Another Look at Cognitive Abilities and Motivational Processes in Science Achievement: A Multidimensional Approach to Achievement Validation

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PREFACE

In 1995, Richard E. Snow wrote in CRESST's proposal to the Office of Educational Research and Improvement that his previous work showed that "psychologically meaningful and useful subscores can be obtained from conventional achievement tests" (Baker, Herman, & Linn, 1995, p. 133). He went on to point out that these subscores represented important ability distinctions and showed different patterns of relationships with demographic, "affective" (emotional), "conative" (volitional), and instructional-experience characteristics of students. He concluded that "*a new multidimensional approach to achievement test validation* should include affective and conative as well as cognitive reference constructs" (italics ours, p. 134).

Snow (see Baker et al., 1995) left hints of what he meant by "a new multidimensional approach" when he wrote, "the primary objective of this study is to determine if knowledge and ability distinctions previously found important in high school math and science achievement tests occur also in other multiple-choice and constructed response assessments. . . . A second objective is to examine the cognitive and affective correlates of these distinctions. And a third objective is to examine alternative assessment designs that would sharpen and elaborate such knowledge and ability distinctions in such fields as math, science, and history-geography" (p. 133).

We, as Snow's students and colleagues, have attempted to piece together his thinking about multidimensional validity and herein report our progress on a research program that addresses cognitive and motivational processes in high school science learning and achievement. To be sure, if Dick had been able to see this project through to this point, it might well have turned out differently. Nevertheless, we attempted to be true to his ideas and relied heavily on the theoretical foundation of his work, his conception of aptitude (Snow, 1989, 1992).

Snow called for broadening the concept of aptitude to recognize the complex and dynamic nature of person-situation interactions and to include motivational (affective and conative) processes in explaining individual differences in learning and achievement. Previous results, using a mixed methodology of large-scale statistical analyses and small-scale interview studies, demonstrated the usefulness of a multidimensional representation of high school science achievement. We identified three distinct constructs underlying students' performance on a standardized test and sought validation evidence for the distinctions between "basic knowledge and reasoning," "quantitative science," and "spatial-mechanical ability" (see Hamilton, Nussbaum, & Snow, 1997; Nussbaum, Hamilton, & Snow, 1997). Different patterns of relationships of these dimensions with student background variables, instructional approaches and practices, and out-of-school activities provided the groundwork for understanding the essential characteristics of each dimension. We found, for example, that gender differences in science achievement could be attributed to the spatial-mechanical dimension and not to aspects of quantitative reasoning or basic knowledge and facts.

Our studies, reported in the set of six CSE Technical Reports Nos. 569–574,* extend the groundwork laid down in Snow's past research by introducing an extensive battery of motivational constructs and by using additional assessment formats. This research seeks to enhance our understanding of the cognitive and motivational aspects of student performance on different test formats: multiple-choice, constructed response, and performance assessments. The first report (Shavelson et al., 2002) provides a framework for viewing multidimensional validity, one that incorporates cognitive ability (fluid, quantitative, verbal, and visualization), motivational and achievement constructs. In it we also describe the study design, instrumentation, and data collection procedures. As Dick wished to extend his research on large-scale achievement tests beyond the National Education Longitudinal Study of 1988 (NELS:88), we created a combined multiple-choice and constructed response science achievement test to measure basic knowledge and reasoning, quantitative reasoning, and spatial-mechanical ability from questions found in NELS:88, the National Assessment of Educational Progress (NAEP), and the Third International Mathematics and Science Study (TIMSS). We also explored what science performance assessments (laboratory investigations) added to this achievement mix. And we drew motivational items from instruments measuring competence beliefs, task values, and behavioral engagement in the science classroom. The second report in the set (Lau, Roeser, & Kupermintz, 2002) focuses on cognitive and motivational aptitudes as predictors of science achievement. We ask whether, once students' demographic characteristics and cognitive ability are taken into consideration, motivational variables are implicated in science achievement. In the third report (Kupermintz & Roeser , 2002), we explore in some detail the ways in which students who vary in motivational patterns perform on basic knowledge and reasoning, quantitative reasoning, and spatial-mechanical reasoning subscales. It just might be, as Snow posited, that such patterns interact with reasoning demands of the achievement test and thereby produce different patterns of performance (and possibly different interpretations of achievement). The fourth report (Ayala, Yin, Schultz, & Shavelson, 2002) then explores the link between large-scale achievement measures and measures of students' performance in laboratory investigations ("performance assessments"). The fifth report in the set (Haydel & Roeser, 2002) explores, in some detail, the relation between varying motivational patterns and performance on different measurement methods. Again, following Snow's notion of a transaction between (motivational) aptitude and situations created by different test formats, different patterns of performance might be produced. Finally, in the last report (Shavelson & Lau, 2002), we summarize the major findings and suggest future work on Snow's notion of multidimensional achievement test validation.

