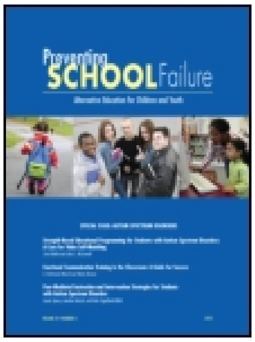

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Assessing the Relation Between Seventh-Grade Students' Engagement and Mathematical Problem Solving Performance

AMY E. LEIN,[1] ASHA K. JITENDRA,[1] KRISTIN M. STAROSTA,[2] DANIELLE N. DUPUIS,[1] CHEYENNE L. HUGHES-REID,[3] and JON R. STAR[4]

[1]*University of Minnesota, Minneapolis, MN, USA*
[2]*Colonial Intermediate Unit 20, Easton, PA, USA*
[3]*Nemours/Alfred I duPont Hospital for Children, Wilmington, DE, USA*
[4]*Harvard University, Cambridge, MA, USA*

In this study, the authors assessed the contribution of engagement (on-task behavior) to the mathematics problem-solving performance of seventh-grade students after accounting for prior mathematics achievement. A subsample of seventh-grade students in four mathematics classrooms (one high-, two average-, and one low-achieving) from a larger intervention study assessing improvement in middle school students' proportional reasoning was assessed on initial mathematics achievement, on-task behavior, and mathematics problem-solving performance. Results suggested that engagement uniquely predicted mathematics problem-solving performance after controlling for prior mathematics achievement. Furthermore, the authors found differential rates of engagement for the three achievement groups. Based on an analysis of engagement by instructional lesson, the authors offer suggestions for addressing engagement when designing instruction.

Keywords: engagement, mathematics achievement, middle school, on-task behavior, problem solving

School and classroom engagement have received attention over the years because of students' increasing disaffection with school (Fredricks, Blumenfeld, & Paris, 2004; National Research Council & Institute of Medicine, 2004). A growing body of evidence suggests that early school engagement is predictive of students' long-term achievement trajectories (Ladd & Dinella, 2009). Furthermore, previous research indicates that diminished engagement in secondary school is associated with adolescent outcomes such as increased school dropout rates (Christenson & Thurlow, 2004; Finn & Rock, 1997), substance abuse (Bond et al., 2007), mental health problems (Wang & Holcombe, 2010), future unemployment, poverty, and incarceration (Martin & Halperin, 2006; National Mathematics Advisory Panel [NMAP], 2008).

The research on school engagement demonstrates that children can benefit from schooling when the classroom environment is engaging and motivating in ways that facilitate learning (Ladd & Dinella, 2009). Typically, research has investigated connections between engagement and background characteristics of students (e.g., socioeconomic status, history of poor achievement in school) (Anderson & Keith, 1997; Parkerson, Lomax, Schiller, & Walberg, 1984; Reynolds & Walberg, 1992). Given that such student characteristics are not amenable to change, recent research has focused on malleable student characteristics (e.g., attitude, motivation, engagement) (Fredricks et al., 2004), as well as instructional features influencing engagement (e.g., teacher–student relationship quality, perceived authenticity of school work, perceived support for learning and autonomy) and academic achievement (Dotterer & Lowe, 2011; Greene, Miller, Crowson, Duke, & Akey, 2004; Hughes, Luo, Kwok, & Loyd, 2008; Marks, 2000; Park, 2005).

Within academic achievement, students' competence in mathematics is particularly important. In fact, mathematical competence accounts for a unique amount of variance in future employment success above and beyond reading skills and IQ (NMAP, 2008; Rivera-Batiz, 1992). The National Mathematics Advisory Panel (NMAP) report (2008) emphasized the importance of not only computational fluency, but also conceptual understanding and problem-solving skills. Failure to develop problem-solving skills in concert with conceptual understanding and computational fluency contributes to poor mathematics performance as children age. Specifically, many middle school students remain "unprepared for [the] complex and novel problem solving" (Nathan & Kim, 2009, p. 91) that is increasingly required of students as they progress through middle and high school. As such, it is critical that research investigates variables (e.g., engagement) that predict mathematical problem-solving performance.

