Beliefs and Expectations about Engineering Preparation Exhibited by High School STEM Teachers

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Background
If we are to effect change in teacher practices and decision making regarding instruction, college preparation, and career success in engineering, then knowledge of teachers' beliefs and expectations about engineering needs to be understood.

Purpose (Hypothesis)
The primary purpose was to develop a statistically reliable survey instrument to document teachers' beliefs and expectations about pre-college engineering instruction, college preparation, and career success in engineering, called the Engineering Education Beliefs and Expectations Instrument (EEBEI), and to compare teachers' views.

Design/Method
Using two samples of teachers, EEBEI was established as a statistically reliable survey and was used to examine the beliefs and expectations of Project Lead the Way (PLTW) and non-PLTW teachers. The results were used to further examine teachers' decisions in advising fictional students (described in vignettes) with varying academic and socioeconomic profiles.

Results
High school STEM teachers report their instruction was influenced by students' interests, family background, and prior academic achievement. Comparisons between PLTW and non-PLTW teachers revealed that non-PLTW teachers agreed more strongly that an engineer must demonstrate high scholastic achievement in math and science whereas PLTW teachers were more likely to report that science and math content was integrated into engineering activities. Although teachers report that students' socioeconomic status was not influential when asked explicitly, it did influence situated decision-making tasks using fictional student vignettes.

Conclusions
Findings address challenges of STEM integration and reveal conflicting purposes of K–12 engineering education as being for a select few or to promote technological literacy for all students, which affects recruitment, instruction, and assessment practices.

Keywords
K-12 engineering education, STEM, teacher beliefs

I. Introduction

Education research shows that instructional practice and teacher decision making are influenced by teachers' beliefs about learning and instruction (Brophy and Good, 1974; Deemer, 2004; Grossman, 1990; Nathan and Koedinger, 2000b; Rosenthal and Jacobson, 1968). Furthermore, the educational experience for students is dependent on the quality and effectiveness of teachers, more than perhaps any other single alterable factor (Leinhardt and Greeno, 1986; Nye, Konstantopoulos, and Hedges, 2004; Rowan, 2004). This study has three central goals. First, to develop a statistically reliable survey instrument that documents teachers' beliefs and expectations about pre-college engineering instruction and preparation for students' access to college engineering programs and future career success in engineering. We call this general survey the Engineering Education Beliefs and Expectations Instrument (EEBEI, pronounced "eebee"). Second, to measure and interpret teachers' views using EEBEI, as well as to identify differences that may exist among teachers with different training and program objectives. Third, to examine teachers' decisions in advising fictional students (described in vignettes) with varying achievement, gender, ethnic, and socioeconomic profiles.

To frame this work, we first review some of the prior research on teacher beliefs more broadly and then we review research specifically related to engineering education. We next lay out our research goals and describe the analytic methods used to address them. We report results from our initial administration of the EEBEI showing it to be a statistically reliable instrument for assessing STEM (science, technology, engineering, and mathematics) teachers' beliefs about engineering education and preparation, and confirm these findings with a second sample of teachers. We also show that the EEBEI can detect differences in the beliefs and expectations exhibited by high school teachers of college preparatory mathematics and science courses when compared to technical education teachers using the Project Lead the Way (PLTW) pre-college engineering curriculum. To further understand how teachers' beliefs and expectations reveal themselves in advising and decision-making contexts, we then examine teachers' decisions in advising fictional students (described in vignettes) with varying achievement, gender, ethnic, and socioeconomic profiles who are seeking to pursue future studies and careers in engineering and related technical fields. We conclude with a discussion of how differences in teachers' beliefs reflect alternate criteria for access to and success in engineering, as well as some of the challenges that teachers face when addressing recent goals to reform engineering education.

A. Prior Research on Teacher Beliefs

To understand teaching and learning, broadly conceived, educational researchers have concluded that it is essential to understand teachers' beliefs about their students and about the learning process (Garner and Alexander, 1994; Shulman, 1986). Teachers' knowledge and beliefs about learning and instruction are powerful mediators of decision making and action (e.g., Peterson, Carpenter, and Fennema, 1989; Sherin, 2002). Teachers generally report that their perceptions of students are the most important factors in instructional planning, and they consider their views of student ability to be the characteristic that has the greatest influence on their instructional planning decisions (Ball, 1988; Borko and Shavelson, 1990; Borko et al., 1992; Clark and Peterson, 1986; Fennema et al., 1992; Romberg and Carpenter, 1986; Thompson, 1984). Furthermore, teacher beliefs have an impact on students' educational experiences (Brophy and Good, 1974; Carpenter et al., 1989). For example, using time sampling methods, Good and Brophy (2003) found that teachers who lacked good strategies for working with low-achieving students or who identified some students as less able, provided those students with less support. When teachers had high expectations for students, however, these students typically met the higher expectations of performance. In a separate intervention study, teachers whose views about mathematics learning became more "cognitively guided" (i.e., emphasizing instruction built on students' pre-existing knowledge) attended more carefully to students' thinking when devising classroom instruction (Carpenter et al., 1989).

Beliefs about learning and instruction are mental constructions mediated by cultural, social, and psychological influences, rather than directly rooted in scientific evidence (Calderhead and Robson, 1989; Pajares, 1992; Thompson, 1992). As such, teachers' beliefs and expectations of students' knowledge and behaviors are not always accurate (Nathan and Koedinger, 2000a, 2000b). Understanding the beliefs held by educators is central to effecting change and improving instruction (Fenstermacher, 1979, 1994; Richardson, 1994). Consequently, teacher educators and educational researchers need to be able to design educational programs that address teacher beliefs and, when appropriate, strive to change them. Documenting these beliefs becomes an essential element toward achieving this aim.

In a recent statement laying out a future research agenda for the field of engineering education, the Steering Committee of the National Engineering Education Research Colloquies (2006) highlighted the need to understand the "engineering teaching culture." For effective engineering education reform to take place, it is necessary to incorporate teachers' attitudes and beliefs about instruction and learning (Van Driel et al., 1997). Furthermore, as part of the growing need to better understand and improve learning and instruction within engineering education, there is an awareness of an increased need to understand learners and teachers (e.g., Fink, Ambrose, and Wheeler, 2005).

Many of the themes that have been addressed in education more broadly also apply to teacher beliefs about engineering education. Yet much of the research on teachers and teacher beliefs about engineering education has been specific to higher education programs of instruction (e.g., Quinlan, 2002; Van Driel et al., 1997). This is to be expected, given the professional nature of engineering as a field of study. Yet there is a genuine need to understand the beliefs and expectations about engineering education and instruction of K-12 teachers. As noted in a recent report from the National Academy of Engineering (Custer and Daugherty, 2009), these views have serious implications for the perceived place and purpose of engineering in the K–12 curriculum.

Early results from a beliefs survey of elementary grade teachers ($N = 120$) by Cunningham (2009) suggest that curriculum plays a powerful role in shaping instruction, serving as a tool to help teachers reconsider how they teach, what they teach, and who is capable of learning engineering. Another notable study is work by Yasar and colleagues (2006) on K-12 teachers' knowledge and perceptions of engineers and engineering practice. The emphases of their research were to document the importance of teaching design, engineering, and technology; teachers' familiarity with engineering and design; perceptions of engineers; and perceived characteristics of engineering practices. The authors argued that understanding teachers' views in this area is a necessary step toward developing long-range plans to better integrate technology and design into K–12 education. Our current work seeks to extend this prior research.

Beyond these studies, a literature review found limited empirical research on teachers' beliefs and attitudes toward pre-college engineering education. There is relevant research in other STEM fields that highlight the importance of understanding teachers' beliefs and expectations about student learning and success. Benner and Mistry (2007) found that higher teacher expectations were positively and directly associated with students' own educational expectations and post-secondary academic attainment. They also found that teacher expectations exerted influence on students' self-concepts, which in turn affected their academic performance. In another study, data collected from 99 science high schools from teachers ($N = 1{,}680$) in various areas of science (including chemistry, biology, principles of technology, physics, anatomy, geology, and environmental and physical sciences) showed that school culture—the goals identified and supported by the school—was a significant predictor of teachers' instructional practices and students' perceptions of goal mastery in science classrooms. In a related study, Lavigne, Vallerand, and Miquelon (2007) found that science teachers' support for the development of student autonomy affected students' beliefs about their own competence and autonomy within science learning, which in turn influenced students' motivation and ultimately affected their intentions to pursue science careers. Research in mathematics education suggests that the perceived support from social agents (teachers and parents) affects students' beliefs about mathematics, which affects their achievement goals, which in turn shapes their efforts in learning mathematics (Chouinard, Karsenti, and Roy, 2007). Although few findings pertain directly to pre-college engineering, these studies point to the importance of documenting teacher beliefs in advancing our understanding of the influences on students' future academic performance and success in engineering.