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* This report and its companions (CSE Technical Reports 569, 570, 572, 573, and 574) present a group of papers that describe some of Snow's "big ideas" with regard to issues of aptitude, person-situation transactions, and test validity in relation to the design of a study (the "High School Study") undertaken after Snow's death in 1997 to explore some of these ideas further. A revised version of these papers is scheduled to appear in *Educational Assessment* (Vol. 8, No. 2). A book based on Snow's work, *Remaking the Concept of Aptitude: Extending the Legacy of Richard E. Snow,* was prepared by the Stanford Aptitude Seminar and published in 2002 by Lawrence Erlbaum Associates.

ANOTHER LOOK AT COGNITIVE ABILITIES AND MOTIVATIONAL PROCESSES IN SCIENCE* ACHIEVEMENT

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Abstract

This report examines the role of affect and conation in high school students' science test performance. It provides a profile of partial correlations of standardized multiple-choice and constructed response test scores with affect and conation scores (after accounting for general ability and student background) at three distinct levels of generality: domain-specific, task-specific, and situation-specific. Results show differential patterns of correlations, varying with level of generality of affective and conative constructs, and with different aspects of science achievement represented by the dimensions of basic knowledge and reasoning, quantitative science reasoning, and spatial-mechanical reasoning. The discussion invokes several theoretical frameworks to interpret these results. The report concludes by stressing the need for empirical and theoretical integration in the study of noncognitive elements in academic task performance.

The call for the study of noncognitive aspects in learning and performance of academic tasks has been a centerpiece in Richard E. Snow's theory of aptitude (see *Remaking the Concept of Aptitude,* Stanford Aptitude Seminar, 2002, for a full account of Snow's theory). Although the importance of noncognitive elements of performance has been recognized since the early days of the scientific exploration of intelligence by Binet and his followers, they have not become an integral part of contemporary thinking about cognitive functioning. Instead, the study of affect and conation has followed independent trajectories, mostly within the domain of "personality" and only marginally making use of cognition. Hilgard (1980) pointed out that "[f]or two hundred years many psychologists took for granted that the study of mind could be divided into three parts: cognition, affect, and conation" (p. 107). The cognitive domain refers to analysis and interpretation and includes such processes as reasoning, remembering, and symbol manipulation; the affective domain refers to temperament and emotions; and the conative domain encompasses

* An earlier version of this report was presented at the annual meeting of the American Educational research Association in Seattle, Washington, in April 2001, under the title *Another Look at Cognitive Abilities and Motivational Processes in High School Science Achievement.*

motivation and volition. The role of affect and conation in academic cognitive functioning is the focus for this report. Although, the Stanford Aptitude Seminar (2002), reporting and extending Snow's thinking, has coined the term "affcon" to refer generally to affective and conative processes, for consistency and simplicity in this report, we speak of motivational processes, or just motivation.

Our analyses seek to sketch a provisional portrait of the involvement of motivational variables in the performance of high school students in the domain of science. Snow's conception of aptitude provides the overall theoretical framework for our work (Snow 1989, 1992; see also Stanford Aptitude Seminar, 2002). Performance in academic tasks, according to this theory, is a dynamic process involving a continuous stream of person-situation transactions. Students bring to the performance situation—the classroom, the formal test, the independent study—a repertoire of aptitude resources that have been developed and structured throughout their learning histories. These resources represent cognitive and motivational propensities such as mental schemes, response sets, knowledge and skill components, heuristic problem-solving strategies, self-regulatory processes, mood and emotion tendencies, and self-perceptions about competence, to name but a few. During performance, situational task demands and opportunities—Gibson's affordances—interact with the repertoire of propensities via complex assembly and control processes to produce observable responses. Past research has consistently demonstrated that both conative and affective factors can alter the perception of situations and the outcome of cognitive efforts.

But how such influences operate during learning and performance situations remains largely unexplained. To enhance the understanding of such influences, our study surveys a wide range of motivational resources and their contribution to performance in different tasks reflecting different facets of achievement in high school science learning.

Motivational constructs considered in this study include efficacy beliefs and confidence, goal orientations, moods and emotions, values, effort, and engagement. These variables represent the major categories in a taxonomy of motivational constructs proposed by Snow, Corno, and Jackson (1996). The Stanford Aptitude Seminar (2002) underscored the need to examine different levels of generality of motivational constructs. "Self-regulation," for example, may denote a broad construct, but becomes more specific when particular a domain of knowledge is concerned (Alexander, 1995). The Seminar concluded: "Researchers who focus on only one level of a construct can miss important information. Ultimately, most data collection will benefit from both the magnifying glass and the panoramic camera." We, therefore, organize our investigation to follow three levels of specificity, moving from general domain constructs to task-specific and, finally, situation-specific constructs. At each level we ask: "After accounting for general cognitive ability and student background characteristics, how strongly do motivational variables correlate with success in different science achievement tasks?" We examine science classroom grades and scores on a standardized science test, including both multiple-choice and constructed response items, as representative of the measurable outcomes in typical learning and performance school situations.

Method

Sample

High school students (N = 491) enrolled in science classes in a northern California high school participated in the study during the 1999-2000 academic year. In the first semester, students completed cognitive and motivational measures and provided information about background characteristics (e.g., gender, ethnicity, parental education). In the second semester, students took a science achievement test. Science grades were also collected from teachers. As is common in such surveys, the final data set reflects varying numbers of missing responses across various instruments—the average sample size for the measures discussed in this report was 388.

