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Promoting Interest and Performance in High School Science Classes

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We tested whether classroom activities that encourage students to connect course materials to their lives will increase student motivation and learning. We hypothesized that this effect will be stronger for students who have low expectations of success. In a randomized field experiment with high school students, we found that a relevance intervention, which encouraged students to make connections between their lives and what they were learning in their science courses, increased interest in science and course grades for students with low success expectations. The results have implications for the development of science curricula and theories of motivation.

Many educators and funding agencies share the belief that making education relevant to students' lives will increase engagement and learning (*1*–*6*). However, little empirical evidence supports the specific role of relevance in promoting optimal educational outcomes, and most evidence that does exist is anecdotal or correlational (*1*–*3*, *5*, *7*, *8*). The purpose of our research is to demonstrate how an intervention specifically designed to enhance the relevance of science to students' lives can enhance interest in science and classroom performance, particularly for students who are most at risk for being disengaged from school.

Numerous curricular reform efforts have emphasized applying science to students' lives, such as providing out-of-school research experiences (*7*, *9*), creating learning modules for specific topics [e.g., "Acids, bases, and cocaine addicts" (*10*, *11*)], developing an undergraduate course [e.g., "The biology and chemistry of everyday life" (*12*, *13*)], and redesigning the academic structure of entire high schools (*14*). For example, the Metro Nashville Public School District redesigned several of its high schools into career academies within which students can choose from thematically focused learning communities (*15*). The intention of these career academies is to enable students to "connect what they learn in school with their career aspirations and goals" (*14*). Although many of these programs have produced positive outcomes, such as improvements in retention in academic programs (*13*) or performance on achievement tests (*7*, *10*–*12*), it is not clear that these effects were due to personal relevance. These educational reforms are multifaceted, and an emphasis on relevance is just one of several components that may have contributed to the programs' outcomes. For example, other potentially effective components are small group instruction (*12*, *16*), repeated exposure to the material (*10*), individual mentoring and teaching (*14*), individualized and/or team-based projects (*7*, *13*, *16*), hands-on activities (*9*), visualization exercises (*11*), increased autonomy (*6*), and increased knowledge development (*17*, *18*).

Programs that emphasize personal relevance may be particularly empowering for students who are disengaged from school because of a lack of confidence. Students can become energized if they believe they are competent in science and can successfully perform classroom tasks. As described by expectancy-value models of motivation (*19*), both an individual's expectancy for success and his or her perception of value for the activity facilitate student motivation. Research on expectancies reveals that expecting to successfully perform a task leads to greater persistence, performance, and interest in academic activities (*19*, *20*). Thus, students who do not believe that they can do well in the classroom are at risk for performing poorly and becoming less interested in academics.

In addition to lacking confidence, students with low success expectancies may not perceive, or may have a harder time perceiving, relevance and value in their schoolwork (*21*). These students may require external support, from teachers or classroom activities, to foster or maintain task engagement (*22*). Interventions that facilitate the perception of relevance in a topic might promote attention and learning for students with low success expectancies (*23*). Instead of withdrawing from the activity, these students may become energized as they discover reasons for exerting effort and becoming more involved in learning (*24*). In contrast, more-confident students may not need this type of motivational boost because their effort and involvement in school are already strong (*22*, *24*).

Reduced interest in academics is particularly problematic for long-term outcomes such as educational and career choices. Research on the development of interest (i.e., experiencing positive affect, value, and knowledge with an activity)

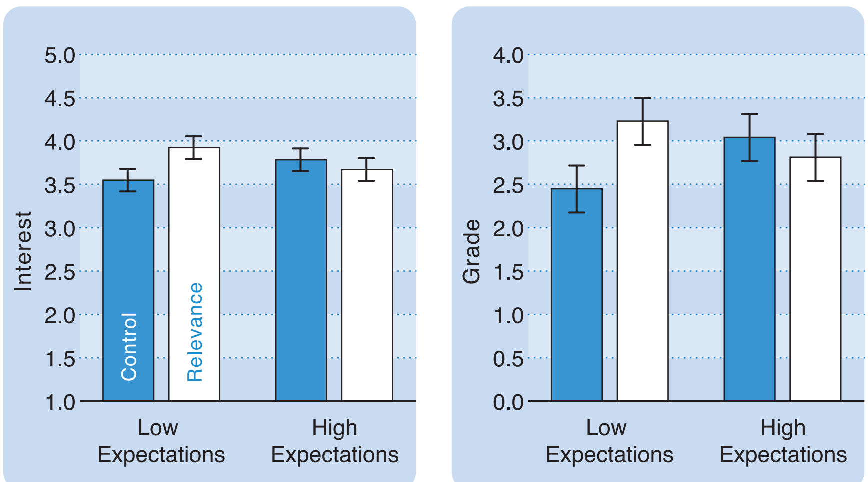

Fig. 1. Science interest (**left**) and course grades (**right**) as predicted by the relevance intervention and performance expectations. Predicted values are computed from the multiple regression equation for the interaction between the relevance intervention and performance expectations (low = –1 SD, high = +1 SD) on final course interest and second-quarter grades. Error bars represent ±2 SEM (0.12 for interest and 0.28 for grades).

