sharing answers and doing each other's work. By holding each group member accountable for learning, the incentive structure supports individuals teaching one another and regularly assessing one another's learning.

Affective perspective

Based largely on Dewey's (1943) experiential philosophy of education, affective or humanist theorists (e.g., Kohn, 1986; Sharan, 1990) generally emphasize intrinsic rather than extrinsic motivations. Based on the proposition that group work in a non-threatening environment can lead naturally to learning, humanist theorists generally assert that the role of the instructor should be to facilitate more frequent and less constrained interaction among students rather than to serve as an unquestioned authority. From this perspective, students, particularly women and members of underrepresented groups, have greater opportunities to be heard and also to learn by participating in more collaborative and democratic teaching and learning processes (Belenky et al., 1986).

Cognitive perspective

A third perspective on small-group learning may be described as cognitive. Proponents of a cognitive perspective generally contend that interactions among students increase achievement because of more intense information processing. Developmental cognitive theories are generally grounded in the pioneering work of Piaget (1926) or Vygotsky (1978). These theories generally hold that face-to-face work on ill-structured tasks, projects with several possible paths leading to multiple acceptable solutions, facilitate cognitive growth. From this viewpoint, the opportunity for students to discuss, debate, and present their own and hear one another's perspectives is the critical element in small-group learning. Students learn from one another because in their discussions of the content, cognitive conflicts will arise, inadequate reasoning will be exposed, and enriched understanding will emerge.

An alternate cognitive perspective might be described as cognitive elaboration. Research in cognitive psychology has long held that if new information is to be retained, it must be related to information already in memory. Therefore, learners must engage in some sort of cognitive restructuring, or elaboration, of the material. One of the most effective means of elaboration is explaining the material to someone else. For example, Dansereau (1988) and his colleagues report that pairs of college students working on structured cooperative scripts, during which one takes the role of recaller and the other as listener, can learn technical material or procedures far better than students working alone.

Forms of small-group learning

Small-group learning in undergraduate SMET occurs in a great variety of forms. An annotated bibliography of SMET resources in higher education (Cooper & Robinson, 1997) identifies several types of small-group learning practices currently in use. In this meta-analysis, we include cohort groups, various types of structured cooperative learning, brief activities for pairs of students during breaks in lectures, and several types of informal collaborative work among students. We also represent links and commonalities among these procedures, as suggested by Matthews and her colleagues (1995), while noting important differences in underlying assumptions and methods of implementation. This inclusive approach follows from our observations of substantial differences in how particular practices are implemented and notable similarities among divergent procedures.

Research questions

The two sets of research questions guiding the meta-analysis focus on undergraduates in SMET courses and programs. First, we address the main effects of small-group learning on three broad categories of outcomes among SMET undergraduates: achievement, persistence, and attitudes. Second, we address four categories of conditional effects of small-group learning. First among these four categories is potential sources of bias in the meta-analysis method. For example, are the effect sizes that we report biased because most of the research is taken from journals, which tend to publish predominantly statistically significant results? Second, we question whether the effects of small-group learning differ for various groups of students (e.g., majors or nonmajors, first-year or other students, men or women, predominantly white or predominantly underrepresented groups). Third, we examine whether characteristics of different small-group learning procedures (e.g., time spent working in groups) are related to the outcome measures within the three broad categories. Fourth, we look more closely at different types of outcomes within the three broad categories (e.g., attitudes toward learning SMET material, motivation to achieve, and self-esteem within attitudinal outcomes).

Meta-analysis method

Literature search procedures

We screened a wide variety of electronic and print resources to identify references for possible inclusion in this study, including ERIC, Education Index, PsycLIT, *Dissertation Abstracts International*, Medline, CINAHL (nursing and allied health), and ASEE (American Society for Engineering Education) conference proceedings. In addition, we reviewed the reference sections of the myriad studies that we collected in an effort to identify other potentially relevant research. Finally, we contacted several researchers and practitioners who are active in the field and asked them to provide relevant research or to identify additional sources of studies.

Inclusion criteria

Five criteria determined whether a research report qualified for inclusion in the meta-analysis. First, the study examined undergraduates in science, mathematics, engineering, or technology courses or degree programs at accredited postsecondary institutions in North America. Technology refers to the study of vocational technology (e.g., allied health), not to the use of technology inside or outside the classroom (e.g., computer-assisted instruction).

Second, studies must incorporate small-group work inside or outside of the classroom. Small-group work refers to cooperative or collaborative learning among two to ten students. Third, the study was conducted in an actual classroom or programmatic setting rather than under more controlled laboratory conditions. Fourth, the research was published or reported in 1980 or later on the grounds that recent studies may be more relevant to the current global context in which students learn. Fifth, the research reports enough statistical information to estimate effect sizes.[1]

Metric for expressing effect sizes

The metric that we used to estimate and describe the effects of small-group learning was the standardized mean difference (*d*-index) effect size (Cohen, 1988). For two-sample analyses, we calculated the effect size by subtracting the control group's average[2] score from the experimental group's average score and dividing the difference by the average of the two standard deviations. For single-sample analyses, we subtracted the average score on the pretest from the average score on the posttest, and again divided the difference by the average of the two standard deviations. For proportions, such as those associated with data on persistence or retention, we created contingency tables and estimated chi-square statistics.

Calculations of average effect sizes

One of the assumptions underlying meta-analysis is that effects are independent from one another. A problem arising from calculating average effect sizes is deciding what represents an independent estimate of effect when a single study reports multiple outcomes. Our meta-analysis used shifting units of analysis (Cooper, 1989). Each finding-level effect size, the effect related to each separate outcome measure, was first coded as if it were an independent event. For example, if a single study of achievement reported effect sizes on midterm and final exam scores, the two nonindependent findings were coded separately and reported as redundant. For estimates of the effects of small-group learning on achievement based on independent samples, the two effect sizes were averaged and reported as nonredundant.[3] The latter procedure generally results in conservative estimates of effects.

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[1] In addition to the number of participants in experimental and control groups, qualified studies report either means and standard deviations, chi-square statistic, *F* ratio, *t* value, *r* index, *p* value, or *z* score.

[2] Unless otherwise noted, average refers to the mean.

[3] Each independent effect size was multiplied by the inverse of its variance, then the sum of these products was divided by the sum of the inverses.