Address correspondence to Amy E. Lein, Department of Educational Psychology, University of Minnesota, Education Sciences Building, 56 East River Road, Minneapolis, MN 55455, USA. E-mail: leinx032@umn.edu

School Engagement and Mathematical Problem Solving

The authors identified eight studies that assessed the contribution of engagement to academic achievement while accounting for prior academic achievement (Bodovski & Farkas, 2007; DiPerna, Volpe, & Elliott, 2005; Dotterer & Lowe, 2011; Guay & Vallerand, 1997; Hughes et al., 2008; Ladd & Dinella, 2009; Onatsu-Arvilommi & Nurmi, 2000; Wang & Holcombe, 2010). Of these, four specifically examined the contribution of engagement to mathematics performance (Bodovski & Farkas, 2007; DiPerna et al., 2005; Hughes et al., 2008; Onatsu-Arvilommi & Nurmi, 2000). Of these, only two studies addressed problem solving in addition to basic mathematics skills (DiPerna et al., 2005; Onatsu-Arvilommi & Nurmi, 2000). Results from both studies suggest that prior mathematics achievement predicts current mathematics performance in both direct and indirect ways. Onatsu-Arvilommi and Nurmi (2000) found that poor mathematics skills appeared to predict development of maladaptive strategies (i.e., helpless behavior, task-irrelevant behavior, and lack of persistence) at the beginning of students' first year of school, which in turn predicted poor mathematics performance the following year. DiPerna et al. (2005) found that for students in elementary school, prior mathematics achievement predicted both current mathematics achievement as well as student motivation (i.e., goal-directed behavior regarding academic tasks). Student motivation served to predict student engagement in the classroom, which, in turn, also predicted current mathematics performance.

In summary, few studies have examined the contribution of engagement to mathematics competence in general, and word problem solving in particular, especially during the critical middle school years. In middle school, students begin navigating the challenging transition from additive to multiplicative reasoning, which influences mastery of higher-level mathematics (Boyer, Levine, & Huttenlocher, 2008; NMAP, 2008). Furthermore, previous studies relied primarily on self-report, or teacher- and parent-rating scales to the exclusion of direct observational measures. Self-report measures and rating scales are often criticized for failing to eliminate bias, whereas "classroom observations conducted by trained observers are the best predictors of student achievement" (Lawrenz, Huffman & Robey, 2003, p. 409). We conducted a study to explore the contribution of directly observable behavioral indicators of engagement to the mathematics problem-solving performance of middle school students, while accounting for prior mathematics achievement. In addition, we explored rates of engagement across students in high-, average-, and low-achieving classrooms and across instructional lessons to determine if engagement varies across achievement groups and whether certain instructional features may serve to motivate and facilitate student engagement. Specifically, three questions guided this study: (a) To what extent does engagement (i.e., on-task behavior) predict seventh-grade students' mathematical problem-solving performance after controlling for prior mathematics achievement? (b) Do students in high-, average-, and low-achieving classrooms differ in their rates of engagement? (c) What instructional features enhance engagement for students in the high-, average-, and low-achieving classrooms?

Method

Setting and Participants

The data reported in this study were collected as part of a larger intervention study assessing improvement in middle school students' proportional reasoning. Participants in the larger study were recruited from eight seventh-grade classrooms in a middle school in the northeastern United States. The eight classrooms, randomly selected from 24 seventh-grade classrooms in the middle school, included two high-, four average-, and two low-achieving classrooms. Based on student grades in mathematics from the previous school year, students were assigned to classrooms that were designated as academic (high achieving), applied (average achieving), and essential (low achieving). Blocking by achievement group status, classrooms were randomly assigned to either the intervention or a "business as usual" control condition. The larger study included two separate investigations that evaluated the effects of the intervention on proportional problem solving following instruction in ratios and proportions (Study 1) and then percent (Study 2) three months later. The intervention is a multicomponent package designed to teach solving real-world problems comprising proportion and percent word problems, and incorporates four major features: priming the mathematical structure of problems, modeling the mathematical situation via visual representations, explicit teaching of problem-solving strategies and metacognitive strategy use, and encouraging procedural flexibility. Control classrooms received instruction on the same topics (i.e., proportion and percent) using procedures outlined in the district-adopted textbook.

The present study focuses on results of student engagement for a subsample of 24 students in the treatment classrooms only in Study 2 for the following reasons. First, intervention effects are not the focus of this study, and student engagement was examined in Study 2 only. Second, previous analysis demonstrated statistically significant differences between conditions for high-achieving students only, favoring the intervention condition on the problem-solving measure. Last, the correlation between prior mathematics achievement and problem solving was the same for both the intervention and control conditions. The intervention for Study 2 included nine lessons, each 45 minutes in length. Six instructional lessons were delivered in whole-class instructional arrangement, whereas one lesson was completed with students working in small groups, and the remaining two were review lessons.