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demonstrates that interest is a more powerful predictor of future choices than prior achievement or demographic variables (*22–25*). For example, Harackiewicz and colleagues (*25*) found that interest in an introductory undergraduate psychology course during freshman year was more predictive of subsequent course taking and majoring in psychology over a 7-year span than were grades from that introductory course. Interest development can begin in situations that promote student engagement with the material [i.e., situational interest (*24*)]. If students repeatedly experience situational interest in relation to a particular topic, they may eventually develop a more enduring interest in the topic (i.e., individual interest). A crucial factor in the progression from situational to individual interest is finding personal meaning and relevance in a topic (*24*). Perceiving a topic to be useful and relevant for other activities or life goals (i.e., utility value) predicts both subsequent interest and performance (*8*).

Making science courses personally relevant and meaningful may engage students in the learning process, enable them to identify with future science careers, foster the development of interest, and promote science-related academic choices (e.g., course enrollment and pursuit of advanced degrees) and career paths. The first step in this process is to investigate whether emphasizing relevance in the classroom promotes interest and performance in science courses. Thus, the goal of our research was to examine the effectiveness of a curricular intervention on interest and performance in high school science classes, particularly for students with low performance expectations.

We conducted a randomized field experiment of a motivational intervention that was designed to help students make connections between their high school science classes and their lives. The intervention was embedded within the entire semester of ninth-grade science courses. We investigated whether this intervention would increase student interest in science, performance in the course, and interest in science-related careers compared with a control condition where students wrote summaries of the material they were studying. Because students wrote about science topics in both conditions, knowledge activation was controlled, and the conditions differed only in terms of personal relevance activation. We predicted that the relevance intervention would promote interest in science and performance in the course, particularly for students with low performance expectations. Subsequently, we expected that increased science interest would lead to more interest in science-related courses and careers.

Participants were 262 high school students taught by seven science teachers (biology, integrated science, and physical science) from two high schools in a small, midwestern city in the United States. Students were 92% ninth-graders (8% tenth-graders), 52% female, 66% Caucasian, 15% African-American, 12% Asian, and 8% Hispanic. The analysis covered one academic semester. Students were randomly assigned within each classroom to either write about the usefulness and utility value of the course material in their own lives (relevance condition, $N = 136$) or write a summary of the material they were studying (control condition, $N = 126$). Teachers were informed that the research concerned the effectiveness of writing assignments but were blind to our hypotheses and students' experimental conditions. To ensure this, the researchers randomly assigned students to conditions at the beginning of the semester by giving students booklets with identical covers but with different instructions inside depending on experimental condition. Students completed their essays in these books, which were collected by the researchers after each assignment, every 3 or 4 weeks starting at the beginning of the semester. Students wrote from 1 to 8 essays [mean (M) = 4.7, SD = 1.4] throughout the semester. The researchers provided teachers with information regarding whether students had completed the essays, but teachers remained blind to condition throughout the semester (*26*).

Students' success expectancies and initial interest in science were measured at the beginning of the semester. Students' interest in science and future plans for science-related courses and careers were measured at the end of the semester [see table S2 for self-report items (*26*)]. Second-quarter grades were obtained from school records for one of the high schools ($N = 100$ students).

The data were analyzed by using multiple regression with dummy codes representing the nesting of students, teachers, and schools (*26*). The focal predictor was the interaction between the dummy code for experimental condition (0 = control, 1 = relevance) and students' performance expectations for the course. We predicted that this interaction term would be negative, such that the intervention effect would be more positive for those with low as opposed to high performance expectations. To examine effects of sex and race and whether the condition effects varied by sex and/or race, the regression models included dummy codes for sex, race, and their interactions with condition (*26*).

As predicted, there was a significant negative interaction between the relevance intervention and students' expectations for success on science interest ($\beta = -0.11$, $P = 0.05$), and the same negative interaction was also significant on second-quarter grades ($\beta = -0.18$, $P = 0.03$). The predicted values from the regression equation indicate that students with low-success expectancies (one standard deviation below the mean) reported more interest in science at the end of the semester (and received higher course grades) in the relevance condition than in the control condition, whereas students with high-success expectancies (one standard deviation above the mean) reported similar amounts of interest (and course grades) regardless of experimental condition (Fig. 1). There were no statistically significant interactions with gender or race, indicating that the intervention did not have differential effects (tables S4 and S5). Lastly, interest in science at the end of the semester was a significant predictor of interest in future science-related courses and careers ($\beta = 0.58$, $P < 0.01$; table S6).

Our results demonstrate that encouraging students to make connections between science course material and their lives promoted both interest and performance for students with low-success expectancies. The effect on performance was particularly striking, because students with low-success expectancies improved nearly two-thirds of a letter grade in the relevance condition compared with the control condition, which is comparable to other social-psychological interventions aimed at reducing the black-white achievement gap (*27*). Differences between conditions for students with high-success expectancies were not statistically significant. These results provide experimental support for expectancy-value models of motivation that hypothesize that perceived value is an important contributor to interest, performance, and future plans (*19–21*).