Measures

Lau and Rowser (2002) provided a detailed account of the items and scales used in this study, including estimates of reliability. Table 1 summarizes the instruments and gives the labels we use in our displays.

Cognitive abilities. Four measures were used to evaluate students' fluid, crystallized (verbal and quantitative), and spatial abilities. Two tests from the Educational Testing Service kits (French, Ekstrom, & Price, 1963) were administered to measure fluid (hidden figures test) and spatial (cube comparisons test) abilities. The measure of crystallized quantitative ability included items from the National Education Longitudinal Study of 1988 (NELS:88), which were investigated in a previous study (Kupermintz & Snow, 1997), whereas the measure of verbal ability included items from a practice Standardized Achievement Test (SAT). A total score

Table 1

Study Instruments

Science test total and subscores
Dweck's Academic Confidence Measure (SCIEFF)
Eccles's Science Value (including interest, importance, usefulness) (SCIVAL)
Science-Related Self-Regulation During Learning (SLFREG)
Classroom Behavioral Engagement and Attention (ENGAGE)
Positive Emotions in Science Class (POSEMOT)
Negative Emotions in Science Class (NEGEMOT)
Standardized Test Efficacy Beliefs (TESTEFF)
Perceived Value of Standardized Test (TESTVAL)
MSLQ Domain-Specific Academic Test Anxiety (Worry) (TESTANX)
Effort Expended on Standardized Tests (TESTEFRT)
Science Test Use of Strategies (STRATEG)
Effort During Science Test (EFFORT)
Mood During Science Test (MOOD)
Energy Level During Science Test (ENERGY)
Science test total and subscores
Multiple-Choice Total Score (NCTOTAL)
Constructed Response Total Score (CRTOTTAL)
Basic Knowledge and Reasoning (MC_BKR)
Quantitative Science (MC_QS)
Spatial-Mechanical Reasoning (MC_SM)
Science Grade (SCIGRADE)

was computed from the first principal component of these measures to represent general cognitive ability.

Motivational measures. Motivational constructs included (a) students' efficacy beliefs about their ability to master science content and their ability to perform well on different types of science assessments (Bandura, 1997), as well as their confidence in their abilities in the domain of science (Dweck, 1986); and (b) students' valuation of the domain of science, including interest, usefulness, and importance (Eccles & Wigfield, 1995). Classroom engagement was assessed by students' self-reports of how much attention they paid in class, their degree of participation in science activities, amount of homework they completed, and their involvement in self-regulated learning activities. To assess test engagement, a survey was administered immediately after students completed the science achievement test. The test engagement measure assessed students' use of cognitive strategies, mood, energy level, and effort expended during the test. In addition, students responded to a test anxiety instrument.

Science achievement. The science achievement measures used in this study consisted of 30 multiple-choice items and 8 constructed response items. The core set of items was selected from the NELS:88 science test, and was augmented by multiple-choice and constructed response items from the National Assessment of Educational Progress (NAEP) and the Third International Mathematics and Science Study (TIMSS). We used separate total scores for the multiple-choice and constructed response segments of the test. In previous studies (see Hamilton, Nussbaum, & Snow, 1997), we identified three distinct science achievement dimensions in the NELS:88 multiple-choice test: basic knowledge and reasoning (BKR), quantitative science reasoning (QS), and spatial-mechanical reasoning (SM).

We reconstructed these dimensions and used the BKR, QS, SM subscores to examine their differential correlations with the motivational variables.

Analytic Strategy

We kept our analyses deliberately simple. For each of the achievement measures, we calculated the partial correlation with the set of motivational variables, controlling for general cognitive ability as well as for student's gender, ethnicity (White vs. non-White), and parental education. A correction for differential reliability was introduced, using the alpha coefficients, to make the comparisons among the correlations less sensitive to the effects of attenuation related to measurement error. These correlations provide a profile of the unique contributions of the motivational measures to the success of performance in each of the achievement indicators. We focus our attention on the commonalities and differences among the various profiles. This strategy allows us to construct a provisional portrait of the influence of motivational aptitude constructs on science performance, as a first step, without committing prematurely to a restrictive theoretical model. The development of a more coherent and comprehensive theoretical framework can then be aided by our results.

Results

We begin by examining, in Figure 1, the pattern of correlations (controlling for student background characteristics) between general cognitive ability and the science achievement measures.