Our long-term aims are to improve K-16 engineering education and provide more effective programs for attracting and cultivating effective practitioners in engineering and other technical fields. Like Cunningham (2009) and Yasar and colleagues (2006), we argue for the value of documenting K–12 teachers' beliefs about engineering education. Our emphasis is complementary to theirs in that we provide findings about both teachers' beliefs about influences on their instructional practices and teachers' expectations about the impact of social and academic factors on students' preparation and success with future studies and careers in engineering. In addition, we report on differences among STEM teachers by comparing the views espoused by teachers of technical education classes to those of teachers of college preparation classes in mathematics and science.

B. Pre-college Engineering Education: The Project Lead the Way Curriculum

Project Lead the Way (PLTW) is one of the most widely used pre-college engineering curricula in the United States. The program has been adopted by over 10 percent of U.S. high schools, and is present in all 50 states (PLTW, 2009). Thus, findings based on PLTW have far-reaching implications. PLTW is designed to integrate engineering, math, science, and technology into the students' academic program of study at the middle and high school levels. The high school program Pathway to Engineering™ offers seven high school courses including three one-year foundation courses (Introduction to Engineering Design, Principles of Engineering, and Digital Electronics) as well as specialization courses (Aerospace Engineering, Biotechnical Engineering, Civil Engineering and Architecture, and Computer Integrated Manufacturing). These courses can be used for credit at some PLTW-accredited colleges and universities. In addition, there is an engineering research capstone course, Engineering Design and Development (PLTW, 2004).

Everyone teaching PLTW courses must attend an extensive professional development program, including training provided by PLTW's network of affiliate colleges and universities. This training aims to make teachers proficient in project- and problem-based instruction. In addition to hosting summer training institutes and ongoing professional development, national affiliates offer teachers opportunities to earn graduate-level college credits.

II. Research Goals

We were motivated by three central goals. First, we wanted to design and field-test a reliable statistical instrument that could measure the degree to which teachers exhibited certain beliefs, attitudes, and expectations about their own instructional practices; teachers' views of their students; and the factors that the teachers perceived as critical for success in engineering studies and careers. We set out to determine reliability through internal consistency by presenting high school teachers with a collection of similar but non-identical statements about the views of interest and soliciting their levels of agreement. We also gave the survey to a second group of teachers to document the replicability of the initial reliability results. Once we established the instrument reliability, we used it to address our second goal- to identify statistically significant differences in beliefs and expectations among teachers with different program affiliations and professional training. We addressed this goal by dividing our initial sample of teachers into two groups: those teaching college preparatory classes in mathematics and science (MS group) and those teaching career and technical education classes in the PLTW engineering program (PLTW group). We report on these differences and consider their implications in a later section.

Third, we presented all of the teachers with extended vignettes portraying fictitious students with different academic, ethnic, gender, and socioeconomic profiles, in order to document teachers' specific judgments (e.g., advising recommendations) as well as to reveal their possibly latent beliefs about engineering performance and success which might not show up using the overt probes that made up the survey. The vignettes focus on two factors: student academic performance and student social background. Our analyses uncovered the impact of these factors even when they were not consciously acknowledged by teachers. We then examined the implications of these findings in light of different agendas for K–12 engineering education and the stated aims of the current movement in engineering education reform.

III. Research Methods

A. Sample Selection

Participants were STEM teachers (science, technology, engineering, and mathematics) throughout the Midwest. E-mail addresses were obtained through the state departments of education. From an initial list of 1,178 e-mail addresses, we originally obtained 168 responses (a response rate of 14.26 percent). However, 25 responses contained missing information on at least one construct item, so these were excluded based on our initial criteria. This led to a final sample size of 143 complete responses (85 percent of initial set) used for the major analysis.

A second nation-wide sample of teachers was used to see if we could replicate the initial reliability analysis. These participants were science, mathematics, and technical education teachers who were part of a longitudinal study examining changes in beliefs that followed engineering education professional development and classroom instruction. We obtained the names of teachers who were planning to be enrolled in a two-week summer training institute as a pre-requisite to teaching any PLTW course in the future from the national PLTW office. We originally obtained 116 responses with unique, valid entries and proper consent; however, 34 of these responses contained missing information. The final sample of 82 (70 percent of the original set), those who furnished complete responses, was used for the replication analysis.

B. Sample Demographic Characteristics

The survey was implemented in such a way that all items were required to be answered in order for the participant to continue forward through the survey. The questions were ordered as follows: construct items, vignette items, and demographic information. In other words, in order to have demographic data on an individual, that individual must have already completed the vignette items. Demographic information is presented in Table 1. Although only 139 cases had full data for construct items as well as vignette items, demographics and percentages included elsewhere in the text are based on the main sample of 143 respondents unless otherwise noted. As shown in Table 1, the majority of respondents in the primary sample were white (97.7 percent) and male (57.4 percent). One-sixth of respondents were from urban areas. Our sample shows that 31.1 percent of these teachers attained a bachelor's degree as their highest degree, 68.2 percent also attained a master's degree, and 0.74 percent ($N = 1$) earned a doctoral degree. Of the teachers who responded to the survey questionnaire, 10.3 percent had taught at most 3 years, 27.9 percent had taught 4-10 years, 35.3 percent had taught 11-20 years, and 26.5 percent had more than 20 years of teaching experience. PLTW or non-PLTW status was determined by teachers' responses to a specific question asking whether they taught PLTW. The demographic breakdown of the second sample is also shown in Table 1.

Teachers also differed by content areas of instruction. In the sample, 15.3 percent reported teaching engineering courses using PLTW, 20.6 percent taught math, 49.6 percent taught science courses, and 14.5 percent indicated that they taught a mix of the three content areas.

For group totals (column totals of Table 1), our primary interest was to distinguish between technical education teachers of

Teacher Responses	Primary Sample			Replication
	Overall (*N* = 143)	PLTW Teachers (*N* = 43; 30.07%)	Non-PLTW Teachers (*N* = 100; 69.93%)	Non-PLTW Teachers (*N* = 82; 100%)
		Years Teaching		
	(N = 136)	*(N = 40)*	*(N = 96)*	*(N = 78)*
0–3	10.29%	7.50%	11.46%	20.51%
4–10	27.94%	40.00%	22.92%	26.92%
11–20	35.29%	27.50%	38.54%	33.33%
20^{+}	26.47%	25.00%	27.08%	19.23%
		Degree		
	(N = 135)	*(N = 39)*	*(N = 96)*	*(N = 77)*
B.A.	31.11%	28.21%	32.29%	41.56%
M.A.	68.15%	71.79%	66.67%	55.84%
PhD.	0.74%	---	1.0%	2.60%
		Areas of Instruction		
	(N = 131)	*(N = 39)*	*(N = 92)*	*(NA*)*
Technical Education	15.27%	51.28%	---	---
Math	20.61%	5.13%	25.00%	---
Science	49.62%	17.95%	58.00%	---
Mix	14.5%	25.64%	9.00%	---
		Gender		
	(N = 136)	*(N = 40)*	*(N = 96)*	*(N = 78)*
Male	57.35%	77.50%	48.96%	73.08%
Female	42.65%	22.50%	51.04%	26.92%
		Race/Ethnicity		
	(N = 132)	*(N = 40)*	*(N = 92)*	*(N = 77)*
White/Caucasian	97.73%	95.00%	98.91%	92.21%
African American	---	---	---	6.49%
Hispanic	---	---	---	---
Other	2.27%	5.00%	1.09%	1.30%
		Location		
	(N = 136)	*(N = 40)*	*(N = 96)*	*(N/A*)*
Urban	15.44%	22.50%	12.50%	---
Non-urban	84.56%	77.50%	87.50%	---

*Due to technical issues survey items asking about areas of instruction and locations were not presented to the replication sample.

