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Utility-value intervention promotes persistence and diversity in STEM

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We tested the long-term effects of a utility-value intervention administered in a gateway chemistry course, with the goal of promoting persistence and diversity in STEM. In a randomized controlled trial (N = 2,505), students wrote three essays about course content and its personal relevance or three control essays. The intervention significantly improved STEM persistence overall (74% vs. 70% were STEM majors 2.5 y later). Effects were larger for students from marginalized and underrepresented racial/ethnic groups, who were 14 percentage points more likely to persist in STEM fields in the intervention condition (69% vs. 55%). Mediation analysis suggests that the intervention promoted persistence for these students by bolstering their motivation to attain a STEM degree and by promoting engagement with course assignments. This theory-informed curricular intervention is a promising tool for educators committed to retaining students in STEM.

psychological interventions | STEM diversity | STEM persistence | expectancy-value theory

Introductory chemistry is one of the first science courses that aspiring scientists, medical professionals, and engineers take in college. It serves as a gateway to undergraduate degrees in STEM (science, technology, engineering, and mathematics) and thus represents a critical opportunity for science educators to shape students' academic and career trajectories. Such gateway courses are also notorious for the substantial loss of students who abandon STEM pursuits, particularly members of groups that have been historically marginalized and who are underrepresented in STEM fields (1–4). This complicated problem demands new pedagogical approaches as reflected in calls by professional associations, funding agencies, and policymakers to reimagine gateway science courses in ways that encourage active engagement and promote persistence and diversity in STEM fields (5–7). To grow and broaden the next generation of STEM professionals, we must develop evidence-based strategies that support students' long-term trajectories in STEM.

Thinking about Value in Gateway STEM Courses

One of the most important factors to consider is how students think about what they're learning in their gateway science courses. According to expectancy-value theory, when students believe that course content is personally valuable, they are more likely to engage in coursework, develop interest, earn higher grades, and persist in STEM (8–11). Fortunately, STEM fields are rich with value: College graduates with STEM degrees are in high demand (12), and careers in these fields provide individuals with intellectually stimulating jobs that encourage innovation and address pressing societal problems, such as public health crises and climate change. This value attracts many students to STEM, but unfortunately when students enter gateway courses, the material can feel disconnected from the goals that brought them there in the first place (13). To sustain and deepen students' appreciation for the value of STEM, it is important to encourage active learning in ways that help students connect course content to their personal goals.

Utility-value interventions (UVIs) help students discover and reflect on the usefulness and value of course topics for themselves through writing assignments that are integrated into the curriculum (14, 15). In these assignments, students are instructed to explore the personal usefulness (i.e., utility value) of course material and discuss its relevance for their own lives or the lives of close others. Students can connect course material to whatever is important to them, which allows them to connect course topics to their interests, their future goals, and others (e.g., their family, community, or society) as they reflect on what they are learning. Evidence indicates that UVIs can improve engagement and performance for all students, on average, and that effects tend to be largest for struggling students, first-generation college students, and for students from marginalized and underrepresented racial/ethnic groups (16–20). UVIs are theorized to be particularly effective for these students because

Significance

Introductory college science courses are a common point of attrition from STEM fields, particularly for students from marginalized backgrounds. To address this problem, we tested a psychological intervention in an introductory chemistry course. The intervention consisted of three short writing assignments that encouraged students to reflect on the relevance of course topics to their own interests, values, and goals. The intervention increased the number of students majoring in STEM fields (measured 2.5 y later) by 4 percentage points overall, and by 14 percentage points among students from marginalized and underrepresented racial/ethnic groups. This intervention can serve as a first step toward developing science curricula that align with diverse undergraduates' needs, goals, and interests, and thereby broaden participation in STEM.