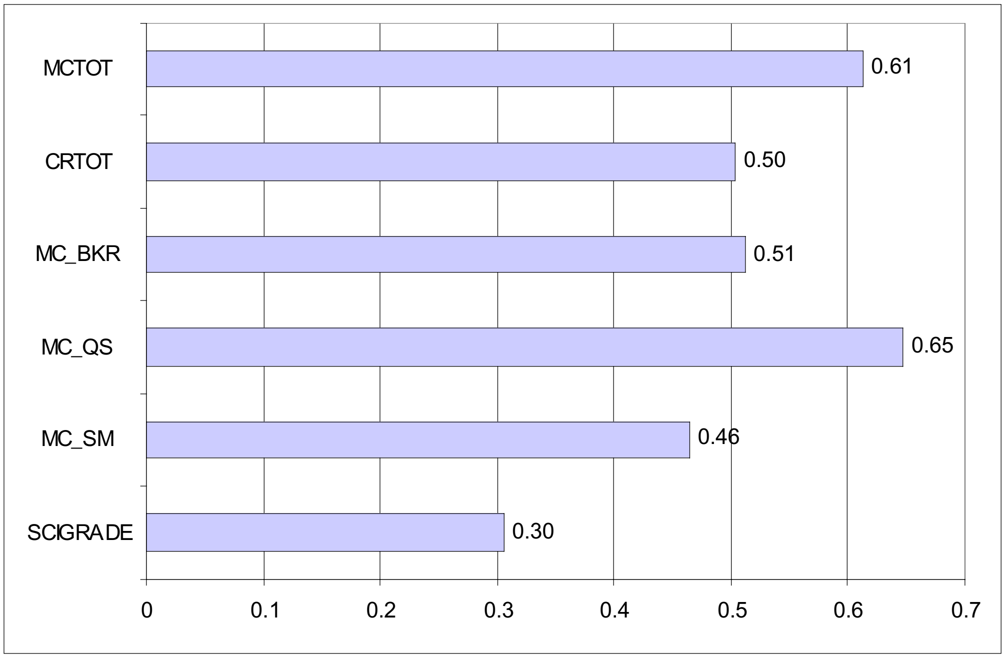

Figure 1. Partial correlations between cognitive ability and science achievement measures controlling for student background characteristics.

General cognitive ability was strongly correlated with test performance, especially with the quantitative science dimension. As expected, the correlation of cognitive ability with grades in a science course was much smaller.

Domain-Specific Motivational Resources

Figures 2 and 3 present the partial correlations[1] between different measures of science achievement and broad domain-specific motivational variables—efficacy beliefs in ability in science (SCIEFF), perceived value and importance of science (SCIVAL), self-regulation during science learning (SLFREG), engagement in science class (ENGAGE), and positive and negative emotions in science class (POSTEMOT and NEGEMOT, respectively).

[1] As a general guideline for evaluating the magnitude of the reported correlations, for our average sample size a correlation of approximately .10 is significant at the .05 level and a correlation of approximately .15 is significant at the .01 level. As a protection against underestimation of Type I error, we generally consider correlations of .2 and above as meriting closer attention.

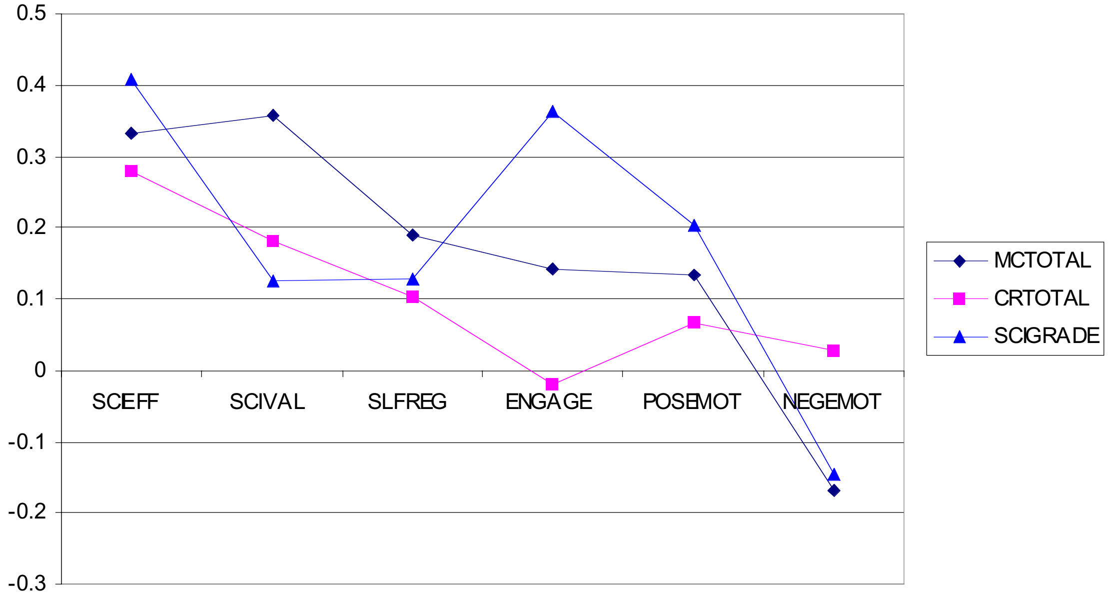

Figure 2. Partial correlations between domain-specific motivational variables and different science achievement measures.