Table 1. Demographic information for primary sample by group and replication sample overall.

PLTW engineering classes and academic teachers of mathematics or science (MS). In those cases where teachers taught both academic and technical education courses, we examined the number of classes taught and the level of advancement of the class (e.g., general science vs. AP chemistry). In each case we were able to provide unambiguously mutually exclusive assignments to either the PLTW or the MS group.

C. Materials and Procedures

Surveys are instruments designed to measure latent psychological constructs that serve as proxies for the actual beliefs and attitudes that mediate teachers' views, judgments, and actions. The EEBEI survey measures teachers' beliefs and attitudes indirectly by examining the degree to which they agree or disagree (along a scaled continuum of responses) with given statements.

The EEBEI survey was field-tested on two samples of teachers. For these administrations, we refer to the survey as the EEBEI-T when used with K–12 teachers. (In other studies we are also examining the effectiveness of the EEBEI with guidance counselors and college instructors.) The initial and replication administrations of the EEBEI-T were performed online with all participants using a secure system provided by the University of Wisconsin. Participants read through and agreed to an IRB-approved consent statement following Federal guidelines for working with human subjects. All participants were offered $10 in compensation for their efforts.

An initial set of Likert scale items across nine hypothesized constructs was developed based on expert insight and the pilot testing of items with teachers, engineering educators, and guidance counselors. Details of instrument development and item inclusion for the final survey are reported elsewhere (Nathan et al., 2009). Briefly, the initial draft survey was developed by members of a diverse research team (STEM K-12 educators, engineers, education researchers, and a cognitive scientist) using an iterative process involving group and individual feedback from K–12 and higher education engineering instructors. An early version of the complete survey was field-tested by volunteer technical education teachers and the program director from the local school district who provided written and oral feedback. Changes were again made to both content and format before a final version was accepted.

In the accepted version, respondents received 102 items in common: 70 Likert scale items, 16 items based on the four vignettes, and 16 demographic items. The Likert scale items were organized *a priori* in nine theoretically motivated constructs to capture aspects of teachers' beliefs about instruction and engineering preparation. Each of the nine original constructs was subject to an internal-consistency reliability analysis using a commercial statistics software package (SPSS). As is customary with such analyses, some of the original Likert scale items were dropped during the reliability analysis. One construct was determined to have insufficient reliability; another was deemed irrelevant to the current investigation. The remaining 42 items comprised seven constructs that had sufficient statistical reliability and relevance to inform the analysis of the factors related to the dimensions of engineering preparation most appropriate for the scope of this study.

Below are two example survey items. A 5-point Likert scale (with a midpoint of 3) was used to rate teachers' beliefs about the *frequency* of occurrence of the events stated in some survey items. Item 8a shows a statement followed by the five choices with the verbal anchors for each frequency scale score shown in parentheses:

8a. The math content being taught in my courses is explicitly connected to engineering.

1 (Never) 2 (Almost Never) 3 (Sometimes) 4 (Often) 5 (Almost Always)

A 7-point Likert scale (with a midpoint of 4) was used for rating teachers' levels of agreement with statements. Item 6a shows a statement followed by the seven choices with the verbal anchors for each agreement scale score shown in parentheses:

6a. To be an engineer a student must have high overall academic achievement.

1 (Strongly disagree) 2 (Disagree) 3 (Somewhat disagree) 4 (Neutral) 5 (Somewhat agree) 6 (Agree) 7 (Strongly agree)

Teachers visited a supplied Web link and, after giving consent for the study, selected the "radio button" that best fit the degree to which each statement matched their own views. The online system ensured that only the given choices were selected (no intermediate values were possible). Because space on a page was not a factor for the online presentation, every item was accompanied by the complete set of verbal anchors for every numerical rating choice, minimizing errors due to forgetting or reversing the scales.

In addition to the Likert scale items, teachers were presented with four vignettes and asked to predict the likelihood of success in post-secondary engineering studies and careers of four fictional students based on course grades, overall GPA, gender, ethnicity, family income, parental occupation, technical experiences in and out of school, and engineering interests. The vignettes were designed to investigate two general factors that education policy research identifies as particularly influential on student academic achievement: students' prior academic achievement and the social background of students' families (Rothstein, 2004). The vignettes allowed us to document teachers' expectations of how academic and social factors influenced student outcomes and the extent to which teachers weighed these student factors when making predictions about student success in engineering studies and careers.

For example, two of the vignettes concerned fictitious students who shared similar characteristics such as gender, social class status, and high interests in engineering, yet differed in academic abilities as indicated by their overall grade point averages (GPA) and course grades. Using these student profiles, teachers were asked to advise these students about pre-college engineering course enrollment and to offer predictions about these students' levels of success in advanced engineering studies and future careers. Differences in advising recommendations and predictions of student success can be attributed to differences in how teachers weighed the influences of students' academic abilities on engineering preparation. Two other vignettes highlighted the differences in students' economic circumstances after controlling for gender (female), academic abilities (high), and technical interests in digital electronics. Thus, differences in teachers' advising and predicting of these students' levels of success were likely to be attributed to teachers' perceptions of social background as an important factor in student success in engineering studies.

IV. Results

A. Ratings from the Initial Administration of the EEBEI-T Survey

In this section we report and interpret the mean survey ratings that teachers gave in the initial survey administration ($N = 143$). We developed our constructs in a top-down fashion drawing on the knowledge of practitioners in the field as well as on the research team. Details of the instrument development and the specific frequency distributions of responses for each item are presented elsewhere (Nathan et al., 2009c). Consequently, we did not initially conduct an exploratory factor analysis, but rather an internal-consistency reliability analysis. Doing so had the added benefit of forming constructs that were readily interpretable rather than statistically combining items and then providing interpretations of the constructs *a posteriori*. In the next two sections we report on the findings from the internal-consistency reliability analysis of these constructs and the replication of the findings with a second sample of teachers. Table 2 summarizes the seven constructs that were central to our study. The titles and verbal interpretation shown for each construct were inferred and did not appear anywhere on the survey, but are meant to help the reader understand the overall meaning conveyed across the range of items given. In addition, we show the total number of final items followed by whether it was a 5-point or 7-point rating scale.

Constructs with a 5-point scale (Constructs A, B, F, and G) had a midpoint of 3. As described earlier, these constructs assessed teachers' ratings of the frequency with which these conditions occurred. Mean ratings above 3 indicate that, overall, teachers believed that these conditions were more common than uncommon. Data from Construct A showed that teachers' views were, on average, right at the midpoint of the scale, indicating that their lessons were sometimes shaped by students' academic performance. Construct B showed that teachers, overall again, rated right near the midpoint of the rating scale, meaning that as a group they sometimes used students' interests and cultural backgrounds to inform classroom activities. The responses for Construct F showed that teachers believed that they sometimes or often did make the relation between science and mathematics content to engineering activities explicit to students. Construct G revealed that teachers believed that their schools rarely provided resources such as career day or internships for students interested in engineering.

Constructs with a scale ranging from 1 to 7 (Constructs C, D, and E) used a 7-point scale, with a midpoint of 4. These constructs assessed teachers' levels of agreement ratings with the statements. A rating of 1 was used for strong disagreement and 7 for strong agreement. Mean

Construct Title and Interpretation	Items (n)	Scale (Mid)	Survey 1 (N = 143)		Survey 2 (N = 82)	
			Mean	α *	Mean	α
A. Influences on Instruction: Students' Academic Abilities. *My lessons are influenced by students' academic performance.*	5	1–5 (3)	3.08	0.70	3.19	0.76
B. Influences on Instruction: Students' Backgrounds and Interests. *I integrate students' interests and cultural backgrounds into classroom activities.*	7	1–5 (3)	3.00	0.83	3.06	0.85
C. Beliefs and Knowledge about Student Out-of-School Activities. *Students' science / math / technical learning takes place in the home and community*.	5	1–7 (4)	5.69	0.78	5.78	0.78
D. Careers in Engineering: Academic Achievement. *To be an engineer a student must have high academic achievement in math, science and technology courses.*	6	1–7 (4)	4.88	0.83	4.66	0.72
E. Careers in Engineering: Social Network/Background. *The student whose parent is an engineer, who is male, and either white or Asian, is most likely to pursue engineering.*	8	1–7 (4)	4.34	0.80	4.42	0.77
F. Teaching for Engineering: Academic Courses. *The science and math content taught in my courses is explicitly connected to engineering.*	3	1–5 (3)	3.12	0.92	3.67	0.87
G. Environmental and Structural Support. *My school provides resources for students interested in engineering (e.g., internships, career day, professional development opportunities)*.	8	1–5 (3)	2.71	0.78	3.07	0.80

*Cronbach's *alpha*, with a range from 0 to 1.0, higher scores indicating higher reliability.