The subsample (17 female, 7 male) of 24 participants included a representative sample of six students from each of the four treatment classrooms based on teacher judgments of high-, average-, and low-performing students, who were observed and assessed for on-task behavior. The subsample consisted of 7 (29%) Hispanic, 4 (17%) African American, and 12 (50%) Caucasian students. Of the 24 students, 1 (4%) was an English language learner, 15 (63%) were eligible for free or reduced-priced lunch, and 2 (8%) were students with learning disabilities who had Individualized Education Plans for both mathematics and reading. The mean age of the sample was 12.78 years (range = 12.17–14.17 years; $SD = 0.44$).

Measures

Predictor Measures

We used the mathematics subtest of the Stanford Achievement Test–Tenth Edition [SAT-10] (Harcourt Brace & Company, 2003) to assess students' prior mathematics achievement (i.e., general mathematical knowledge and skills). The SAT-10 is a norm-referenced, group-administered achievement test that includes two mathematics subtests that assess mathematical content recommended by the National Council of Teachers of Mathematics (NCTM, 2000). The content on the problem-solving (PS) subtest consists of 30 items and is designed to assess number theory, geometry, algebra, statistics, and probability. The procedures subtest includes 20 items and assesses computational skills that are presented in context.

The Behavioral Observation of Students in Schools (B.O.S.S) (Shapiro, 2004) was used to assess student engagement as indexed by on-task behavior in mathematics classrooms. Research assistants observed and recorded both active engagement (e.g., reading aloud, writing, raising hand) and passive engagement (e.g., listening to the teacher or peer, looking at the blackboard or worksheet, silently reading assigned material) using a 15s momentary time sampling system. In each classroom, we first determined the order for observing the six students. Next, we used an audio recorder that cued and time-stamped the start of each 15s interval. We recorded active engagement or passive engagement at the beginning of each 15s interval by circling a + for either AET or PET when the target behavior was observed and a – when either behavior was not observed. We observed each student for four 15s intervals (1 minute) before moving to the second student, and so on until all six students were observed and continued the observation in the same order until the end of the 45-min class period or until the end of instruction. For each student, we calculated an aggregate score for active engaged time (AET) and passive engaged time (PET) by dividing the number of pluses for both AET and PET by the total number of intervals and multiplying by 100, which represents time "on task" (Shapiro, 2004). To assess interobserver agreement, a second observer independently coded 41% of the observations. Average interobserver agreement, calculated as the number of agreements divided by the number of agreements and disagreements multiplied by 100, was 86%.

Criterion Measure

To assess students' mathematics problem-solving performance, we used an 18-item word problem–solving test. Word problems involving proportion and percent were derived from the Third International Mathematics and Science Study (TIMMS), National Assessment of Educational Progress (NAEP), and state assessments. All students were given ample time (about 50 min) to read and complete the items. Each problem was scored 1 when correctly solved and 0 otherwise. The score was the number of correct responses for all items.

Procedure

In November of seventh grade, students were selected for study participation and assessed on incoming mathematics achievement. In late May, we assessed students' mathematics problem-solving performance and recorded students' on-task behaviors during six (whole-class instruction) of the nine instructional lessons using classroom observations. These lessons were selected for observations, because they were similar in instructional features in that they began with a lesson opening [e.g., review key vocabulary, concepts] followed by explicit teacher modeling, guided practice, independent practice, and lesson closure, thus allowing us to compare student engagement across sessions. Teachers conducted the mathematics problem-solving assessment using standardized administration procedures. Five research assistants in education conducted the observations. A videotape of students' classroom behavior provided by the author of the measure was used to train the research assistants to code on-task behaviors. A predetermined criterion of 90% consensus was reached before live classroom observations were conducted. We obtained student assent to be observed during class instruction from the 24 target students prior to implementation. Because research assistants were in the classrooms for the entire duration of the larger study, students were familiar and comfortable with the research assistants' presence and behaved as they normally would otherwise in their classrooms.