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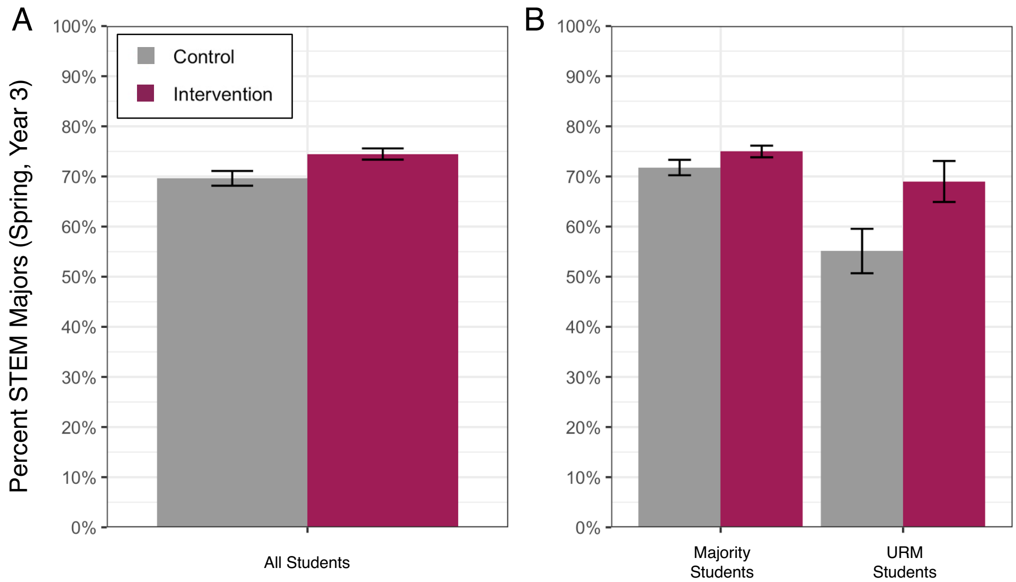

Fig. 1. Percentage of students majoring in a STEM field 2.5 y postintervention, (*A*) by condition, and (*B*) by condition and URM status. Error bars represent ±1 SE.

they can help students connect course content to culturally relevant and personally meaningful values, such as helping their family and community or pursuing equity and social justice (16, 21–24). If UVIs are successful in promoting engagement and interest in early STEM courses, they may also affect students' academic choices and influence persistence. There is some evidence that this can occur; a UVI in a second-year gateway biology course increased the probability of enrollment in the next course in the biology sequence (9, 18). Can the UVI have effects that extend beyond introductory courses and promote long-term change?

The Importance of Intervening in Chemistry

Most of the research reviewed here has been conducted in the context of biology classes, typically taken in the second year of college. It is critically important to test interventions earlier in the STEM sequence, given that attrition tends to be highest during first-year gateway courses (3). In the present study, we analyzed the long-term effects of a UVI, administered in a randomized double-blind study in a large introductory chemistry course, taken by first-year students. We followed more than 2,500 students for two and a half years after taking introductory chemistry and examined their academic trajectories, in terms of STEM course-taking and their ultimate choice of academic major. We hypothesized that a UVI, delivered in an early gateway course, would promote persistence and diversity in STEM throughout students' college years.

Method

We conducted a randomized experiment to test the UVI in a large introductory chemistry class at a public university in the midwestern United States. This chemistry course serves as an early prerequisite for students on prehealth tracks, as well as those studying science and engineering, and it is taken by over one-third of the university's first-year cohort, including nearly every student with STEM-related plans. Participants were 2,505 students from eight lecture sections of the course across the Fall and Spring semesters of a single academic year: 92% first-year students, 56% women (<1% identified as nonbinary), 19% first-generation (FG) college students, and 10% students who identified with racial/ethnic groups that are considered to be underrepresented and minoritized (URM) in STEM by the NSF (25). Specifically, 7% of students identified as Hispanic or Latino/Latina, 3% as Black, 0.6% as American Indian or Alaska Native, and 0.4% as Pacific Islander.[*]

In this study, we tested two versions of the UVI: the "standard" UVI that has been evaluated in previous research, as well as a new version of the UVI: a "prosocial-combined" UVI, which places the same emphasis on personal value but adds additional emphasis on prosocial usefulness. Over the semester, all students completed three 500-word writing assignments. Students in both UVI and control conditions were asked to formulate and respond to a scientific question using the course material. Students in the UVI conditions were also asked to describe how the material could be useful, either personally in the "standard" UVI or useful personally and useful for helping others in the "prosocial-combined" UVI. Here, we evaluate the long-term impact of the UVIs and test whether they can promote persistence in STEM throughout college.

To measure long-term persistence, we examined students' academic majors 2.5 y postintervention, which was the end of junior year for most students in the sample. This is a critical juncture in a student's academic trajectory: By this timepoint, all students are required to declare a major and their academic plans have stabilized (26). In our sample, 73% of students were majoring in a STEM field at this timepoint. We used multiple regression to test for UVI effects on students' Year 3 majors (STEM = 1, non-STEM = 0) and examine whether these effects were moderated by URM and/or FG status.[†] This analysis was preregistered at https://aspredicted.org/L6L_VFD. Details and complete results can be found in *SI Appendix*.