Table 2. Summary of means and construct reliability parameters (α) for EEBEI-T over two survey administrations.

ratings below 4 indicate that teachers generally disagreed with the statements. The responses from Construct C indicated that teachers largely agreed that students learned science, mathematics, and technology in out-of-school settings such as the home or community center. Construct D showed that teachers generally believed that high academic performance in mathematics, science, and technology courses was prerequisite to a career in engineering. Data from Construct E revealed that teachers believed that students' cultural or social backgrounds (e.g., parents as engineers, being of Asian descent) was influential in students' decisions about pursuing a career in engineering.

B. Reliability Analysis for Initial Administration of the EEBEI-T Survey

To account for the indirect nature of survey measures and their inherent subjectivity, we performed internal-consistency reliability analyses on the survey constructs using Cronbach's *alpha* (α), a measure that varies between 0 and 1.0 (Cronbach, 1951). The reliability analysis for the EEBEI-T revealed which items depressed the reliability score for a given construct and suggested item removal in order to increase coherence of the construct. As is common practice, to enhance reliability we only excluded such items if removal did not harm other theoretical aims in the survey design. This action reduced the Likert portion of the survey from 77 to 42 items, distributed over seven constructs. The reliability analysis is summarized in Table 2.

As should be clear from the summary, the reliability analysis for the first survey administration suggested that the EEBEI-T is a well-designed instrument. The relevant parameters are shown in Table 2 for the original sample ($N = 143$). First, with the exception of Construct C, the mean scores of each construct are near the center value for each scale, indicating that responses to these constructs are not statistically skewed. Data for Construct C, which documents teachers' beliefs and knowledge about students' out-of-school activities, showed that teachers in this sample appeared to have a strong consistent level of agreement and could possibly make use of a scale that provided for even greater positive ratings than provided by the 7-point scale. Second, the estimated values for Cronbach's *alpha* were 0.70 and above, indicating an acceptable reliability estimate (Black, 1999; Nunnaly, 1978).

C. Replication of the EEBEI-T Survey

To provide further support for the reliability analysis, the EEBEI-T was administered to a second group of teachers ($N = 82$) from a nation-wide sample of science, mathematics, and technical education teachers who were part of a longitudinal study examining how teacher beliefs change over time. The sample was determined through communication with PLTW personnel so we could find teachers who planned to enroll in the PLTW summer training program. None of the participants in the replication sample were part of the primary sample. As with the primary sample, the means are close to the midpoint of each scale and the reliability estimates are at or above 0.70 (Table 2). Although our interest was to replicate the reliability of the constructs not to compare the mean ratings, we note that the ratings of the second sample were generally consistent with the primary survey results with the exception of Construct G. Furthermore, in each case the construct reliability is above 0.70. Based on the above data from the primary sample and this replication, we conclude that the first goal of developing and field-testing a reliable instrument was achieved.

Construct	Scale (Mid)	MS ($N = 100$)		PLTW ($N = 43$)		Independent Samples: *t*-Tests	
		Mean	Std. Dev.	Mean	Std. Dev.	*t*	*p*-value
A. Influences on Instruction: Students' Academic Abilities	1–5 (3)	3.04	0.516	3.17	0.553	-1.374	0.172
B. Influences on Instruction: Students' Backgrounds and Interests	1–5 (3)	2.97	0.597	3.06	0.689	-0.841	0.402
C. Beliefs and Knowledge about Out-of-School Activities	1–7 (4)	5.64	0.796	5.82	0.734	-1.273	0.205
D. Careers in Engineering: Academic Achievement	1–7 (4)	5.02	0.960	4.53	0.922	2.804	0.006*
E. Careers in Engineering: Social Network/Background	1–7 (4)	4.30	0.782	4.42	0.830	-0.805	0.422
F. Teaching for Engineering: Academic Courses	1–5 (3)	2.87	0.909	3.69	1.014	-4.776	0.000*
G. Environmental and Structural Support	1–5 (3)	2.60	0.760	2.95	0.732	-2.560	0.012*

*P-value is significant at the 0.05 level.

Table 3. Differences in mean ratings between teacher populations. Note: All tests were conducted with 141 degrees of freedom. Scale shows range of allowable responses.

D. Differences in Beliefs Exhibited by Mathematics and Science Teachers and PLTW Teachers

Up to this point, we have addressed the views of these teachers as though they represented a homogeneous population with consistent views. The second goal of this study was to show that the EEBEI-T could detect differences between teachers with different professional training and program foci. One aspect of this was to examine whether expected group differences were reflected in the data. This helps to establish *face validity* or *content validity* (Cronbach, 1971) of the survey because the contents of the items in the instrument were found to be representative measures of the intended concept. As with the prior analyses, we used only the data generated from the first primary survey administration ($N = 143$). Our demographics questions (whether a teacher had taught from the PLTW program) revealed that the samples were composed of technical education teachers using Project Lead the Way (the PLTW group; $n = 43$) and academic teachers of mathematics or mathematics and science (the MS group; $n = 100$). To determine if there were any differences in their responses to the survey at the construct level, we conducted seven independent sample t-tests (assuming equal variance) between these two groups (see Table 3). Because the constructs are thought to be conceptually independent, a Type I error rate of 0.05 was assigned to each test.

For four of the constructs (A, B, C, E), the differences between the PLTW and the MS groups were not statistically significant. This suggests that although these teachers had different professional training and instructional emphases, they expressed the views of the group as a whole. However, the results showed that the EEBEI-T exposed differences in teacher views for some constructs. Specifically, three constructs were found to be statistically different ($\alpha = 0.05$) when comparing group means.

MS teachers were less likely to identify sources of support for engineering in their schools (Construct G) than were PLTW teachers. This result, although interesting, might simply be due to differences in the resources actually offered by schools with lesser and greater commitments to technical education and school-to-work transition programs. It also might signal differences in the awareness of the availability of resources. The greater levels of agreement from PLTW teachers provided one source of face validity for this construct because we would expect pre-engineering teachers to be more aware of the engineering resources offered and more likely to be in schools that offered such resources. Of course, the actual presence of resources is not known, and MS and PLTW teachers might be applying different criteria when considering the availability of legitimate sources of support. Resolving this would entail documenting the actual programs available at each school, which suggests a valuable area of future research.

We found that MS teachers agreed more strongly than did the PLTW teachers that to be successful an engineer needs to demonstrate high scholastic achievement in mathematics, science, and technology (Construct D). Here we see that teachers of academically oriented courses, which often serve a college preparatory function rather than providing technical skills, saw excellence in academic performance as a kind of gatekeeper for engineering. This difference between teachers' perspectives further established face validity for the instrument. This finding also raises the issue about the purpose of pre-college engineering programs and the intended student clientele. Those who expect that high scholastic achievement in mathematics, science, and technology is prerequisite to participation in engineering studies might see engineering as reserved for a select group of students who excel in science and mathematics courses. Those who do not espouse this selective view might see engineering studies as contributing to the technological literacy of all well-educated students. Although both the MS and PLTW groups showed average views that affirm the central importance of high achievement, the MS group exhibited this view far more strongly, suggesting a potentially important division between these two teaching communities. (See the Discussion section for further exploration of these issues.)

PLTW teachers were also more likely than MS teachers to claim that science and mathematics content taught in their classes was integrated with the engineering content (Construct F). This integration can be applied in both directions: college preparatory courses may elect to use engineering contexts to motivate the science and mathematics and demonstrate its applicability in "real world" problem-solving tasks; and engineering courses may highlight the roles that science and mathematics play in engineering design and analysis. This difference between MS and PLTW teachers suggests that teachers using the PLTW curriculum were more likely to perceive that PLTW provided opportunities for the integration of mathematics, science, and engineering. Alternatively, these different groups of teachers might have had different definitions or criteria of what it meant for mathematics and science concepts to be integrated into engineering education activities. This unresolved question suggests another area of future research.