We calculated effect sizes with weighted and unweighted procedures. In the unweighted procedure, each effect size estimate was weighted equally in calculating the average effect. In the weighted procedure, greater weight was given to effect sizes associated with larger samples based on the assumption that the larger samples more closely approximate actual effects in the student population of interest.[4] We tested weighted effect size estimates for statistical significance by calculating 95% confidence intervals. If the confidence interval did not include zero, the effect was characterized as statistically significant.

Tests for conditional effects

We tested potential conditional effects of small-group learning using homogeneity analysis (Cooper, 1989). Homogeneity analysis involves comparing the variance exhibited by a set of effect sizes with the variance expected if only sampling error or chance is evident. If the results of homogeneity analysis suggest that the variance in a set of effect sizes can be attributed to sampling error or chance alone, as indicated by a non-significant total chi-square statistic (Qt), the analysis is complete. In these cases, no tests of conditional effects are necessary because one can reasonably assume that the data in the sample adequately represent a population of students. A statistically significant Qt suggests the need for further division or grouping of the data. Further grouping may be needed by population (e.g., first-year or other students), methodological factor (e.g., research reported in peer-reviewed journal or other source), small-group learning procedure (e.g., time spent learning in groups), type of outcome (e.g., motivation or self-esteem within attitudes), or a range of other potentially relevant factors.

The between-group chi-square statistic (Qb) that we report is used to test whether the average effects of the groupings analyzed are homogeneous. A statistically significant

[4] In the weighted procedure, the nonredundant effect is weighted by the inverse of its variance. Thus, the sample contributes only one effect size weighted proportionally to its sample size. In an analysis that examined the effects of small-group learning on separate findings, however, this sample contributes one effect estimate to each of the two calculations. Thus, the shifting unit approach retains as much data as possible while holding to a minimum any violation of the assumption that the data points are independent.

Qb indicates that the grouping factor contributes to the variance in effect sizes, in other words, that the grouping factor has a significant effect on the outcome measure analyzed. The within-group chi-square statistic (Qw) reported is comparable to the Qt, with significant values suggesting the need for further grouping.

Study coding

The studies that we collected were coded by an analyst with extensive experience coding and analyzing research on small-group learning. Two additional analysts independently checked the coding that we employed for this study. We resolved occasional differences through consensus.

Meta-analysis results

The literature search produced 383 reports related to small-group learning in postsecondary SMET from 1980 or later, 39 (10.2%) of which met the inclusion criteria for this meta-analysis. Of the 39 studies that we analyzed, 37 (94.9%) presented data on achievement, 9 (23.1%) on persistence or retention, and 11 (28.2%) on attitudes. These percentages sum to more than 100 because several studies presented outcomes from more than one category. Most of the reports that we retrieved did not qualify for inclusion because they were not based on research.[5] Characteristics of the 39 included studies are listed in Appendix A.

Main effect of small-group learning

The main effect of small-group learning on achievement, persistence, and attitudes among undergraduates in SMET was significant and positive. We summarize these results in Table 1. Based on 49 independent samples, from 37 studies encompassing 116 separate findings, students who learned in small groups demonstrated greater achievement (d = 0.51) than students who were exposed to instruction without cooperative or collaborative

[5] Studies dated 1980 or later were excluded as follows: 199 (52.0%) did not involve research (including conceptual papers and classroom resources), 92 (24.0%) did not report sufficient quantitative data to estimate effect sizes (including qualitative investigations), 35 (9.1%) were conducted in psychology laboratories, 12 (3.1%) were conducted outside accredited postsecondary institutions in North America, and 6 (1.6%) compared one or more small-group learning methods with each other.

grouping. Similarly, based on 10 independent samples and findings from 9 studies, students who worked in small groups persisted through SMET courses or programs to a greater extent ($d = 0.46$) than students who did not work cooperatively or collaboratively. Finally, based on 12 independent samples, from 11 studies encompassing 40 findings, students in small groups expressed more favorable attitudes ($d = 0.55$) than their counterparts in other courses or programs. These weighted effect sizes did not differ substantially from the unweighted findings. Similarly, redundant effect sizes, based on all nonindependent findings, were comparable to those for the nonredundant or aggregated findings, based on the independent samples reported above.

Insert Table 1 about here

Distribution of effect sizes

The results of the homogeneity analysis reported in Table 1 suggest that the distribution of effect sizes for persistence-related outcomes (see Figure 1) can reasonably be attributed to chance or sampling error alone. The results also suggest that further grouping of the achievement and attitudinal data is necessary to understand the conditional effects of small-group learning. As indicated by statistically significant Qt statistics, one or more factors other than chance or sampling error account for the heterogeneous distribution of effect sizes for achievement (see Figure 2) and attitudes (see Figure 3).

Insert Figures 1 through 3 about here

Conditional effects of small-group learning

Methodological factors. Our analyses of the conditional effects of small-group learning suggested that significant variation in effect sizes for achievement-related outcomes can be attributed to method-related influences. We summarize the results of these analyses in Table 2. Studies that identified the investigator as the instructor reported significantly greater effect sizes ($d = 0.73$) than studies that did not report the investigator as directly involved in instruction ($d = 0.41$). Studies that contrasted an experimental and control group (two-sample research designs) reported significantly greater effects ($d = 0.57$) than studies that analyzed pretests and postests from a single sample ($d = 0.30$). Investigations undertaken at four-year institutions were associated with significantly greater effects ($d = 0.54$) than those at two-year colleges ($d = 0.21$). Importantly, based on data from 276 students representing seven independent samples at six two-year colleges, the average weighted effect size of 0.21 was one of only two statistically nonsignificant results of small-group work reported in our entire study.

Insert Table 2 about here

Several methodological factors were not associated with differences in average effects. The effects of small-group learning did not differ significantly among the highly aggregated SMET fields of study that we examined. The average weighted effect size (*d*) in allied health (including physical therapy and nursing) was 0.66, compared with 0.53 in mathematics (including statistics and computer science) and 0.42 in the sciences (including chemistry, biology, and physics). No evidence of publication bias was apparent. Although effect sizes reported in journals were slightly greater ($d = 0.56$) than those reported in theses, conference proceedings, or other reports ($d = 0.43$), the difference was not statistically significant. The statistically significant Qw statistics reported in Table 2 suggest the need for further grouping of several factors to better understand other method-related conditional effects of small-group learning on achievement.