Data Analysis and Results

We used a multiple regression analysis, where we entered the set of predictors simultaneously, to investigate the first question regarding the extent to which prior mathematics achievement and engagement accounted for the variance in problem solving. Although a power analysis indicated that the sample size was sufficient to answer the research question, we also examined the data for evidence that model assumptions were satisfied for the multiple regression analysis. The data indicated that there were no major violations regarding the assumptions of (a) a linear relationship between predictors and the dependent variable and (b) a normal distribution of residuals. However, conditional homogeneity of variance of the dependent variable across all levels of the fitted values could not be assessed due to the small sample size. The results indicated that the model accounted for 62% of the variance in mathematics problem-solving performance, $F(2, 21) = 16.77$, $p < .001$. Next, we calculated the percentage of unique variance accounted for by each of the predictor variables. We conducted a blocked regression for each predictor variable, in which we entered one variable in the first block of the regression analysis and the other variable in the second block to determine the change in r^2. Engagement was a stronger predictor than prior mathematics achievement and accounted for 26.9% of the unique variance in mathematics problem solving, whereas prior mathematics achievement accounted for 18.4% of the variance (see Table 1).

Regarding the second question (whether high-, average-, and low-achieving students differed in their rates of engagement), we conducted a one-way analysis of variance (ANOVA) with achievement group status as the between-subjects factor on the engagement (AET and PET) scores.

Table 1. Multiple Regression Model Predicting Mathematics Problem Solving

Variable	*b*	*SE(b)*	*b**	*t*	*p*	*Unique* r^2
Constant	−4.68	3.04		−1.54	.138	
SAT-10 mathematics test	0.27	0.09	0.45	3.17	.005	.184
Engagement (AET & PET)	0.14	0.04	0.54	3.83	.001	.269

Note. SAT-10 = Stanford Achievement Test–Tenth Edition; AET = active engaged time; PET = passive engaged time.

The results indicated a statistically significant effect for achievement group, $F(2, 21) = 10.71$, $p < .001$. Follow-up analyses indicated that engagement scores of low-achieving students ($M = 55.81$, $SD = 12.61$) were significantly lower than scores of average- ($M = 79.61$, $SD = 14.42$) and high-achieving ($M = 88.07$, $SD = 8.06$) students; there were no significant differences between scores of average- and high-achieving students.

To address the last question that focused on instructional features that may enhance student engagement, we computed the rate of enagagement for each of the six lessons across achievement groups. The results (see Figure 1) suggest different patterns of engagement for each achievement group. Although engagement was somewhat variable in the first three lessons, high-achieving students showed high and improved rates of engagement. Average-achieving students exhibited a relatively stable, high level of engagement over time. In contrast, the engagement scores of low-achieving students were variable and lower than that of average- and high-achieving students. Interestingly, all three groups showed an increase in engagement during Lesson 4.

Discussion

The primary purpose of this study was to explore the contribution of engagement (on-task behavior) to the mathematics problem-solving performance of seventh-grade students after accounting for prior mathematics achievement. Prior mathematics achievement was significantly predictive of mathematics problem solving, accounting for almost 20% of all variance, and engagement accounted for an even larger proportion of the variance (27%). This finding is in contrast to research suggesting that prior academic achievement is the single strongest predictor of educational outcomes (Anderson & Keith, 1997; Parkerson et al., 1984; Reynolds & Walberg, 1992). Further, the few studies that assessed the contribution of engagement on mathematics competencies found that prior mathematics achievement accounted for the same amount (Bodovski & Farkas, 2007) or a larger proportion of the variance in mathematics performance as did engagement (see DiPerna et al., 2005; Hughes et al., 2008).

Contrary to previous studies that emphasized general mathematics performance, the present study specifically assessed problem solving. Word problems are “typically composed of a mathematics structure embedded in a more or less realistic context” (Depaepe, De Corte, & Verschaffel, 2010, p. 152) and may be considered “as the link between the ‘two faces’ of mathematics, namely its grounding in aspects of reality and the development of abstract formal structures” (Greer, 1997, p. 300). This connection may entail simultaneous activation of prior experiences in the real world and mathematical knowledge. As such, accurate word problem solving may require higher levels of engagement than do other mathematical domains emphasizing procedural knowledge (e.g., computational skill). In the current study, students received a mathematics problem-solving intervention designed to be reflective of real-world problem solving, which possibly was a motivating factor that explained the strong relation between engagement and problem solving.