E. Teacher Responses to the Vignettes

Vignettes were intended to elicit information on teachers' beliefs and expectations for student learning in a more situated manner by revealing influences on teachers' decision making in advising fictional students about engineering studies and predicting student success in technical careers (see the Appendix for an example). The vignettes were also designed to allow us to make certain comparisons about specific factors that might influence teachers' recommendations. Although each vignette presented a moderately rich portrait with several attributes describing student personal characteristics, interests, and academic performance (as noted earlier) we focus here on two major factors that are likely to influence teachers' perceptions of students' engineering preparation: academic performance and social background. Table 4 provides a summary of the student profiles described in the four vignettes.

As Table 4 shows, we designed vignettes that varied these two factors. Vignettes V1 and V3 compare two male students with similar socioeconomic status (SES) who differ in academic performance (course grade and GPA). Vignettes V2 and V4 compare two female students of similar academic abilities who vary in social background.

For each vignette, we asked teachers to do the following: (a) recommend whether a student should enroll in a pre-college engineering course the following year, (b) specify the criteria (e.g., prior academic performance, overall GPA, gender, age, social economic status, family background) the teacher used to make that recommendation, and (c) offer a prediction of the student's future as a working engineer.

Drawing on the information obtained from the Likert scale data, we can advance some predictions about teachers' responses to the vignettes. First, teachers' reported sensitivity to students' interests suggests that there may be an overall bias toward encouraging enrollment in classes requested by students. In addition, teachers

	Vignette 1 (V1)	Vignette 3 (V3)
Compares Academic Performance	*Gender:* Male *Grade:* 10th *Background:* low SES *GPA:* 3.85 *Interests* Wants to enroll in Principles of Engineering; attend college.	*Gender:* Male *Grade:* 10th *Background:* low SES *GPA:* 1.35 *Interests* Assembling body kits on foreign cars; wants to attend college.
	Vignette 2 (V2)	**Vignette 4 (V4)**
Compares Social Background	*Gender:* Female *Grade:* 11th *Background:* high SES *GPA:* 3.45 *Interests* Wants to enroll in Digital Electronics; thinks father's work as an engineer is "cool."	*Gender:* Female *Grade:* 11th *Background:* low SES *GPA:* 3.45 *Interests* Wants to enroll in Digital Electronics; uninterested in her parents' blue-collar jobs.

Table 4. Comparative structure of the vignettes.

indicated strong support for high academic performance as a prerequisite for engineering studies and future success. This led us to predict that teachers would endorse enrollment in engineering courses for V1, V2, and V4 (all high GPA). In pair comparisons, we expected to see V1 (male with high GPA) endorsed over V3 (male with low GPA), with V2 and V4 both receiving high levels of support. Socioeconomic status (SES) was not considered by teachers to be a relevant indicator in their decisions, leading us to expect that V2 (high SES) would not receive any greater support than other high GPA students (the other female, V4, or the male, V1) from lower SES families. Findings from the group differences led us to predict that MS teachers would place greater weight on academic performance than PLTW teachers, although academic achievement was clearly an important consideration for all teachers in the study regardless of group assignment.

Based on these predictions and the design of the vignettes, we conducted four tests for each question (with adjustments to the (α-level using the Holm (1979) procedure to properly control for Type I error rate), comparing V1 to V3, V2 to V4, V1 to V2, and V3 to V4 (see again Table 4). Our analysis showed that respondents did not answer all vignettes the same way and that, as predicted, academic and social characteristics that differed between the student profiles had some effect on teacher judgment. We report general patterns of teacher responses and give statistical tests of significance where appropriate.

We first examine the relative frequencies of teachers' recommendations for student enrollment in a future high school engineering class. Figure 1 shows that, for each of the four vignettes, a large proportion of the teachers (>70 percent) supported student enrollment. As the same teachers responded to each vignette, Exact McNemar tests (signified by the X statistic) for correlated proportions were conducted to determine whether teachers were treating the vignette students differently (McNemar, 1947). The comparison between the two low-SES males, V1 and V3, examined the differences associated with student academic record, controlling for SES and gender. Significantly different proportions of teachers recommended enrollment for V1 (strong academic record) compared to V3, $X(37,0.5) = 1$, $p = 0.000$. The V2-V4 comparison considered SES differences for two female students with relatively strong GPAs and interest in digital electronics. Teachers were more likely to recommend enrollment for a female student if she was presented as high-SES (V2) rather than as low-SES (V4), $X(15,0.5) = 2$, $p = 0.0074$. V3 (low-SES male) versus V4 (low-SES female) pairing allowed us to compare the influence of students' prior experiences in pre-college engineering courses along with differences in academic record and gender. Perhaps not surprisingly, the female student (V4) with a superior academic record and prior experience with engineering garnered significantly more support than the male student, $X(33,0.5) = 5$, $p = 0.0001$.

We also found variations in the influences on teachers' decisions concerning student enrollment in pre-college engineering courses. As Figure 2 shows, although student SES was never identified as a factor when considering student enrollment in these courses, family background was somewhat endorsed, particularly for V2, where 20 percent of teachers reported using student background to make their decision. Specifically, significant differences in the endorsement of family background were found among high-GPA students. The contrast between responses for a low-SES male (V1) and the high-SES female (V2), both with high-GPA, was significant, $X(23,0.5) = 0$, $p = 0.0000$). When V2 was compared to V4, the low-SES female, the contrast was also significant, $X(28,0.5) = 3$, $p = 0.0000$. However, to the teachers in this sample, student social background appeared to be much less important than prior academic performance. Although academic factors were often endorsed by teachers, their influence was not consistent and differed substantially across the student vignettes. We explore the various criteria teachers used to make their recommendations for student enrollment in pre-college engineering studies.

As before, the comparison between the low-SES males, V1 and V3, shows low versus high course grades in mathematics and

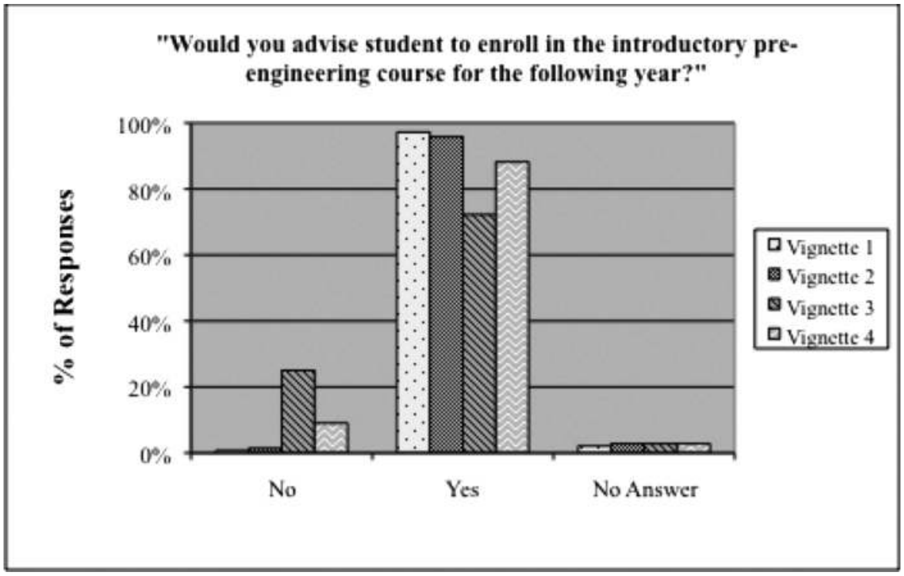

Figure 1. Teachers' recommendations for student enrollment in engineering courses.