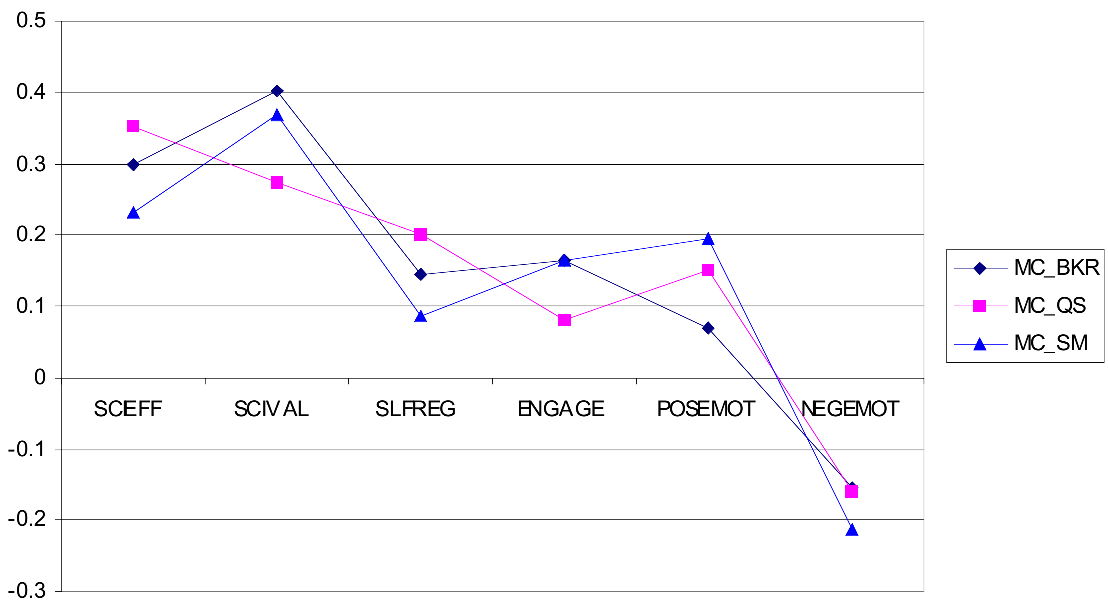

Figure 3. Partial correlations between domain-specific motivational variables and reasoning subscales of the science achievement test.

Generally, scores on the constructed response portion of the science test showed lower correlations with motivational constructs compared to both multiple-choice scores and science grades, with the exception of science efficacy beliefs, with which all three measure of achievement were substantially correlated. Perceived value and interest in science was mainly correlated with the multiple-choice test total score, and reported engagement in a science class was correlated with the science grades. Self-regulation and positive and negative emotions during science class were rather weakly correlated with achievement (Figure 2).

Multiple-choice dimension scores showed little differentiation in their pattern of relationships to the broad motivational constructs, and generally followed the same pattern as the MC total scores. The most noticeable differences were the higher correlation of efficacy with quantitative science and the higher correlations of value with the basic knowledge and reasoning and spatial-mechanical dimensions (Figure 3).

Task-Specific Motivational Resources

In this section, “task-specific” refers to a specific mode of evaluation of science proficiency, namely formal, standardized testing. Motivational constructs in this section address the generalized task of performance on tests rather than performance on any particular test. In Figures 4 and 5, we present the following motivational constructs, broadly related to performance on science tests: efficacy beliefs in the ability to succeed in science tests (TESTEFF), the value of tests as valid measures of proficiency in science (TESTVAL), test anxiety (TESTANX), and the amount of effort typically associated with test taking (TESTEFRT).

The three achievement measures showed remarkable similarities in their associations with the task-specific motivational variables. Test efficacy beliefs, and to a lesser extent, the value placed on the validity of testing and the efforts put into test taking, all exhibited moderate positive correlations with science test scores and grades. Test anxiety, on the other hand, was negatively correlated with performance on all three achievement measures (Figure 4).

A different pictured was revealed for the three science dimensions. Whereas basic knowledge and reasoning and spatial-mechanical scores showed relatively weak correlations with task-specific motivational variables, scores on the quantitative science dimension were more strongly correlated with test efficacy