Similar to the data on achievement, much of the variance in effect sizes for attitudinal outcomes was associated with methodological factors. Unlike the data on achievement, however, the effects of small-group learning differed significantly among

SMET fields of study. The average weighted effect size (*d*) in the sciences was 0.87, compared with 0.62 in allied health, 0.43 in mathematics, and 0.25 in engineering. These differences are based on a relatively small number of independent samples.

Insert Table 3 about here

Also unlike the data on achievement, studies on attitudes with enhanced research designs, which compared an experimental and control group, did not report significantly greater effects ($d = 0.56$) than studies that analyzed pretests and postests from a single sample ($d = 0.55$). The attitudinal data did show evidence of publication bias, with greater effects reported in journals ($d = 0.77$) than in other sources ($d = 0.42$). All attitudinal studies originated at four-year institutions, precluding an analysis by institutional type. We also did not have sufficient data to analyze differences between instruction by the investigator and by other individuals. As in the analysis of achievement-related outcomes, the statistically significant Qw statistics reported in Table 3 suggest the necessity for further grouping to better understand other conditional effects of small-group learning on students' attitudes.

Groups of students. Our conditional analysis of the effects of small-group learning on different groups of students addressed issues of gender and racial or ethnic equity, although we had somewhat limited data from which to analyze contrasts between mixed composition and composition predominantly or exclusively of women or members of underrepresented groups (African Americans and Latinos/as). We summarize the results of these analyses in Table 4. Based on a relatively large number of independent samples ($n = 48$), no significant difference in the positive effects of small-group learning on students' achievement was evident between predominantly female ($d = 0.39$) and heterogeneous or mixed gender groups ($d = 0.55$). An analysis of fewer samples ($n = 12$) indicated that the benefits of small-group learning on students' attitudes were greater for predominantly female groups (d = 0.72) than groups of mixed gender (d = 0.44). This difference is due primarily to the results from a single study, however, as suggested by the much smaller differences in unweighted effect sizes (0.51 and 0.50).

Insert Table 4 about here

Next, we contrasted the effects of small-group learning for students based on the racial or ethnic composition of the group. In so doing, we assumed that groups were predominantly white when reports did not explicitly identify them as heterogeneous or composed predominantly or exclusively of members of underrepresented groups. The positive effect of small-group learning on students' achievement was significantly greater for groups composed primarily or exclusively of African Americans and Latinos/as (d = 0.76) compared with predominantly white (d = 0.46) and relatively heterogeneous (d = 0.42) groups. Sufficient data were not available to analyze the conditional effects of the racial or ethnic composition of groups on students' attitudes.

We also contrasted effects for SMET majors (d = 0.61), preservice teachers (d = 0.40), and other non-majors (d = 0.61) and the effects for first-year (d = 0.52) and other (d = 0.54) students on achievement-related measures. None of these contrasts was statistically significant. Finally, we contrasted the effects of small-group learning on attitudinal outcomes for these groups of students. No statistically significant difference in attitudes was apparent between first-year (d = 0.82) and other (d = 0.55) students, most likely because this contrast was based on a relatively small number of independent samples. Preservice teachers (d = 0.70) expressed significantly more favorable attitudes in general than SMET majors (d = 0.46), although this result was again largely due to the influence of a single study.

Small-group learning procedures. We summarize the conditional effects of various small-group learning procedures in Table 5. The teaching and learning setting was associated with significantly different effects on achievement, with a higher average weighted effect for Supplemental Instruction (*d* = 0.65)--typically study sessions outside of class--than for in-class instruction (*d* = 0.44). The pattern of differences was reversed for attitudinal outcomes. More favorable effects on attitudes were evident for in-class instruction (*d* = 0.59) than for Supplemental Instruction (*d* = 0.24). Various procedures for placing students into working groups--self-selection by students, random assignment by instructors, and non-random assignment by instructors--were not associated with significantly different achievement-related or attitudinal outcomes. This last result was based on relatively small samples.

Insert Table 5 about here

Our opportunities to assess the conditional effects of different small-group procedures in more detail were limited by sparse descriptions of teaching and learning practices in most studies. Still, we were able to examine the time students spent in groups. Our measure was based on available data that reflected the following four factors: (1) the duration of each study (i.e., one semester or more), (2) the number of sessions in which group work was possible, (3) the time available for group work during those sessions, and (4) the time students actually spent working together.

We represented the time that students spent in groups as high, medium, or low. We coded as high any semester or quarter length study that met more than once a week, during which students spent half or more of the course time working in groups. High group time also included small-group workshops that met for a semester or longer. We coded as medium group time shorter term studies, including workshops or seminars that were less than a semester long, and any semester or quarter length study that met more than once a week, during which students spent less than half of the course time working in groups. Medium group time also included courses that met only once a week, during which time students spent an hour or less in groups. We coded as low group time studies in which group work was conducted informally outside of class, used for lecture breaks, or employed only for quizzes and tests. We did not include studies in this contrast when no information about duration was available or when information about the number of class meetings each week was missing.

No significant association between the measures of time spent in groups and achievement was evident. We noted a trend toward greater achievement-related effects with medium group time (d = 0.73) than with group time that was high (d = 0.52) or low (d = 0.52). In contrast, the data suggested that greater time spent working in groups had significantly more favorable effects on students' attitudes, with effects sizes of 0.77 for high group time, 0.26 for medium, and 0.37 for low. The latter result was based on a relatively small number of independent samples.

Outcome measures. Next, we contrasted achievement-related outcomes by the type of assessment method. We summarize the results of these analyses in Table 6. Investigators of 40 independent samples assessed achievement with exams or grades and 13 did so with standardized tests. The effects of small-group learning on achievement were significantly greater when measured with exams or grades (d = 0.59) than with the standardized instruments (d = 0.33). Finally, we took a more nuanced look at types of attitudes, including data from seven samples on attitudes toward learning SMET material, six on self-esteem, and three on motivation to achieve. Although small-group work among students had significant and positive effects on students' attitudes toward learning the material (d = 0.56) and their self-esteem (d = 0.61), the effect on their motivation to achieve (d = 0.18) was one of only two nonsignificant results of small-group work that we report in this study.