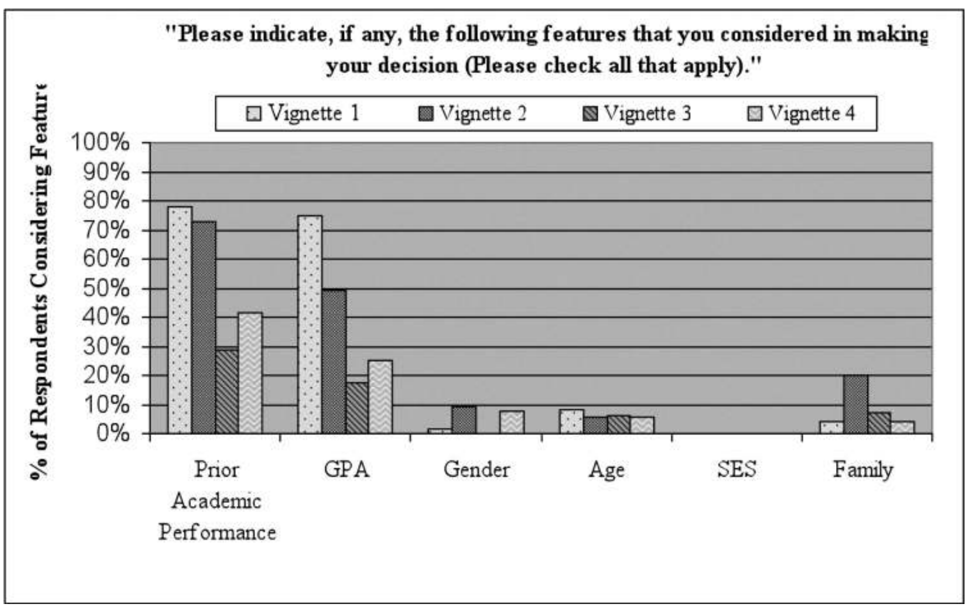

Figure 2. Teachers' perceptions of factors that influence teachers' recommendations for enrollment in pre-college engineering courses. Note: No one identified SES as a factor.

science and overall GPA (see Appendix and Table 4), controlling for family income, student gender (both male), lack of pre-college engineering experience, and parental working class (one has a single mother who works two blue collar jobs; the other has a father working in an auto shop). For the high-GPA student (V1), a large percentage of teachers reported using prior academic performance (78 percent) and GPA (75 percent) to recommend whether a student should enroll in a pre-college engineering course the following year. For the low-achieving student (V3), academic factors were reported as being used far less often (i.e., less than 30 percent for academic history, less than 20 percent for GPA) to endorse future enrollment in engineering courses. There was a significant difference between V1 and V3 on the use of both prior academic performance in enrollment decisions, $X(78,0.5) = 4$, $p = 0.0000$, and GPA, $X(59,0.5) = 1$, $p = 0.0000$. This difference is a potentially important effect and suggests that science, mathematics, and technical education teachers—all of whom may be predisposed to support enrollment in pre-college engineering courses-are more inclined to use prior academic performance to justify their enrollment decisions for a higher—achieving student, but are much less likely to refer to academic records to justify their decisions for a lower achieving student.

The comparison between the high achievement females, V2 and V4, highlighted the differences in student social backgrounds: One student (V2) from a higher socioeconomic background had a father who was an engineer; another student (V4) with a lower-socioeconomic background had parents with "blue collar" jobs. Both were female with identical GPAs and grade levels. For the student from the more privileged background (V2), 73 percent of the teachers reported using prior academic performance and 50 percent indicated using overall GPA as criteria to recommend future enrollment in a PLTW course. For the student from a less advantaged background (V4), a much smaller proportion of teachers reported using prior academic performance (only 42 percent) or GPA (25 percent) as criteria to promote future enrollment in a PLTW course. The difference in the proportion of teachers who used prior academic performance in their enrollment decisions between V2 and V4 was statistically significant, $X(62,0.5) = 9$, $p = 0.0000$, as was the difference in those who used GPA ($X(42,0.5) = 4$, $p = 0.0000$). This striking effect suggests that socioeconomic characteristics of a students' family may influence the decision-making processes of teachers with regard to engineering studies *even when the level of prior academic performance does not markedly differ*.

We conducted a secondary analysis of the comparisons between V1 and V2: two students who both had high GPAs and good grades in math and science, but varied in family background. The female student (V2) had a father in engineering; the male student (V1) was being raised by a single mother working double shifts. The female's family background appeared to influence the teachers' decision making to pursue future engineering courses. (Twenty percent of teachers factored this in for the female vs. 5 percent for the male.) Knowledge of history of engineering in the family appears to be an important component in teacher's decisions. However, the GPA was weighted much less heavily for the female (50 percent) than for the male (75 percent), $X(18,0.5) = 3$, $p = 0.0075$.

Lastly, comparing V3 with V4 permits comparison of students' prior experiences in pre-college engineering courses with other factors such as GPA and gender. The female (V4) had one course (*Introduction to Engineering Design*) with a B grade, but otherwise had mid-level grades. The male (V3) had hands-on experience with cars, but no school-based engineering experience. He also showed poor grades and had no advanced mathematics or science. Prior experience in the pre-college engineering program appears to have made the female's academic record a stronger factor for advising the student about enrolling in a future engineering course than it was for the male. A greater proportion of teachers based their enrollment decisions on prior academic performance for V4 than V3, $X(47,0.5) = 14$, $p = 0.0079$. Academic and experiential factors appear to have been a factor in teachers' decisions.

Overall, academic factors weighed heavily with teachers, although having a parent as an engineer also contributed to teachers' decisions regarding engineering pursuits. Teachers were more likely to support students with higher GPAs for engineering studies. As shown in Figure 2, when asked explicitly, teachers reported that they did not use social background (SES) as a factor when making their decisions about pre-college engineering enrollment in any of the four vignettes. However, in a more tacit exploration of teacher decision making, comparisons between students with varying social background (V2 vs. V4) but comparable academic histories suggest that teachers implicitly accounted for social background when forming opinions about a student's future enrollment in engineering courses. This influence was demonstrated by the significant Exact McNemar tests that showed that teachers judged the students differently. Taken together, data obtained from the vignettes revealed that both academic factors and information about social factors played an important role in teachers' perceptions about students' engineering preparation even though teachers might not have been consciously aware of these latter influences.

The third question asked teachers to make predictions about a student's success in a future career as an engineer. As shown in Figure 3, at least 49 percent of the respondents reported that they could not predict success based on the information provided in the vignettes. Teachers predicted that students with higher academic preparation (V1) and who also had parents who were engineers (V2), were likely to do well in engineering. In contrast, a large majority of the teachers did not expect students with lower academic preparation (V3) who also came from lower social backgrounds (V4) to excel.

Although academic factors were understandably an important consideration for predicting future success in engineering, we cannot

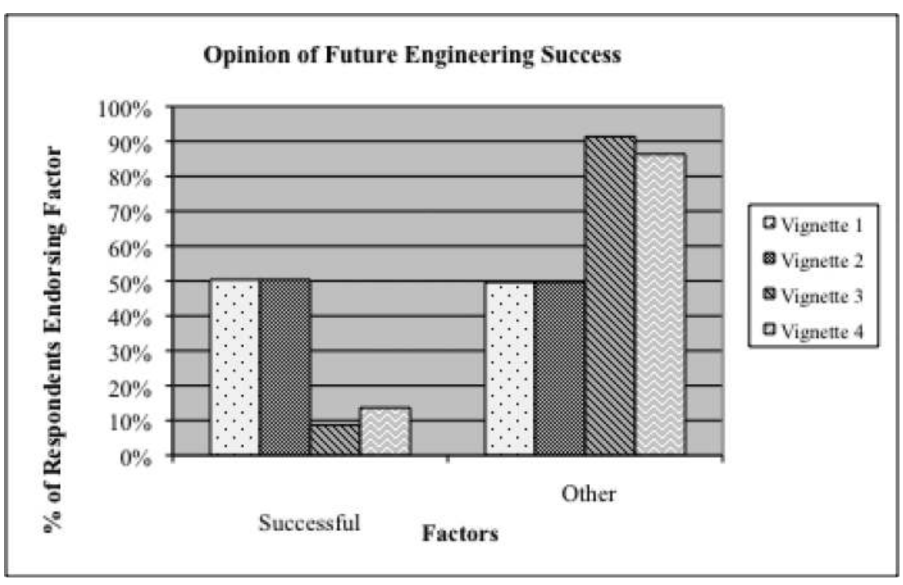

Figure 3. Teachers' predictions of student success in engineering careers.

overlook the role that social backgrounds appeared to play in teachers' decisions. This role was most evident in the comparisons between V2 (higher SES) and V4 (lower SES). Both students differed in social background but shared similar characteristics such as high prior academic performance, gender (female), and grade level (eleventh grade). However, 50 percent of the teachers predicted that V2 would succeed in engineering compared to 13 percent for V4. After dichotomizing predictions into either "Successful" (will do well or be rapidly promoted) or "Other" (would struggle, be in a technical position, would not work in engineering, or unable to predict), comparisons of the proportions were found to be significantly different between designated vignette pairs: V1 versus V3, $X(58,0.5) = 0$, $p = 0.0000$; and V2 versus V4, $X(55,0.5) = 2$, $p = 0.0000$.