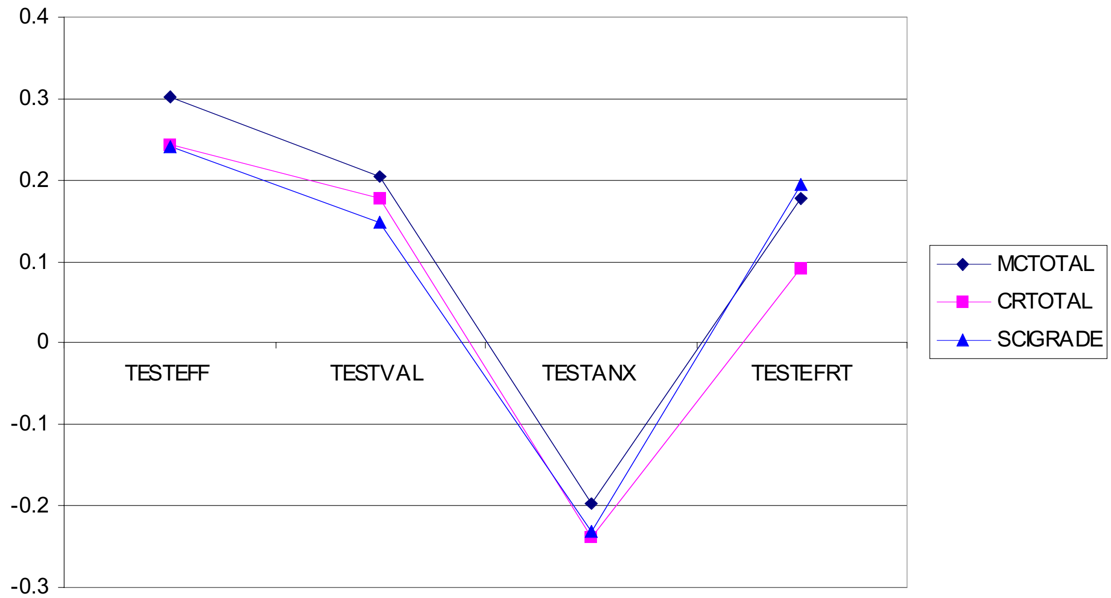

Figure 4. Partial correlations between task-specific motivational variables and different science achievement measures.

beliefs, test value, and test anxiety. No differentiation was evident for the weak correlations with test effort (Figure 5).

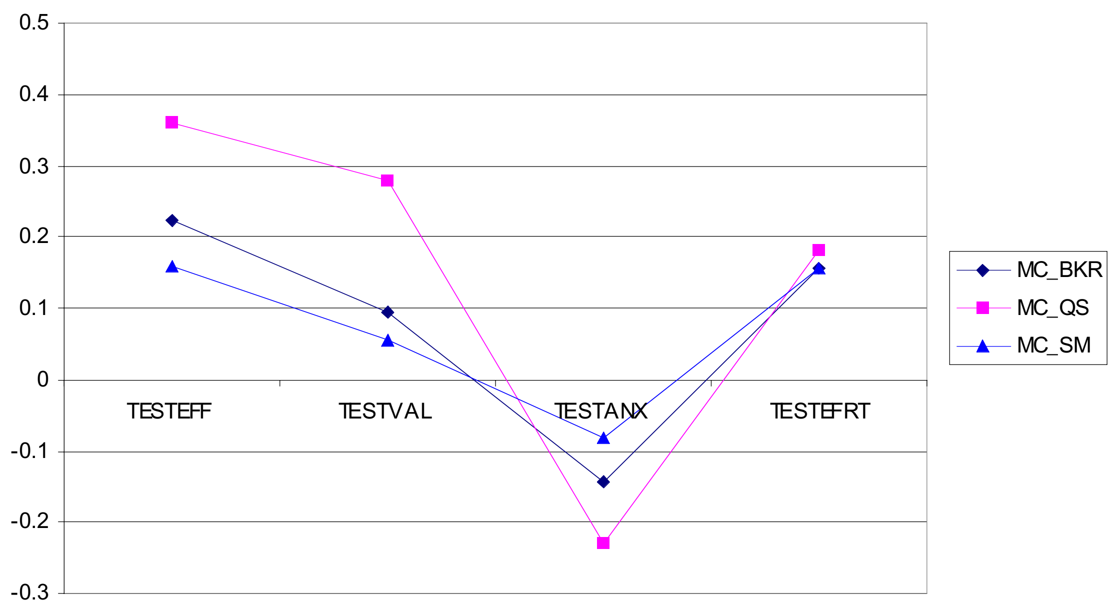

Figure 5. Partial correlations between task-specific motivational variables and reasoning subscales of the science achievement test.

Situation-Specific Motivational Resources

This section presents findings for motivational constructs closely embedded in a specific test situation. These constructs represent, in Figures 6 and 7, students' accounts of their immediate experiences while taking the science test we administered as part of this study: use of strategies (STRATEG), amount of effort (EFFORT), general mood (MOOD), and level of energy (ENERGY).

The situational specificity is clear in the patterns of relationships in Figure 6. Science grades were not correlated with any of the situation motivational variables (save for a weak correlation with effort). Different patterns of association were also detected for the multiple-choice and constructed response scores. Both were correlated with test effort and to a lesser extent with positive mood during the test. The multiple-choice scores, however, were moderately correlated with use of strategies, and more weakly with level of energy; these correlations were lower for the constructed response scores.

Further differentiation was revealed when examining the three science dimensions. Basic knowledge and reasoning exhibited the strongest correlations with the situation-specific motivational variables, whereas spatial-mechanical showed the weakest associations (with the exception of level of energy, with which quantitative science and spatial-mechanical showed negligible correlations; see Figure 7).