Insert Table 6 about here

Discussion and conclusions

Robust main effects

The results of the meta-analysis suggest that small-group learning has significant and positive effects on undergraduates in SMET courses and programs. Average main effect sizes are consistently around half a standard deviation, exceeding most findings in comparable reviews of educational innovations. Based on a synthesis of more than 300 meta-analyses, the average effect of classroom-based educational interventions on student achievement is 0.40 (Hattie et al., 1997). For educational interventions in general, effect sizes exceeding 0.33 are generally considered to have practical significance (Gall et al., 1996). The 0.51 effect of small-group learning on achievement reported in this study would move a student from the 50th percentile to the 70th on a standardized test. Similarly, a 0.46 effect on students' persistence is enough to reduce attrition from SMET courses and programs by 22%.[6] The 0.55 effect on students' attitudes far exceeds the average effect of 0.28 (Hattie et al., 1997) for classroom-based educational interventions on affective outcome measures. Even if these large effects could be attributed primarily to greater expectations and efforts accompanying the novelty of most educational innovations (reported by Walberg, 1984, as an estimated average effect of 0.28), this possibility does not represent a major criticism of small-group learning. Indeed, one might consider any educational program or practice that can achieve such high effects as worthwhile.

The main effect of small-group learning on achievement is particularly robust, as suggested by analyses of the potential influence of unretrieved studies, commonly known as the file drawer problem, and other indicators. Analyses of the file drawer (Orwin, 1983) indicate that 29 independent samples reporting zero-effect-sizes not identified by our search would be needed to lower the average weighted effect size for achievement from 0.51 to 0.32, an effect size that is not considered practically significant. Unretrieved reports of

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[6] Using Cooper's (1989) procedure, the difference in proportions = $\frac{d}{\sqrt{d^2 + 4}}$

zero-effect-size from four independent samples would be needed to lower the average weighted effect size for persistence from 0.46 to 0.32, and nine would be needed to lower the average weighted effect size for attitudinal outcomes from 0.55 to 0.32. Given the scope of our search for qualified research and the consistently positive effects reported across independent samples, it is unlikely that unretrieved studies would have a substantial impact on the magnitude of the effects that we report.

Further evidence of the robustness of the effects is found in the small differences between unweighted and weighted, redundant and nonredundant effect sizes. These small differences suggest that the effects are not unduly influenced by a few unrepresentative studies. In addition, the independent samples that we analyzed are based on responses from a large number of students: 3,471 on achievement, 2,014 on persistence, and 1,293 on attitudes. (Some respondents are counted for two or three outcomes.) Importantly, *all* average effect sizes are positive, and only two, achievement at two-year colleges (based on responses from 276 students) and motivation to achieve (based on responses from 483 students), are not statistically significant.

Conditional effects of small-group learning

Methodological factors. We present our analyses of conditional effects as exploratory because of the relatively small number of independent samples involved. The file drawer problem is particularly acute in these analyses. Overall, our analyses of the conditional effects of methodological factors support the robustness of the effects of small-group learning on achievement, persistence, and attitudes. We did not analyze conditional effects for the persistence data because the homogeneous variance suggests that their distribution can reasonably be attributed to chance or sampling error alone. For achievement-related outcomes, however, the difference in results between two-sample and one-sample studies is consistent with the proposition that studies with enhanced research designs report greater effects of small-group learning.

A common criticism of meta-analysis relates to bias resulting from the undue influence of statistically significant results reported in journals over unpublished reports of statistically nonsignificant results, the latter of which frequently are not submitted to or accepted by journal editors because they are not considered newsworthy. We were able to measure publication bias because we reviewed both published and unpublished research reports. Publication bias was evident in studies of attitudes, but not of achievement. One might interpret this result as suggesting that journal editors and reviewers are not biased toward reporting predominantly significant and positive results of small-group learning on students' achievement, but, at the same time, are somewhat biased toward reporting predominantly significant and positive results of small-group learning on students' attitudes. Alternately, the quantitative data required for meta-analysis may reflect students' ambivalence toward learning in unfamiliar ways. Any conclusions should be regarded as tentative, however, because our analysis includes only four studies of attitudes reported in journals. Importantly, effect sizes not reported in journals, including achievement-related effects from 20 independent samples encompassing 1,305 students, were significant and positive on average.

In general, our data support the inference of robust effects across the disciplines. No significant differences on achievement-related outcomes for students in different fields of study are apparent. Based on analyses of a relatively small number of samples, the positive effects of small-group learning on students' attitudes in the sciences appear to be somewhat greater than those in other SMET fields. Substantive interpretations of potentially different effects by aggregated SMET fields of study (science, mathematics, engineering, and technology--represented by allied health) are difficult, however, without additional data related to the types of tasks on which group members work and the working relationship among the group members.

Effects on achievement in studies that identified the investigator as the small-group instructor were greater than in studies that did not. Still, the average effect sizes for both groups were positive and significant. At least two explanations are possible. One is that investigators who also served as instructors may have biased the research results toward their expectations. Alternately, investigators may have tended to implement small-group learning procedures somewhat more effectively than their counterparts. These two explanations are not mutually exclusive.

Groups of students. Our analyses of the effects of small-group learning on different groups of students produced significant and positive results for achievement-related outcomes. The effects were consistent for the different groups we studied and did not vary significantly between men and women; SMET majors, preservice teachers, and other nonmajors; or first-year and other students. These general effects are particularly important because they suggest that some small-group work is more effective than purely lecture-based instruction in the gateway courses taken by majors who strive toward SMET professions, to preservice teachers who aspire to convey the excitement of SMET to students, and to other nonmajors who hope to gain SMET literacy. In addition, the positive effects of small-group learning were significantly greater for members of underrepresented groups (African Americans and Latinos/as).

Small-group work also led to more favorable attitudes among men and women; SMET majors and preservice teachers; first-year and other students. More favorable attitudes were especially evident in groups of women. These results are particularly important given widespread efforts among policymakers and practitioners to develop favorable attitudes toward SMET among all students.

Small-group learning procedures. We also found that Supplemental Instruction (typically study sessions outside of class) has greater effects on students' achievement than in-class collaboration, and in-class collaboration has more favorable effects on students' attitudes than Supplemental Instruction. Various procedures for assigning students to groups do not seem to have significantly different effects on student achievement. The analysis suggests that the more time students spend working in groups, the more favorable their attitudes become.

Outcome measures. The effects of small-group learning were conditional upon the way that achievement was assessed and the type of attitude measured. Significantly greater average effects sizes were apparent when achievement was measured by nonstandardized exams or grades than when achievement was measured with standardized tests. The general lack of detailed descriptions of the assessment instruments and the types of tasks associated with each assessment in the research reports that we analyzed impede clarity on questions of why, however.