F. Differences in Responses to the Vignettes Exhibited by Mathematics and Science Teachers and PLTW Teachers

Tests relating PLTW and MS teachers' patterns of endorsements for enrollment and success when comparing fictional students described in the vignettes, and the factors that influenced these decisions, showed no statistically reliable differences. Although caution should always be exercised when interpreting null results, investigation of the data showed that teachers in both groups used the situated information from the student profiles to make their decisions. This suggests that although teachers of the engineering courses and of the academic mathematics and science classes exhibited some reliable differences in their beliefs and expectations about learning and teaching engineering, as measured by the Likert scale items, they also seemed to evaluate the student characteristics provided in the vignettes similarly when making situated decisions about enrollment or future success. One reason for this may have been that there was little cost for teachers to endorse enrollment into engineering classes because this fictional account provided no trade-offs. We address this limitation in the final section.

G. Summary of Findings

Generally, teachers' decisions were affected similarly by the academic and social factors assigned to each of the vignettes. As predicted from the Likert scale responses, teachers heavily weighted academic information when deciding whether to endorse students for enrollment in engineering courses and when predicting their likelihood of success in a future engineering career. Consistently, teachers were significantly more likely to give greater support to V1 over V3 for enrollment (see again Figure 1) and career success (see again Figure 3), where both vignettes described male students from low-SES families who differed predominantly in their academic record. Furthermore, teachers reported using GPA and academic performance as factors affecting their decisions. Surprisingly, teachers also showed differences in their assessments between high-performing females who differed largely in family SES, showing significantly greater endorsement for course enrollment (see again Figure 1) and career success (see again Figure 3) for V2 over V4. These influences are examined in the discussion that follows.

V. Discussion and Conclusions

Previous education research indicates that instructional practices and teacher decision-making processes are influenced by teachers' beliefs and expectations about student learning and about teachers' own instructional practices (Brophy and Good, 1974; Grossman, 1990; Nathan and Koedinger, 2000b). Evidence shows that teachers' classroom practices can have a direct impact on student outcome measures (Nye, Konstantopoulos, and Hedges, 2004; Rowan, 2004). Furthermore, teacher beliefs influence curriculum reform efforts (Ball, 1996; Koehler and Grouws, 1992; Sosniak, Ethington and Varelas, 1991) because teachers filter prescribed changes through the lens of their pre-existing viewpoints (Nespor, 1987; Pajares, 1992). Teachers' beliefs can, for example, contribute resistance to systemic reform or greatly diminish its impact (Cuban, 1993; Kagan, 1992). To effect meaningful and sustainable change in engineering education practices, knowledge of teachers' beliefs and expectations will need to be rigorously documented so that education policies and programs are commensurate with teachers' views, even as those policies and programs may also strive to change them.

Development of a reliable beliefs instrument, along with measures of STEM teachers' beliefs and expectations about engineering access and success, contribute directly to the documentation process. Overall, this analysis indicated that, although MS and PLTW teachers showed many commonalities in their views of students and instruction, there were important differences. In this final section we contextualize our findings by discussing how differences among teachers' views of the relationship between academic and engineering success relate to conflicting purposes of STEM education more broadly. We also examine the challenges that teachers face in addressing current reform initiatives to integrate engineering education more effectively with science and mathematics.

A. Teachers' Views Relating Academic Success and Engineering Access

One of the most striking disparities between the teachers was their differing emphases on academic achievement signaling success in engineering. Although both PLTW and MS teachers agreed that scholastic achievement was a factor in pursuing engineering, those teachers who focused on pre-collegiate mathematics and science education weighed academic preparation more heavily when considering factors that led to successful engineering preparation (Construct D). These views speak to broader issues about the purpose of engineering education at the secondary level and criteria for access and success. Indeed, writing in the latter half of the last century, the Nobel laureate Herbert Simon (1969/1996), one of the founders of cognitive science, observed that "Engineering schools gradually became schools of physics and mathematics" (p. 111). As Cajas (1998) noted, this is still evident decades later, although the field has started to implement educational reforms emphasizing the role of design and control as well as of collaboration and globalization (National Academy of Engineering, 2005).

Engineering studies and professional practices are unquestionably steeped in the language and tools of mathematics and science. However, practicing engineers present a more nuanced picture of the relationship between mathematics knowledge and engineering practice than is suggested by the perceptions of the teachers in this study. Anderson and colleagues (2009) conducted interviews with practicing engineers ($N = 45$) and surveys of engineers, engineering managers, and individuals with engineering backgrounds ($N = 280$). When asked about essential engineering skills and notable qualities related to their work, engineers placed problem solving and mathematics within a rich array of considerations. For example, in the engineer survey, communication skills rather than mathematics or science knowledge were the most highly reported of the "essential skills" (62 percent), followed by using resources to solve problems (57 percent). Problem solving was the most frequent common response among those interviewed when asked to describe a recent event at work that made it notable, but this was given by only 44 percent of respondents. In their explanations, engineers framed their work more broadly: "Engineering is not about numbers and formulas. Engineering is more about interacting with your customers." "It was an amazing blend of teamwork, urgency, logical planning, analysis and testing, often with ethical consequences." "It required creativity, subject matter knowledge, good experimental skills, communication, interdisciplinary cooperation, and a whole lot of persistence."

In an ethnographic study, Gainsburg (2006) observed that structural engineers in the workplace blended standard mathematical algorithms flexibly with nonroutine methods of solving quantitative problems. The particular calculations observed were rarely beyond basic algebra or geometry, and only a small portion of the time was devoted to actually doing calculations. Furthermore, most of the mathematics observed was used to support greater aims involved in making sense and justifying methods and conclusions that had already been made. Findings from the mathematics were themselves often negotiated as part of a larger process that also involved intuition, practicality, and political considerations.

Teachers' views emphasizing academic performance did not reflect this more complex and integrative role. Rather, many of the teachers showed beliefs consistent with the *symbol precedence view* exhibited by high school mathematics teachers, who favored teaching mathematics through the introduction of formal representations and systems of notation while withholding application problems (such as algebra story problems) until (or *if*) students showed mastery of symbolic equations (Nathan and Koedinger, 2000a, 2000b). These views of mathematical development are deep-seated, but have been found to be at odds with performance data from middle school, high school, and college-level students who actually perform better on story problems than matched equations (Koedinger, Alibali and Nathan, 2008; Koedinger and Nathan, 2004; Nathan and Kim, 2007). Although mathematics and science are certainly central aspects of engineering design, analysis, and evaluation, overemphasizing them at the expense of other aspects of engineering, such as design and craftsmanship, communication, teamwork, and situating engineering within a global and societal context, overly simplifies the nature of contemporary engineering (Shuman, Besterfield-Sacre, and McGourty, 2005) and may effectively exclude technically competent and motivated students who have not demonstrated high academic achievement in their mathematics and science courses.

This division also reflects some of the competing purposes for K–12 engineering education (Custer and Daugherty, 2009). Generally, those who believe that K–12 engineering should be a pathway to engineering studies in higher education are likely to see engineering education as appropriate "for a select few" and to argue that the pre-college engineering experience "should be designed to maximize and enrich the mathematics and science backgrounds of highly capable students." In contrast, those who believe that engineering education contributes to a well-rounded education by addressing the broad need for technological literacy are likely to see the subject as an important avenue for all students (Lewis, 2007). These differing views can create competing tensions within engineering education that shape recruitment, instruction, and assessment practices in the K–12 classroom.