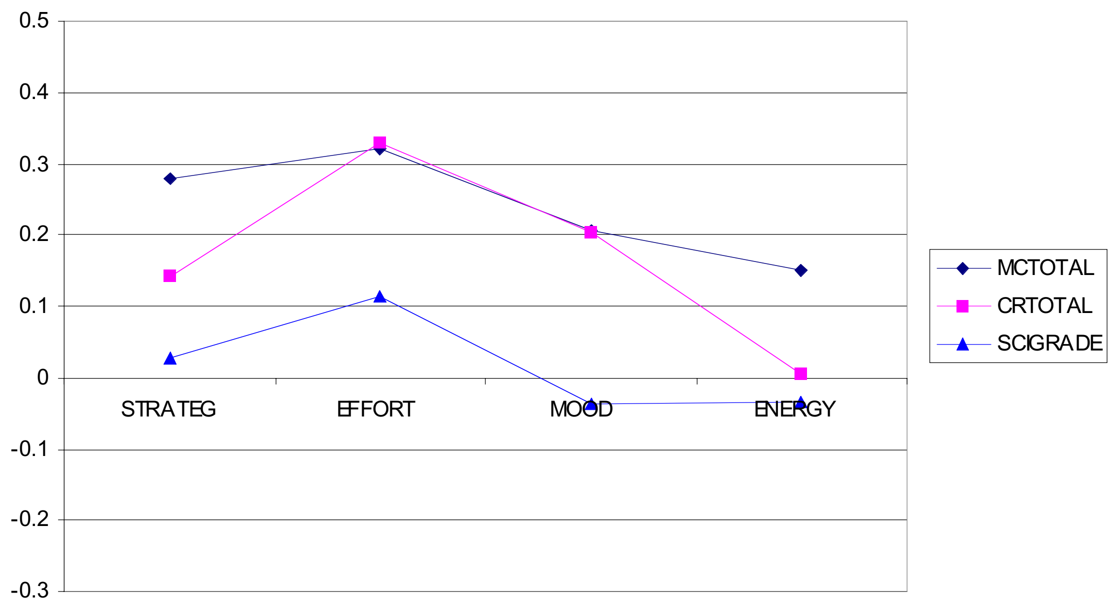

Figure 6. Partial correlations between situation-specific motivational variables and different science achievement measures.

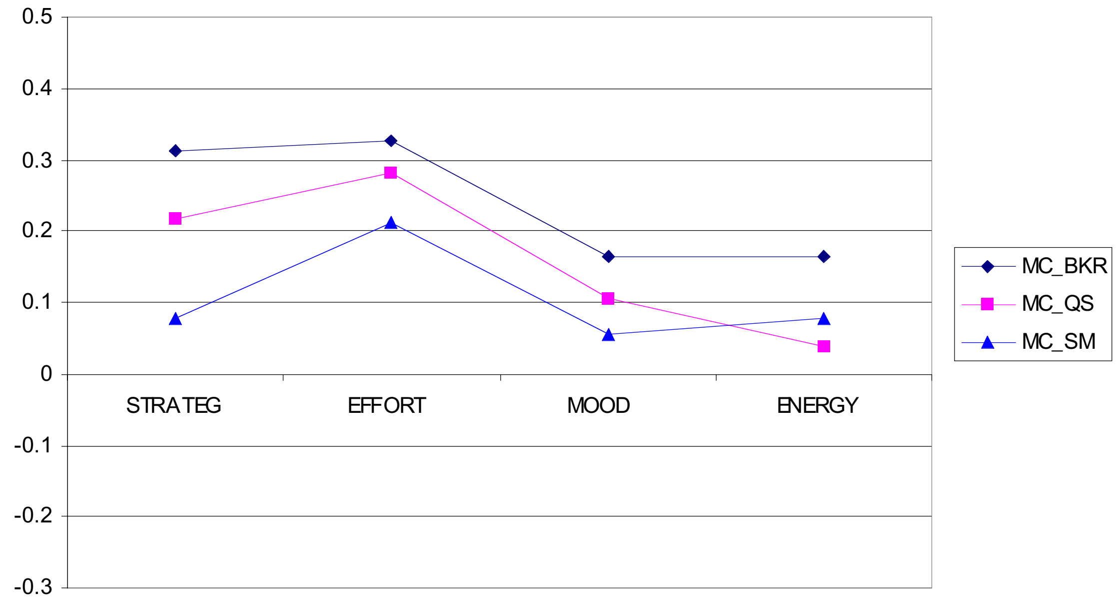

Figure 7. Partial correlations between situation-specific motivational variables and reasoning subscales of the science achievement test.

Discussion

This report provides a provisional portrait of the extent to which motivational aptitude constructs are implicated in the academic performance of high school students in the domain of science, over and above what can be predicted from considering the contribution of general cognitive ability and background characteristics. This portrait is obviously incomplete and can serve only as a starting point. Nevertheless, it leads to some valuable insights as to the nature of affective and conative components of performance.

Overall, our findings demonstrate the importance of considering motivational resources in explaining performance on academic tasks. Though cognitive ability is undoubtedly a critical aptitude resource, our results show that the unique contributions of noncognitive propensities are worthy of notice and, eventually, explanation. We also note that the differential pattern of correlations of motivational variables with different achievement measures supports the situative approach to cognitive performance, advocated by Snow and his collaborators. Grades in science, for example, were more strongly related to the broad motivational constructs, and especially to engagement in science class, than to the situation-specific constructs. At the same time, we find it intriguing that students who reported high value and interest in science as a domain were more likely to achieve high scores on a multiple-choice test, especially on the basic knowledge and spatial-mechanical dimensions, than to receive higher science grades for their performance in class.