One possible interpretation is that nonstandardized exams and grades are not as objective in assessing student learning as standardized instruments. This interpretation is consistent with the proposition that investigators who also served as instructors may have biased the research results toward their expectations. Another is that the standardized tests used in these studies may tend to assess content knowledge rather than higher-order thinking skills and problem solving ability. Research reviews (e.g., Cohen, 1994; Pascarella & Terenzini, 1991) suggest that less constrained interactions or more frequent discussions between students and faculty or among students lead to greater higher-order thinking or problem-solving ability, but not necessarily to greater content knowledge.

Finally, the finding that small-group learning leads to greater self-esteem among college students is consistent with previous research (e.g., Johnson, Johnson, & Smith, 1991a; Johnson, Johnson, & Smith, 1991b). Small-group learning also leads to more favorable attitudes toward learning the material. Perhaps the nonsignificant effect of small-group learning on students' motivation to achieve reflects the need for more widespread implementation of one or more of the procedures associated with cooperative learning (cf., Johnson & Johnson, 1989; Johnson, Johnson, & Smith, 1991a; Johnson, Johnson, & Smith, 1991b) under some conditions. Procedures necessary for cooperative learning (in contrast to collaborative learning or other small-group methods) include communicating a common goal to group members, offering rewards to group members for achieving their group's goal, assigning interrelated and complementary roles and tasks to individuals within each group, holding each individual in each group accountable for his or her learning, providing team-building activities or elaborating on the social skills needed for effective group work, and discussing ways in which each group's work could be accomplished more effectively. This interpretation is consistent with the results of Walberg's (1984) research synthesis suggesting that cooperative learning produces average effect sizes of 0.76 on student learning outcomes--an effect considerably larger than most reported in this study. Alternately, the measures of motivation to achieve in these studies might reflect relatively stable personality traits that are not as amenable to change through short-term (e.g., semester-long) interventions as other attitudes toward learning.

Limitations of the study

The meta-analysis is limited in a number of ways. Perhaps its greatest limitation is closely related to its greatest strength. By including only field studies, the analysis gains external validity (reflecting teaching and learning in realistic contexts), but sacrifices some internal validity relative to more controlled laboratory studies. Consequently, the main effects of various small-group learning methods can be generalized with a great deal of confidence, although opportunities for comparing the relative effectiveness of divergent small-group learning practices (i.e., to what extent were cooperative learning procedures applied?) on different groups of students in various settings are more limited. It remains unclear whether the reported effects can be attributed primarily to certain planned practices and procedures in particular (such as one or more of those associated with cooperative learning) or the holistic properties of educational environments that are greater than the sum of their parts. Analyses of laboratory studies and of studies that compare two or more small-group learning methods might provide greater clarity on the conditional effects of various small-group learning procedures. More precise descriptions of procedures employed in field studies might also help.

Our analyses of the conditional effects of small-group work were also limited somewhat by relatively small samples, particularly for students at two-year colleges. In addition, primarily because of the breadth of our focus on effectiveness, we did not attempt to analyze issues of efficiency (e.g., time and expense preparing lessons) or other barriers (e.g., faculty reward structures or lack of resources) to broader implementation of small-group learning. These issues have been addressed by the National Science Foundation (1996), and warrant continued investigation.

Implications for theory, research, policy, and practice

Despite its limitations, this meta-analysis has important implications. The results suggest that small-group learning is effective in undergraduate SMET courses and programs, and support more widespread implementation of small-group learning in undergraduate SMET. Students who learn in small groups generally demonstrate greater academic achievement, express more favorable attitudes toward learning, and persist through SMET courses or programs to a greater extent than their more traditionally taught counterparts. The reported effects are relatively large in research on educational innovation and have a great deal of practical significance.

Results of the analyses of student groups have particularly important implications for policy and practice because they are consistent with the proposition that small-group work is warranted during the first year of college for all students in SMET courses and programs. In addition, the results suggest that small-group learning may have particularly large effects on the academic achievement of members of underrepresented groups and the learning-related attitudes of women and preservice teachers. Moreover, our analysis of small-group learning procedures suggests that greater time spent working in groups leads to more favorable attitudes among students in general and that even minimal group work can have positive effects on student achievement. Furthermore, small-group learning can reduce attrition in SMET courses and programs substantially. The 22% difference in attrition that we report is based on data from various groups of students, from multiple postsecondary institutions, reflecting vastly divergent forms of small-group work.

One important next step is to forge stronger links between learning theory and practice. Although research indicates that small-group learning has significant effects, we do not have a unified theoretical basis for understanding how and why that is the case (Gamson, 1994). A great deal of work remains to move beyond a "black box" approach and to gain a greater understanding of how and why small-group learning is effective (Cohen, 1994; Hertz-Lazarowitz et al., 1992; O'Donnell & Dansereau, 1992). The necessity for a theoretical foundation for practice is supported by research (e.g., Johnson & Johnson, 1989; Woolfolk Hoy & Tschannen-Moran, in press) suggesting that faculty are likely to abandon instructional innovations when initial problems occur if they are not familiar with the theories behind their implementation. Yet knowledge of theory alone is not enough to inform practice. Practitioners must be adept at understanding nuances of situations to determine when a principle actually is applicable. Resources available for practitioners are listed in an annotated bibliography by Cooper and Robinson (1997) and are also described in the web site for the National Institute for Science Education at the Wisconsin Center for Education Research.

From our viewpoint, work toward improving learning in undergraduate SMET should increasingly involve researchers and practitioners sharing diverse perspectives and comparing data collected and analyzed through various methods. We hope for bridges between practitioners of different small-group learning methods and links among researchers who work with quantitative and qualitative methods. Perhaps the most important component of future analyses is the need for more detailed descriptions of small-group processes or procedures by investigators or instructors who report research on the effects of their work. What was done that can be replicated? A second important component is the need for more detailed descriptions of the type of task in which students were involved. Was the task well-structured, with predefined procedures leading to a single answer; or ill-structured, with several possible paths toward more than one acceptable outcome? A third factor is the need for more authentic assessment of higher-order thinking and problem solving. Fourth, comparisons of the effects of various forms of small-group learning are needed. Fifth, reporting grading procedures would help future analyses a great deal. Were students graded on a curve or through criterion-based measures? Sixth, research on the conditional effects of small-group learning on college students based on achievement level is needed. Is small-group learning effective in general (as suggested by this study) or could it have differential effects on high- or low-achieving students. Seventh, questions of efficiency need to be addressed as well as questions of effectiveness. What are potential barriers to more widespread implementation of small-group learning and how might they be surmounted?