In addition, the present study examined differences in rates of engagement among students in different achievement groups and across instructional lessons. Both average- and high-achieving students responded to the intervention with high levels of engagement. Although low-achieving students showed relatively low rates of engagement, the fact that they were engaged for about 56% of the time is encouraging. In addition, the results indicated a dramatic increase in student engagement for Lesson 4 (i.e., the introductory lesson on percent of change involving sales tax) for students across the three achievement groups. Interestingly, low-achieving students ($M = 90.2\%$) demonstrated the highest rate of engagement for this lesson compared to average-achieving ($M = 85.4\%$) and high-achieving ($M = 89.3\%$) students. Although all lessons used the same instructional format (e.g., lesson opening, teacher modeling, guided practice), Lesson 4 differed in that it was also designed to explicitly connect students with not only the content and instruction but also the teacher to develop student competence via correcting perceived teacher error. Student interest in this lesson may have

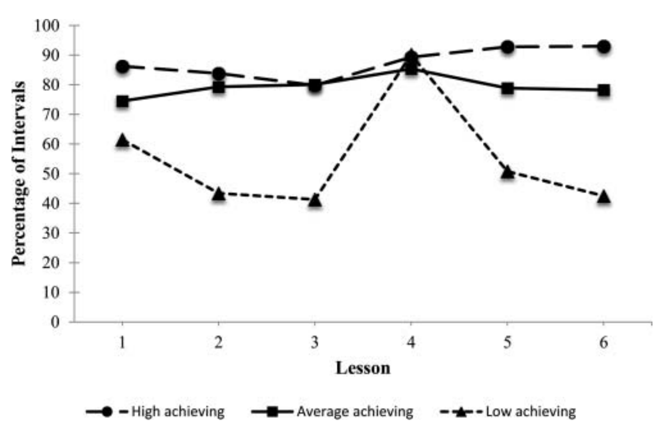

Fig. 1. Rate of engagement by lesson and achievement group status.

been activated when the teacher begins the lesson by telling the students about taking a lamp that was on clearance for $10 to the check-out counter and taking a $10 bill to pay for it. When the cashier says it costs $10.70, the teacher gets angry and shows the big sticker on the lamp that says $10. The teacher stops at this point in the lesson to ask students to help figure out what is going on, because the lamp costs $10.70 even though the sticker says it costs $10. The students respond that the teacher needs to pay sales tax on the purchased lamp.

The previous dialogue illustrates that when teachers entertain students by making mistakes, they relate to students and enable student self-expression (Pogrow, 2008). Such connective instruction is known to predict engagement even more than academic rigor (e.g., creating an academic focus for the class, providing challenging work, questioning students to check for understanding and to support higher order thinking) and lively teaching (e.g., use of games and fun activities, working in groups, using project assignments) (Cooper, 2014). When students are provided with an opportunity to correct the teacher, they experience meaningful relationships that enable them to connect with the teacher and content. The instruction in this lesson likely enhanced student perception of personal competence and autonomy and led to high levels of engagement. This type of connective classroom instruction is especially critical for students in middle school (see Marks, 2000) and students with a history of low performance in mathematics (see Bodovski & Farkas, 2007).

Study Limitations

There are several limitations to the present findings. One limitation of our study is the small sample of students from one middle school that was not ethnically diverse. Future research is needed to replicate the study findings with a larger, more ethnically diverse sample. Second, we operationalized engagement using a specific measure that may not adequately address the multifaceted construct comprised of behavioral, emotional, and cognitive engagement (see Fredricks et al., 2004). Specifically, our definition of engagement (i.e., on-task behavior) focused only on the behavioral component of engagement. Perhaps a more comprehensive definition of the construct is needed to select appropriate, multiple measures (e.g., observations, student self-report, rating scales completed by teachers and parents) to better understand how the various dimensions of engagement relate to mathematical problem solving (Lawrenz et al., 2003). Future research using multiple measures is needed to validate the present findings. Third, this study did not consider instructional features influencing engagement (e.g., teacher–student relationship quality, perceived authenticity of school work, perceived support for learning and autonomy). As such, the role of specific instructional features as mechanisms for classroom engagement needs to be explored in future research. Fourth, this study did not address the number of opportunities to respond that teachers provided. Future research could examine whether the number of opportunities to respond influences engagement.

Another limitation of the study is that the intervention might have attenuated the relationship between prior mathematics achievement and problem-solving skills such that engagement played a significant role in explaining variance in subsequent problem-solving skills. Last, given that the effect of engagement is influenced by other observed and unobserved variables (e.g., teacher interest, instructional quality of classrooms, instructional method, classroom climate), future research should investigate the relations between engagement and other variables using longitudinal data to examine the reciprocal effects over time.