A possible explanation for this pattern may involve an association between interest in science and exposure to science-related extracurricular activities. Both BKR and SM reflect knowledge and skills less critically associated with classroom learning, as compared with the quantitative science dimension. This hypothesis is supported by the strong correlation ($r = 0.51$) between value and interest in science and a composite representing students' reports of activities such as participating in a science club, reading science-related magazines, and talking with parents and friends about science-related issues. Further support comes from the finding reported by Hamilton et al. (1997) of a positive correlation between the frequency of visits to science museums and the SM dimension.

Our findings concerning the influence of efficacy beliefs, both domain-specific and task-specific, lend themselves to the explanations suggested by expectancy-value theories. Eccles-Parsons et al. (1983) defined expectancy as individuals' beliefs about how well they would perform on future tasks in a given domain. These theories posit that expectancies for success and values serve the function of preparing and energizing individuals to engage with a task, to seek out task challenges, and to persist at particular tasks, all contributing to successful performance via a process Snow called "the commitment pathway" (Snow, 1989; see also Stanford Aptitude Seminar, 2002). Eccles and her colleagues (Eccles, 1984; Eccles-Parsons et al., 1983; Eccles, Adler, & Meece, 1984) found that expectancies for success predicted achievement in mathematics and English. Our findings add achievement in science to the list.

In contrast to the pattern for task value, the quantitative science dimension was related to task-specific evaluation of self-efficacy and value, as well as test anxiety. Compared with the BKR and SM dimensions, QS items more closely resembled material likely to be encountered in a high school science classroom and required application of more advanced concepts and specialized, course-based knowledge. It is therefore plausible to hypothesize that students associated a general reference to "a science test" with questions similar to QS items. Remember also that this dimension has the strongest correlation with the general cognitive ability construct, suggesting that QS typifies a prototypical "cognitive" task more than either BKR or

SM do, thereby resulting in enhanced sensitivity to the availability of task-specific motivational resources.

Another intriguing finding is the higher correlation of BKR with the situation-specific motivational variables. Isen, Daubman, and Gorgolione (1987) concluded that learners in a good mood organize what is presented more systemically and meaningfully; Bower (1981) demonstrated that an elated person finds material easier to recall than a depressed one. Organization and recall were typical characteristics of the task demands of BKR items, especially compared to items representing the QS dimension. As for the correlation with the intensity of use of test strategies, it seems appropriate to invoke Heckhausen's (1991, p. 175) "Rubicon model," referring to a sharp qualitative difference between conative and volitional processes. Conation is key when shaping goals; it concerns values, incentives, and evaluation of likelihood of success—processes in the realm of motivation. Volition, on the other side of the Rubicon, is key when implementing actions leading to the accomplishment of chosen goals; it concerns practicalities of implementation but not a re-evaluation of goals (except, possibly, in the face of consistent failure). Volitional processes can be categorized as contributing to performance or interfering with it through the operation of what Kuhl called "action controls." Action controls are devices for maintaining intentions (Kuhl & Kazén-Saad, 1989, p. 387). Action-oriented individuals make deliberate of use such devices to complete tasks. Questions similar to those representative of our test strategies construct—such as "Should I consider a different way to solve this problem?" and "Am I reacting too slowly?"—are example of action controls. Because BKR items required less specialized knowledge and demanded efficient organization of work (albeit at a rather rudimentary level, double-checking answers or eliminating obviously incorrect response options, for example), it appears that this dimension was more susceptible to the effects of volitional action controls.

Some limitations of the current study should also be recognized. Obvious limitations are the reliance on self-report instruments, the representativeness of our sample, and the potential confusion of correlation and causal explanations. Because these are "standard" concerns in this type of research, we need not elaborate here. This study offers only a snapshot of the complex motivational and cognitive processes operating at the "interface" of person-situation transactions (see Stanford Aptitude Seminar, 2002, chap. 8). Further elaboration of these processes is needed and will require extensive dynamic modeling beyond what was possible in this study. But more can be done even with the existing data. We considered only simple linear relationships between motivational and performance variables. A natural extension we plan to implement as a next step in our investigation will introduce interactive and nonlinear relationships. Yet our findings provide the necessary grounding from which to launch a more elaborate inquiry.

Finally, the cognitive, affective, and conative qualities of performance are not provinces; they operate in synergy. Keeping them separate, as we did in this provisional study, simplifies the research but limits our ability to understand the totality of the performing individual. A sketch of the road ahead was offered by Snow et al. (1996):

> We . . . need an integrated model of affective and conative with cognitive functioning and development. . . . However, [we also need] another kind of integration . . . , one that views individual human functioning in educational settings as a whole, open, adaptive system, and assesses it as such. . . . Fragmentation of human personality into particular variables and pursuit of multivariate empirical relationships is a fruitful research strategy up to a point. But individuals are more than lists of variables. Somehow we need to find ways to put the fragments and relationships back into a pattern that describes integrated activity. . . . The trick may be to find multiple models that criss-cross in ways that help fill in the information that any one model leaves out. (p. 295)

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