Results

Overall, the UVI significantly increased the likelihood of majoring in a STEM field by 4 percentage points relative to control (74% vs. 70%, $P = 0.008$, Fig. 1*A*). The two versions of the UVI did not differ in their effectiveness, $P = 0.487$, so they are combined as "intervention" in all figures. Critically, the intervention had a stronger effect for URM students, improving STEM persistence by 14 percentage points relative to the control condition (69% vs. 55%, $P = 0.020$, Fig. 1*B*).

[*]We acknowledge that the experiences of Black, Hispanic or Latino/Latina, and Indigenous students differ greatly, as do the causes of inequality in STEM for members of these different groups. In the present research, we combine these groups using the shorthand term "URM" because of a shared history of marginalization in STEM.

[†]These analyses were conducted using path models and FIML, rather than with logistic regression. This decision was preregistered and informed by Gomila (27). However, we also replicated our analyses using logistic regression with listwise deletion and the substantive conclusions do not change.

To explore when the academic paths of students in the intervention and control conditions began to diverge, we examined students' intentions to major in a STEM field (collected at the beginning and end of the chemistry class) and subsequent course-taking after the intervention semester (obtained from institutional records). Students' self-reported majors were coded as "STEM" or "undecided/non-STEM," and we coded whether students enrolled in two or more STEM courses in each semester (indicating a probable STEM major). Fig. 2 displays the percentage of students, by condition, who were classified as probable or declared STEM majors over time using these measures. We found that 1) most students (~93%) entered chemistry expecting to major in a STEM field, 2) the intervention had no significant effect on students' self-reported majors at the end of the class, and 3) in the following semesters, students in the control condition began to move away from STEM majors at a higher rate than those in UVI conditions, suggesting that the UVI prevented attrition from STEM over time.

We found a similar pattern for URM students, except that attrition was greater in the control group and intervention effects were more pronounced (Fig. 3).

How Did the UVI Prevent STEM Attrition? These powerful findings raise an important question: how did the utility value intervention prevent attrition from STEM over the course of two full academic years? To explore this question, we first revisited the short-term effects of this intervention (28). In particular, we focused on the four primary outcome variables considered in the short term: course performance, interest in chemistry, engagement with chemistry coursework, and plans to obtain a STEM degree. Engagement was measured in terms of the average length of students' writing assignments (29, 30), and students' plans and interest were assessed via a questionnaire at the end of the semester.

There was no overall intervention effect on chemistry performance for racial majority students, although the prosocial-combined UVI improved chemistry grades for confident FG students, relative to both the standard UVI and control, $ps \leq 0.021$. For URM students, the overall UVI effect on performance was negative but nonsignificant, $\beta = -0.09$, $P = 0.102$. The UVIs also had no overall effect on interest in chemistry, either for racial majority students or URM students, $ps \geq 0.446$, although the prosocial-combined UVI increased interest in chemistry for confident FG students relative to the standard UVI, $P = 0.009$, mirroring the effect for this group on performance. Among URM students, the UVIs enhanced interest for confident students, $P = 0.028$, paralleling the effect for confident FG students. On engagement, there was a significant overall effect of the UVI for both racial majority and URM students, $ps < 0.020$. For URM students, the UVI also strengthened STEM degree plans at the end of the intervention semester, $\beta = 0.14$, $P = 0.021$. This was not the case for racial majority students, $P = 0.593$.

The finding that the UVIs had no significant overall effects on chemistry grades or interest in chemistry (for either majority or marginalized students) rules these variables out as mediators of the long-term effects that we report here. In contrast, short-term effects on engagement (for all students) and STEM degree plans (for URM students) more closely resemble the long-term intervention effects on STEM persistence; these effects suggest that the intervention may have bolstered students' motivation in STEM, both within the course itself (i.e., engagement) and prospectively (i.e., degree plans).

In a series of mediation analyses (details in *SI Appendix*), we found evidence that engagement partially mediated the overall intervention effect on persistence, 95% CI = [0.002, 0.011], such that students who were more engaged in course writing assignments were more likely to persist in STEM. Moreover, this effect was more pronounced for URM students, 95% CI = [0.002, 0.026]. In addition, UVI effects on persistence for URM students were also mediated by STEM degree plans, 95% CI = [0.001, 0.025]. These results suggest that the UVI may have promoted long-term persistence by increasing students' motivation to engage