The primary challenge, however, is in moving from analysis to action. The magnitude of the effects reported in this study exceeds most findings in comparable reviews of research on educational innovations and supports more widespread implementation of small-group learning in undergraduate SMET. Small-group learning is clearly successful in a great variety of forms and settings, and holds considerable promise for improving undergraduate SMET education. As recommended by the National Research Council (1996), "Innovations and successes in education need to spread with the speed and efficiency of new research results" (pp. 5-6). Effective action will require bridges among policymakers at national, state, institutional, and departmental levels, and practitioners and scholars across the disciplines. Through collaboration among representatives of these diverse groups, progress can be made toward promoting broader implementation of small-group learning.

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Note. * included in meta-analysis

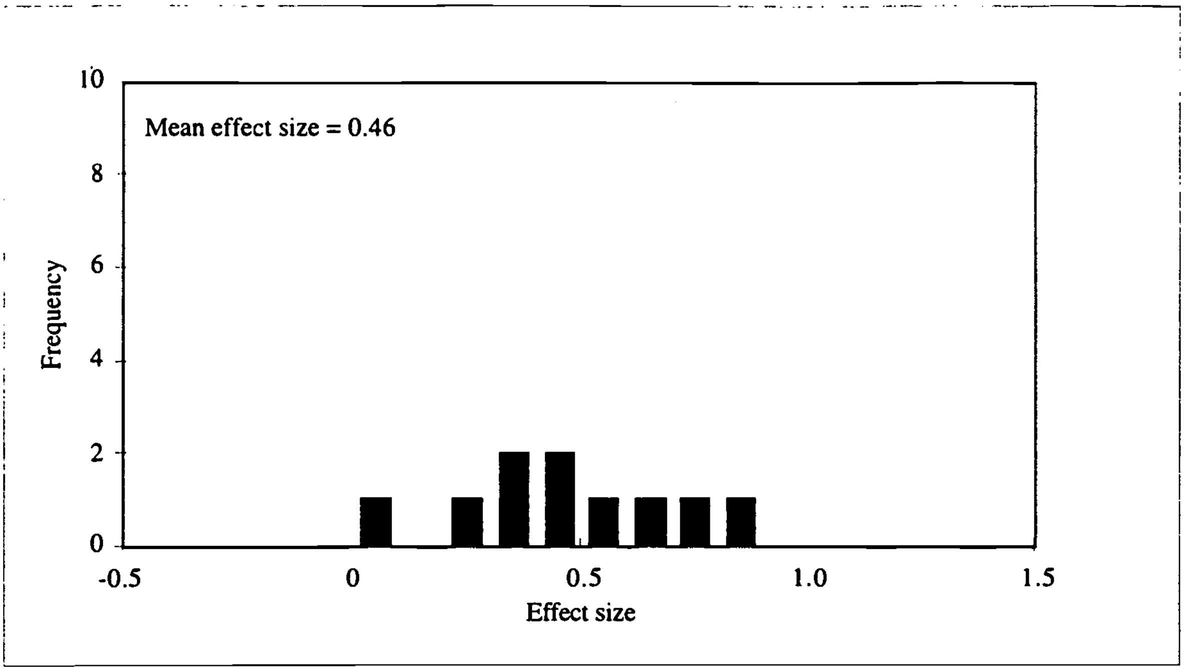

Figure 1. Distribution of nonredundant weighted effect sizes for persistence (n = 10).

Note. Based on data from 2,014 students.

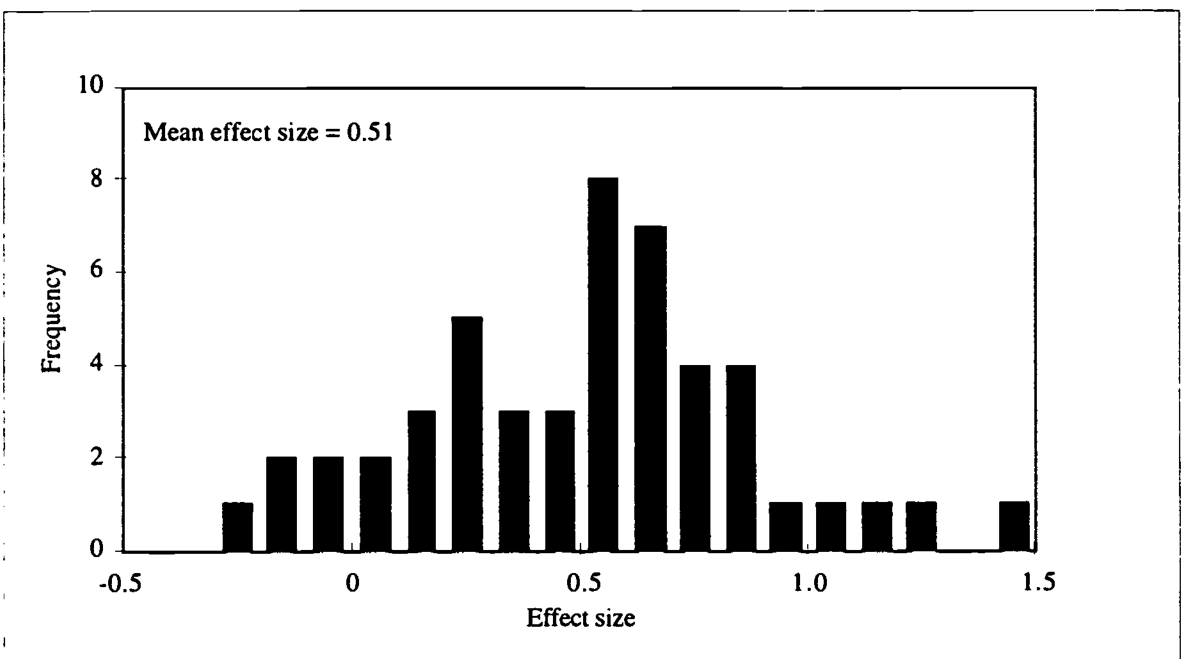

Figure 2. Distribution of nonredundant weighted effect sizes for achievement (n = 49).