We also elicited information on teachers' beliefs and expectations for student learning in a more situated manner, by presenting teachers with vignettes of fictional students seeking advice about enrolling in pre-college engineering courses and pursuing future careers in engineering. When comparative analyses were made across the vignettes, we saw that prior academic performance was applied unevenly across the fictional students. It was strongly applied to the male and female students with high grades and privileged family circumstances, but much less frequently applied for the female student with a strong academic record who came from a less advantaged background. Although when explicitly asked, teachers did not report social background as a factor that influenced their decisions, comparisons of the profiles of students with varying social background but comparable academic histories suggest that it did influence teachers' endorsements for pre-college engineering enrollment and predictions of future success in the engineering profession. Based on this, we found that the vignettes provided an important complementary set of findings to the Likert scale items about the influences on decision-making processes used by teachers.

B. Challenges of STEM Integration in the Classroom

Central to the current reform movement in engineering education is the acknowledgment of the need to go beyond technical education on the one hand and academic preparation on the other. The knowledge and skills offered by each needs to be integrated in order to promote effective engineering practices. This need is clearly evident in several significant initiatives, such as the reauthorization of the Perkins Career and Technical Education Improvement Act of 2006, which mandated the integration of technical education with mathematics and science so that "students achieve both academic and occupational competencies"; the increased attention on STEM education as an integrated program in science, technology, engineering,and mathematics; and recent policy initiatives such as the U.S. Department of Education "Race to the Top" program. Yet PLTW teachers diverged from science and mathematics teachers about the degree to which they believed that science and mathematics content was integrated into classroom engineering activities. Technical education teachers were more likely to hold the view that PLTW instruction effectively integrated science and math content into engineering activities (Construct F). This finding suggests that, along with differing classroom experiences, teachers in these different programs might apply different criteria for assessing the level of integration of these topics. Disparities between teachers of the different content areas provide further evidence of the persistent disconnections among the constituent STEM fields (Brophy et al., 2008).

That PLTW teachers report more frequent integration in their instruction raises concerns, given recent analyses of pre-college engineering curricula and classroom instruction. In those analyses, the explicit integration of mathematics and science was not common (Nathan et al., 2009a; National Academy of Engineering, 2009; Prevost et al., 2009; Welty, Katehi, and Pearson, 2008). In practice, many mathematics and science concepts are present in the curriculum, but they tend to be implicitly embedded within the classroom activities (e.g., Redish and Smith, 2008), computer-aided design software, measurement instruments, and computational tools used in the classroom, though their explicit integration is more frequent in more advanced engineering classes (Prevost et al., 2010).

The implicit presentation of mathematics and science concepts in engineering lessons is potentially problematic given findings from the field of Learning Sciences showing that effective transfer to new tasks and situations is related, in part, to similarity with prior training experiences, as perceived by the learner (Bransford and Schwartz, 1999). To develop the cognitive structures necessary for transfer, novices generally require explicit connections between the old and new material, frequent practice in problem-solving contexts, and timely feedback (Pellegrino, Chudowsky, and Glaser, 2001) so that learners develop a conceptual understanding of the general ideas that are to be abstracted and transferred (Streveler et al., 2008). Thus, the likelihood of transfer of a student's conceptual understanding from a mathematics class to an engineering activity, for example, increases when the connections between the mathematics concepts and the engineering topic are explicitly made by the learner.

As a result, from a pedagogical perspective, many opportunities to connect students' understanding of mathematics and science with the engineering activities go untapped, particularly during the earliest courses. This does little to ground students' understanding of more formal ideas or facilitate the transfer of their conceptual knowledge to the rich application areas provided by the pre-engineering classes. When STEM teachers mistakenly judge implicitly embedded mathematics and science (as identified by classroom and curriculum analyses) as explicitly integrated for their students (as revealed by the belief instrument), the teachers may be tacitly contributing to the lack of students' conceptual development and academic preparation. This concern has been leveled in research showing that enrollment in high school engineering courses does little to advance student performance on high-stakes achievement tests in science and mathematics (Tran and Nathan, 2010, in press).

In any major educational reform effort, teachers should be regarded as change agents, critical to ensuring success (Darling-Hammond and Bransford, 2005). However, teachers may operate with beliefs about learning and instruction that are incompatible with central principles of the reform effort (Battista, 1994; Nathan and Petrosino, 2003). The pool of engineers in the United States is neither large enough nor diverse enough to meet the current needs of a growing, high-tech, global economy (Courter, Nathan, and Phelps, 2007). Yet the "talent pool" among many sectors of the population goes largely untapped (Grose, 2006). As Legand Burge, Dean of the College of Engineering, Architecture and Physical Sciences at Tuskegee University, one of the nation's premiere Black colleges, noted, "there needs to be more of a national commitment to improve the teaching of technology" at the high school level in order to promote engineering (Grose, 2006). This means that reform of engineering education must address not only the design of post-secondary programs, but of K–12 education as well. Furthermore, reform must go beyond a vision of prescribing content knowledge for K–12 teachers: It must include examining teachers' beliefs and expectations about the intellectual preparation of those interested in pursuing engineering studies and technical careers. As the research base in engineering education grows and we develop a better picture of the beliefs and practices of K–12 STEM teachers, we will be better able to design effective professional development and teacher education programs that suit both teachers and learners.

C. Limitations and Future Work

As currently designed, the EEBEI does not collect data that specifically probe teachers' definitions of engineering. To rectify this, rather than reinvent, we suggest that the current instrument could be used alongside instruments that have been successfully developed and tested, such as the one created by Yasar and colleagues (2006). We also acknowledge that teachers' recommendations in response to the vignettes may be due to teachers' overall propensity to encourage students to try engineering. In order to make such recommendations more consequential, in future work we intend to get beyond these general propensities by asking teachers to decide about enrollment when, for example, class space is limited, and endorsement of one student means excluding others.

Although we were able to report data from teachers from both regional and national samples, further replication of these views is warranted. It will also be valuable to employ the EEBEI to other populations in the engineering pathway, such as guidance counselors (see Nathan et al., 2009b) and post-secondary level instructors at both two-year and four-year institutions. Finally, we imagine that this survey can be used as more than an instrument for measuring teachers' beliefs at a single point in time, but as one measuring changes in beliefs due to teaching experiences, specific training programs, or other professional development experiences. Preliminary work in this avenue has already begun in order to measure how teachers' beliefs and expectations change after receiving professional development and engaging in engineering instruction (Phelps et al., 2009).

D. Conclusions

Engineering excellence in the United States serves as one of the primary vehicles for technological innovation, economic prosperity, national security, and advancements in public health. Understanding the more complex role that academic performance plays in the beliefs and expectations of high school teachers is important when examining who will ultimately gain access to future programs of study and to highly economically advantageous career tracks. This study, along with others (Cunningham, 2009; Yassar et al., 2006), contributes to a developing knowledge base of the expectations and beliefs about engineering education held by K–12 teachers. By establishing a reliable instrument that measures teachers' beliefs and identifies differences between professional communities, we aim to contribute to the wide-scale efforts currently in place to expand and improve engineering education and to foster a more technologically advanced society that contributes to the greater good.

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Appendix

Vignette 2

Kim is an 11th grader at your school. She has an overall GPA of 3.45. She is not qualified for the school free/reduced lunch program. Her classmates consider her to be a bit shy, though her teachers think she is a good student. When asked what she wants to do after high school, Kim said that she doesn't know for sure but she thinks that what her father does as an electrical engineer is "cool." She gets very excited when talking about her father's work designing new computer chips. You also learned that Kim's mother is an architect and has been very involved in Kim's life. Kim told you that, after discussions with her parents, she would like to enroll in a pre-engineering course called *Digital Electronics*, a third course in the pre-engineering curriculum sequence purchased by your school through the career technical education program in your district. Kim is currently enrolled in a pre-engineering course called *Introduction to Engineering Design*. Below is a list of courses she is currently enrolled in this semester along with the mid-term grade for each course.

	Schedule	**Grade**
Period 1	English 11	A
Period 2	Introduction to Engineering Design	A
Period 3	Pre-Calculus	B
Period 4	Civics	A
Period 5	Spanish 3	B
Period 6	Physics	A