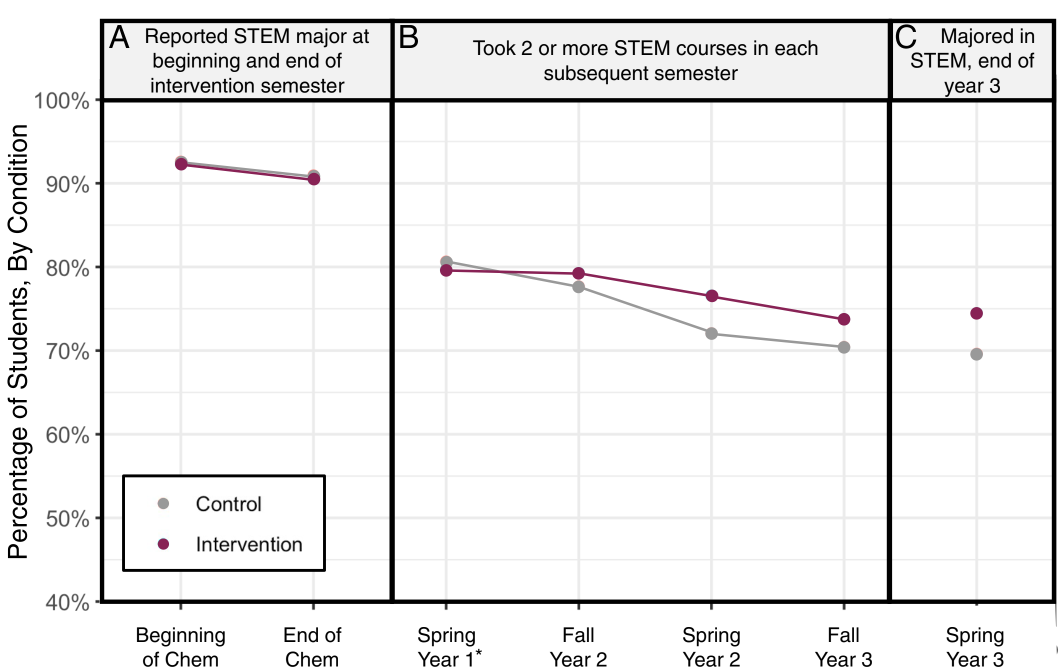

Fig. 2. How the intervention effect on STEM major unfolded over time. The percentage of students, by condition, who (*A*) reported a STEM major at the beginning and end of the intervention semester, (*B*) took two or more STEM courses each semester after introductory chemistry, and (*C*) majored in STEM 2.5 y later (the primary outcome variable); intervention effect, $P = 0.008$. The effect of the intervention on course taking was significant in the Spring of Year 2, $P = 0.010$ and was positive (but nonsignificant) in the Fall of Year 3, $P = 0.086$. *Percentages for Spring Year 1 only include students who took chemistry during the Fall semester; details in *SI Appendix*.