Implications for Practice

This study focused on improving understanding of the combined contribution of on-task behavior and prior mathematics achievement on mathematics problem solving. As one contribution of this research, our results showed that engagement was more predictive than prior mathematics achievement. This finding, in conjunction with descriptive data of engagement for individual lessons presented here, suggests that educators seeking to increase student engagement in middle school need to consider the nature of their teaching practices. However, this study did not empirically test whether specific teaching practices might be particularly important during adolescence. As such, examining the effects of instructional approaches that increase engagement is warranted; one such approach is connective instruction, which emphasizes "integrating connective elements of teacher–student relationships (care, understanding, affirmation, and humor) with connective elements of instruction (relevance and self-expression)" (Cooper, 2014, p. 393). Studies are needed that not only compare student engagement in light of specific teaching practices (e.g., connective instruction) with other instructional approaches (e.g., academic rigor, lively teaching), but also examine the relation between these teaching practices. Although to a lesser extent than connective instruction, academic rigor or press for understanding and lively teaching have also been associated with student motivation and engagement (Anderman, Andrzejewski, & Allen, 2011; Cooper, 2014).

As previously mentioned, one reason engagement may have had a strong influence on mathematical problem solving in our study was that students received a problem-solving intervention that was designed to incorporate research-based instructional practices—explicit problem-solving and metacognitive strategy instruction, scaffolding (i.e., use of schematic diagrams and problem-solving checklists), opportunities for student response and feedback, developing mathematical discourse among students using contextualized problems to make connections among concepts and to the real world—to support student learning. Specifically, teachers relating to students through humor by making a mistake and enabling student self-expression along with the use of a real-world problem that students perceive as relevant in Lesson 4, for example, possibly helped students make connections with the content, the teacher, and instruction to enhance engagement, motivation, and learning during group instruction to benefit all students. These aspects of the lesson may be particularly important for students at risk for school failure.

Conclusion

Academic engagement is critical to successful problem solving. Although our ability to make causal inferences is limited by the nonexperimental nature of the study, the descriptive engagement data for students in different achievement groups and across instructional lessons suggest the importance of attending to teaching practices (e.g., connective instruction, lively teaching, high-quality instruction) that increase student engagement, especially for low-achieving students. Many studies outline instructional features (e.g., making connections between academic content and daily life) that have been linked to increased engagement and subsequent improved academic performance (e.g., Dotterer & Lowe, 2011; Hughes et al., 2008). However, further research is needed to empirically test the effects of these specific instructional features and examine how connective instruction, through building positive teacher–student relations and making students more active participants in instruction, affects engagement, and as a consequence, student achievement (Cooper, 2014).

Author Notes

Amy E. Lein, MEd, is a doctoral candidate in the Department of Educational Psychology at the University of Minnesota. She has over 10 years of experience teaching high school special education and mathematics. Her research interests include educational interventions for struggling students and professional development for teachers.

Asha K. Jitendra, PhD, is the Rodney Wallace Professor for the Advancement of Teaching and Learning in the Department of Educational Psychology at the University of Minnesota. Her research interests include effective instructional practices, primarily in mathematics and reading, for students with mathematics, reading, and learning difficulties.

Kristin M. Starosta, PhD, BCBA-D, is a consultant with Colonial Intermediate Unit 20 in Easton, PA. Her work focuses on supporting schools in their implementation of Multi-Tiered Systems of Supports through Positive Behavior Interventions and Supports (PBIS) as well as supporting individual students with challenging behavior through Functional Behavior Assessment (FBA)–based interventions.

Danielle N. Dupuis, MA, is a doctoral candidate in the Department of Educational Psychology at the University of Minnesota. Her research interests include quantitative methods in education, value-added modeling, teacher effectiveness, and mathematics education.

Cheyenne L. Hughes-Reid, PhD, is a pediatric psychologist at Nemours/A.I. duPont Hospital for Children in Wilmington, DE. She is part of the training team for the APA-approved internship program as well as the postdoctoral training program. Her clinical and research interests include integrated primary care, program development, quality improvement, collaborative care, psychosocial screening, school consultation, training, and assessment and intervention for children with gastrointestinal disorders.

Jon R. Star, PhD, is the Nancy Pforzheimer Aronson Associate Professor in Human Development and Education in the Graduate School of Education at Harvard University. His research interests include flexibility in mathematical problem solving, the effectiveness of curricular and instructional interventions and pre-service teacher preparation, and middle and high school mathematics.

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