Note. Based on data from 3,472 students.

36

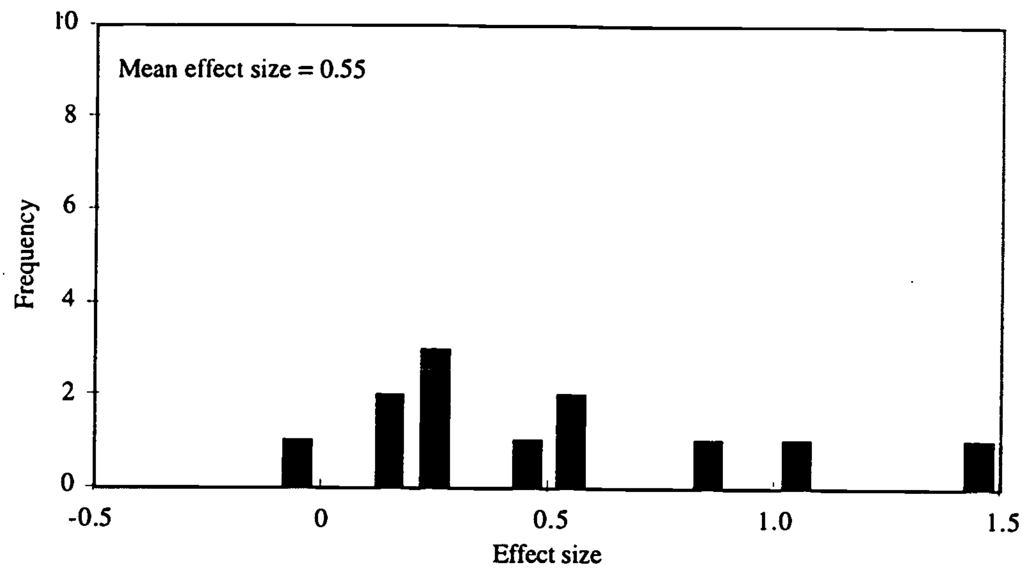

Figure 3. Distribution of nonredundant weighted effect sizes for attitudes (n = 12).

Note. Based on data from 1,293 students.

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Table 1. Main effects of small-group learning.

	Studies	Findings		Average effect size		
Outcome	*N*	*N*	Students	Unweighted	Weighted	Qt
Achievement						
Nonredundant	37	49	3,472	0.51	0.51	90.10*
Redundant		116		0.44	0.44	250.50*
Persistence	9	10	2,014	0.47	0.46	12.75
Attitudes						
Nonredundant	11	12	1,293	0.50	0.55	47.79*
Redundant		40		0.38	0.39	179.97*

Note. All weighted effect sizes are statistically significant (the 95% confidence intervals do not include zero). Unweighted effect sizes were not tested for significance. The number of nonredundant findings represents the number of independent samples analyzed. The number of redundant findings represents the number of total, nonindependent outcomes measured. Students refers to the number of students across independent samples. Nonredundant and redundant findings for persistence are equivalent because no study reported multiple measures from any independent sample.

* $p < 0.05$

Table 2. Method-related effects on achievement.

	Studies	Independent samples		Average effect size			
Measure	*N*	*N*	Students	Unweighted	Weighted	Qb	Qw
Instructor						14.32*	
Investigator	15	18	1,261	0.73	0.73		30.32*
Other	12	18	1,305	0.37	0.41		15.04
Research design						9.03*	
One-sample	6	12	764	0.42	0.30		19.11
Two-sample	31	37	2,559	0.54	0.57		61.95*
Institutional type						6.70*	
Four-year	30	41	3,163	0.57	0.54		76.22*
Two-year	6	7	276	0.15	0.21[ns]		7.15
Discipline						3.85	
Science	9	14	1,071	0.46	0.42		23.59*
Mathematics	22	29	1,956	0.52	0.53		46.25*
Allied Health	6	6	445	0.55	0.66		16.41*
Publication type						2.94	
Journal	21	29	2,166	0.57	0.56		46.81*
Other	16	20	1,306	0.42	0.43		40.34*

Note. Unless noted [ns], all weighted effect sizes are statistically significant significant (the 95% confidence intervals do not include zero). Unweighted effect sizes were not tested for significance.

* $p < 0.05$

Table 3. Method-related effects on attitudes.

	Studies	Independent samples		Average effect size			
Measure	*N*	*N*	Students	Unweighted	Weighted	Qb	Qw
Discipline						22.02*	
Science	3	3	500	0.82	0.87		16.86*
Mathematics	5	5	251	0.43	0.43		1.45
Engineering	1	2	415	0.25	0.25		0.00
Allied Health	2	2	127	0.49	0.62		7.46*
Research design						0.01	
One-sample	4	5	900	0.57	0.55		20.45*
Two-sample	7	7	393	0.46	0.56		27.34*
Publication type						8.44*	
Journal	4	4	485	0.59	0.77		8.05*
Other	7	8	808	0.46	0.42		31.30*

Note. All weighted effect sizes are statistically significant significant (the 95% confidence intervals do not include zero). Unweighted effect sizes were not tested for significance.

* $p < 0.05$

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Table 4. Conditional effects of small-group learning on student groups.

Outcome/ Group	Studies N	Independent samples N	Independent samples Students	Average effect size Unweighted	Average effect size Weighted	Qb	Qw
Achievement							
						3.50	
Pred. women	8	13	737	0.41	0.39		26.42*
Heterogeneous	28	35	2,653	0.54	0.55		57.44*
						12.26*	
Pred. white	25	35	2,308	0.48	0.46		49.26*
Heterogeneous	6	7	351	0.36	0.42		4.96
Pred. underrep. group	6	7	767	0.97	0.76		21.32*
						4.35	
SMET majors	10	11	1,243	0.65	0.61		33.23*
Non-majors	5	8	435	0.62	0.61		4.64
Preservice teachers	6	11	601	0.48	0.40		20.60*
						0.01	
First-year	12	15	1,417	0.52	0.52		31.79*
Other	7	10	766	0.58	0.54		32.40*
Attitudes							
						5.59*	
Pred. women	5	7	530	0.51	0.72		28.93*
Heterogeneous	6	5	763	0.50	0.44		13.27*
						2.91	
First-year	3	3	229	0.73	0.82		17.58*
Other	3	4	814	0.59	0.55		20.36*
						3.85*	
SMET majors	5	6	724	0.51	0.46		36.80*
Preservice teachers	4	4	489	0.52	0.70		6.62

Note. All weighted effect sizes are statistically significant significant (the 95% confidence intervals do not include zero). Unweighted effect sizes were not tested for significance.