Although our experimental design included randomizing students within classrooms, evaluating the effects of the intervention over time, and assessing change in our dependent variables by including pre- and postmeasures in the analyses, this single study requires replication before generalizations can be made about more diverse settings and students. In addition, although the control condition was designed to activate students' content knowledge, further investigations of the cognitive processes instigated by the intervention are warranted (*28*). Nonetheless, our results show how motivational principles can be used to increase interest and performance in science courses early in high school. Our intervention was effective in raising interest and performance, was easy to implement, and required few external resources. This type of motivational intervention can be easily incorporated into almost any course with little cost to the instructor.

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Structural Insight into Nascent Polypeptide Chain–Mediated Translational Stalling

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Expression of the *Escherichia coli* tryptophanase operon depends on ribosome stalling during translation of the upstream TnaC leader peptide, a process for which interactions between the TnaC nascent chain and the ribosomal exit tunnel are critical. We determined a 5.8 angstrom–resolution cryo–electron microscopy and single-particle reconstruction of a ribosome stalled during translation of the *tnaC* leader gene. The nascent chain was extended within the exit tunnel, making contacts with ribosomal components at distinct sites. Upon stalling, two conserved residues within the peptidyltransferase center adopted conformations that preclude binding of release factors. We propose a model whereby interactions within the tunnel are relayed to the peptidyltransferase center to inhibit translation. Moreover, we show that nascent chains adopt distinct conformations within the ribosomal exit tunnel.

In prokaryotes, proteins are synthesized through translation of mRNA by the 70*S* ribosome, a large ribonucleoprotein complex consisting of a large (50*S*) and a small (30*S*) subunit. Although most polypeptides are thought to passively transit through the exit tunnel of the 50*S* subunit during translation, certain nascent chains appear to specifically interact with or adopt a secondary structure within the exit tunnel (*1*–*3*). This can in turn modulate the rate of translation (*4*) and in some cases induce translational stalling to regulate gene expression (*5*). For instance, stalling during translation of the SecM leader peptide in *Escherichia coli* (*6*–*8*) affects the expression of the downstream *secA* gene (*9*).

In bacteria, translational stalling is also used to regulate the expression of the tryptophan-catabolizing enzymes tryptophanase and tryptophan-specific permease, encoded by the *tnaA* and *tnaB* genes, respectively. In the tryptophanase (*tna*) operon of *E. coli*, the *tnaC* regulatory leader gene is located upstream of these two structural genes (*10*), and the spacer region between the *tnaC* and *tnaA* genes contains several potential Rho-dependent transcription-termination sites. When free tryptophan levels are low in the cell, the TnaC leader peptide is translated and the ribosomes are released from the mRNA, allowing Rho to access and terminate transcription before the RNA polymerase reaches the *tnaA/B* genes. In the presence of free tryptophan, however, the stalled TnaC•70*S* complex masks the Rho-dependent transcription-termination sites, and thus transcription of the downstream *tnaA/B* genes ensues (*10*). Trp^{12}, Asp^{16}, and Pro^{24} of the 24-residue TnaC leader peptide are crucial for stalling (*10*–*12*), and the TnaC•$tRNA^{Pro}$ (Pro^{24}) is located within the peptidyl-tRNA (P) site of the ribosome (*13*), indicating that Asp^{16} and Trp^{12} are retained within the exit tunnel. Moreover, mutations in ribosomal tunnel components alleviate stalling (*11*), which suggests that interactions between the TnaC nascent chain and the ribosomal tunnel are an essential feature of the stalling mechanism.

To gain structural insight into the mechanism by which the TnaC leader peptide induces translational stalling, cryo–electron microscopy (cryo-EM) and single-particle analysis were used to reconstruct an empty *E. coli* 70*S* control ribosome (Fig. 1, A and B), and an *E. coli* 70*S* ribosome stalled during translation of the TnaC leader gene by addition of free tryptophan (TnaC•70*S* complex) (Fig. 1, C and D, and fig. S1) (*14*), at 6.6 Å and 5.8 Å (FSC 0.5 criterion) resolution, respectively (figs. S2 and S3). A comparison with the empty 70*S* ribosome (Fig. 1, A and B) reveals additional density for a peptidyl-tRNA positioned within the P site of the TnaC•70*S* complex and for an mRNA spanning the aminoacyl-tRNA (A), P, and exit-tRNA (E) sites (Fig. 1, C and D, and fig. S4). An atomic model of the complete TnaC•70*S* complex, including the mRNA and $tRNA^{Pro}$ at the P site was generated using molecular dynamics flexible fitting (MDFF) (*15*) (fig. S5). Moreover, additional density within the exit tunnel could be attributed to the TnaC nascent chain (Fig. 1, C and D). At high contour levels, density remained very robust for the C-terminal half of the nascent chain (fig. S6), and

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