* $p < 0.05$

Table 5. Conditional effects of small-group learning procedures on outcomes.

Outcome/ Procedure	Studies N	Independent samples N	Students	Average effect size Unweighted	Weighted	Qb	Qw
Achievement							
Setting						6.86*	
In-class	26	34	2,223	0.48	0.44		51.57*
Supplemental	9	13	1,090	0.60	0.65		30.09*
Placement into groups						2.04	
Random	9	13	573	0.46	0.46		11.07
Non-random	7	7	451	0.67	0.65		13.39*
Self-selected	4	5	306	0.50	0.59		4.59
Time in groups						3.98	
High	12	13	1,168	0.53	0.52		24.05*
Med.	8	10	515	0.63	0.73		7.88
Low	7	10	538	0.52	0.52		12.83
Attitudes							
Setting						4.22*	
In-class	8	9	1,140	0.58	0.59		42.57*
Supplemental	3	3	153	0.29	0.24		1.00
Placement into groups						0.22	
Random	4	5	574	0.40	0.34		10.96*
Non-random	2	2	119	0.40	0.44		0.20
Time in groups						17.75*	
High	6	6	666	0.64	0.77		21.81*
Med.	3	4	500	0.31	0.26		0.76
Low	2	2	127	0.49	0.37		7.46

Note. All weighted effect sizes are statistically significant significant (the 95% confidence intervals do not include zero). Unweighted effect sizes were not tested for significance.

* $p < 0.05$

Table 6. Conditional effects of small-group learning within outcome measures.

	Studies	Independent samples		Average effect size			
Outcome	*N*	*N*	Students	Unweighted	Weighted	Qb	Qw
Achievement						10.90*	
Exam/grade	31	40	2,614	0.56	0.59		65.51*
Stand. test	8	13	1,011	0.37	0.33		39.15*
Attitudes						13.34*	
Toward mtrl.	6	7	939	0.53	0.56		20.19*
Self-esteem	6	6	377	0.47	0.61		26.53*
Motivation	2	3	483	0.16	0.18^{ns}		0.54

Note. Unless noted ^{ns}, all weighted effect sizes are statistically significant (the 95% confidence intervals do not include zero). Unweighted effect sizes were not tested for significance.

* $p < 0.05$

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APPENDIX A

Characteristics of studies in the meta-analysis.

First Author	Year	Source	Discipline	Time	Outcome	Effect
Baker, L.	1995	dissertation	computer science	low	achievement	0.04
					persistence	0.36
Basili, P.	1991	journal	chemistry	low	achievement	0.68
Bonsangue, M.	1991	unpublished	statistics	medium	achievement	0.54
Bonsangue, M.	1994	journal	mathematics	medium	achievement	0.42
					persistence	0.75
Borresen, C.	1990	journal	statistics	unknown	achievement	0.87, 0.89
DeClute, J.	1993	journal	physical therapy	unknown	achievement	0.73
Dees, R.	1991	journal	mathematics	high	achievement	0.44
					persistence	0.52
Frierson, H.	1986	journal	nursing	medium	achievement	0.70
Frierson, H.	1987	journal	nursing	medium	achievement	1.21
Ganter, S.	1994	journal	mathematics	unknown	achievement	-0.06, -0.03
Giraud, G.	1996	unpublished	statistics	medium	achievement	0.53
Hall, D.	1992	journal	biology	high	attitudes	0.87
Hanshaw, L.	1982	journal	biology / physical sci.	low	achievement	0.58, 0.60, 0.66
Harding, R.	1994	conference paper	mathematics	unknown	achievement	0.04, 0.33
Iwasiw, C.	1993	journal	nursing	unknown	achievement	0.28
Jimison, L.	1990	dissertation	mathematics	medium	achievement	0.77
Johnson, S.	1992	report	mathematics	high	achievement	0.22
Jones, D.	1996	conference paper	engineering	medium	attitudes	0.24, 0.25
Kacer, B.	1990	unpublished	mathematics	medium	achievement	0.16, 0.39, 0.55
					attitudes	0.56
Keeler, C.	1994a	journal	statistics	low	achievement	0.66, 0.82
					persistence	0.49
Keeler, C.	1994b	journal	mathematics	high	achievement	0.26
					persistence	0.09

Note. Nonredundant weighted effect sizes reported for each independent sample within a study.

First Author	Year	Source	Discipline	Time	Outcome	Effect
Keeler, C.	1995	journal	computer science	high	achievement	0.51
					attitudes	0.30
					persistence	0.90
Koch, L.	1992	journal	mathematics	high	achievement	0.65
					persistence	0.25
Lovelace, T.	1980	journal	mathematics	unknown	achievement	0.75
Lundeberg, M.	1990	journal	chemistry	high	achievement	0.61
Lynch, B.	1984	journal	allied health	low	achievement	0.62
					attitudes	1.02
Mehta, J.	1993	dissertation	mathematics	unknown	achievement	0.96
O'Brien, G.	1994	journal	science	unknown	achievement	-0.19, 0.28, 0.29, 1.18
Overlock, T.	1994	report	physics	unknown	achievement	-0.10
Pisani, A.	1994	dissertation	biology	high	achievement	0.44
					attitudes	0.13
Randolph, W.	1992	dissertation	biology	high	achievement	0.18
Reglin, G.	1990	journal	mathematics	medium	achievement	0.85
					attitudes	0.18
Shearn, E.	1989	conference paper	mathematics	high	achievement	0.37
					attitudes	0.49
Smith, M. E.	1991	journal	chemistry	low	achievement	0.72
Smith, M. J.	1984	dissertation	nursing	low	achievement	-0.22
					attitudes	-0.05
Springer, L.	1997	conference paper	chemistry	high	achievement	0.51
					attitudes	1.46
Treisman, P. U.	1985	dissertation	mathematics	high	achievement	1.02, 1.48
					persistence	0.37, 0.43
Urion, D.	1992	journal	mathematics	medium	achievement	0.58
Valentino, V. R.	1988	dissertation	mathematics	high	achievement	0.20
					attitudes	0.60
					persistence	0.53

Note. Nonredundant weighted effect sizes reported for each independent sample within a study.

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