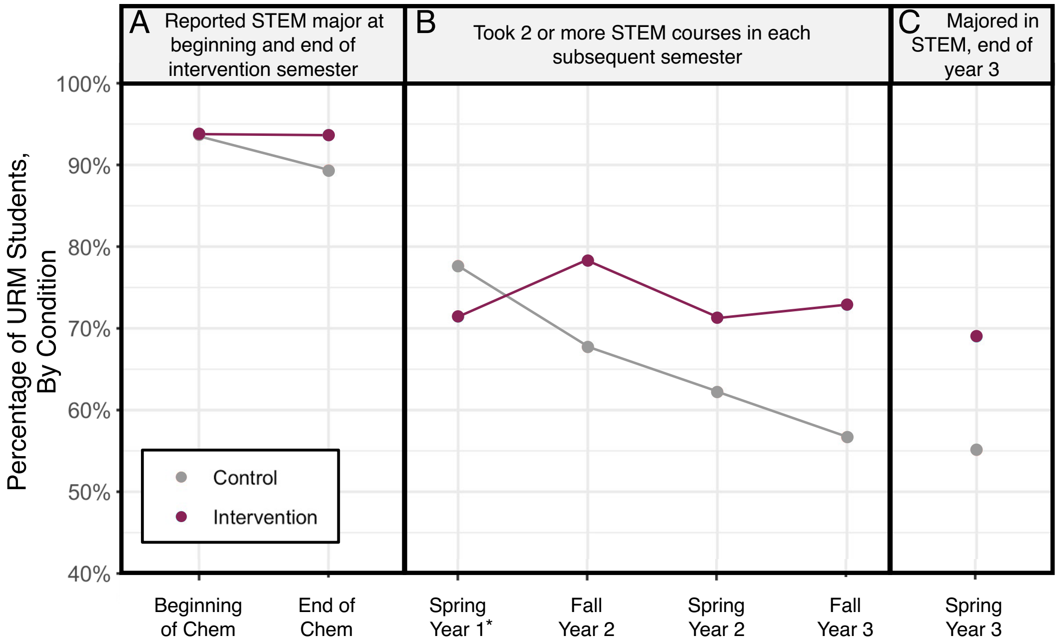

Fig. 3. How the intervention effect on STEM major unfolded over time for URM students. The percentage of URM students, by condition, who (*A*) reported a STEM major at the beginning and end of the intervention semester; end-of-semester intervention effect, $P = 0.145$; (*B*) took two or more STEM courses each semester after introductory chemistry, and (*C*) majored in STEM 2.5 y later (the primary outcome variable); intervention effect, $P = 0.020$. The effect of the intervention on course taking was significant in the Fall of Year 2, $P = 0.049$, was positive (but nonsignificant) in the Spring of Year 2, $P = 0.149$, and was significant in the Fall of Year 3, $P = 0.007$.

with STEM content, both within the course itself and also in planning for the future.

Discussion

Our long-term results are consistent with research showing that students move away from STEM fields after they complete first-year gateway courses and that this attrition is more pronounced for students from marginalized and underrepresented racial/ethnic groups (3, 31). However, our results also demonstrate that retention past the first year does not ensure continued persistence; indeed, students continued to leave STEM fields through their junior year. Critically, our findings reveal that a utility-value intervention administered in an early gateway class can help prevent this attrition over time and that this intervention was particularly effective in promoting persistence for marginalized students. This is the first documentation, to our knowledge, of a direct effect of a psychological intervention on long-term STEM persistence.

The results of our longitudinal and mediation analyses provide insight into the processes by which the UVI effects may have emerged over time. In some cases, interventions can have long-term effects by steering individuals into an environmental "channel" at a critical timepoint that shapes their future trajectories (32–35). For example, if the UVI had increased students' likelihood of enrolling in STEM courses the following semester, this may have boosted persistence by keeping them in the normative course sequence for students pursuing a STEM degree. However, we found no evidence for this process in the present study: Our longitudinal results show no intervention effects on persistence in the semester immediately following the intervention. In other cases, however, interventions can equip students with a psychological resource that helps them overcome challenges later in time (34, 35). Our longitudinal and mediation findings are more consistent with this type of process. Students' motivation in STEM, reinforced during the intervention semester, may have served as a key psychological resource that helped them to persist in a STEM major as they faced challenges and setbacks in subsequent years. For example, when faced with challenges in a later STEM course, students may have been primed to think about the usefulness of that course for their career goals, motivating them to work through the difficulty.

There are several features of the UVI and of this particular context that may have strengthened students' STEM motivation, and in turn, their long-term persistence. First, these assignments were implemented in students' first year of college, a crucial developmental period during which students learn the norms and expectations for what it means to be a STEM major. Reflecting on the relevance of course material may therefore have had an outsized impact on students' impressions of the field during this sensitive timepoint and thereby bolstered their intentions to pursue a STEM degree. Second, UVIs are active learning assignments that help students picture themselves in STEM. By reflecting on how they could use scientific content in their personal lives and careers, students may not only have come to see the usefulness of course content but they may also have appreciated how science is congruent with their values and identity, a powerful source of motivation (8, 20).

By demonstrating that a UVI in a gateway chemistry course can increase STEM persistence by 4 percentage points overall and by 14 percentage points for students from underrepresented and marginalized racial/ethnic groups, we add to the mounting evidence that theory-informed "wise interventions" in the STEM classroom can have long-lasting impacts (34, 36–38). The utility-value intervention can be incorporated into science curricula without requiring instructors to modify lectures or overhaul their courses, and our data point to the high value of adopting these assignments for real, measurable impact over time. Yet, even with something as simple as the utility-value intervention, we know that instructors must also have the right support to implement innovative pedagogical techniques that lift up all students, and especially those from underrepresented groups (39). The utility-value intervention is one such technique for science educators who want to catch and hold the talent of the next generation.

Materials and Methods

This study was approved by the Institutional Review Board at the University of Wisconsin-Madison. Data were collected in a randomized intervention trial across two semesters of an introductory chemistry course at a large, flagship state university (one Fall and one Spring semester). This chemistry course is required for students on prehealth tracks (e.g., premed, predental, prepharmacy), as well as students who are studying engineering, agricultural and life sciences, and environmental sciences. Students typically take this course in the Fall of their first year of college as a prerequisite to more advanced science courses, though the course is also offered in the Spring semester (in which enrollment is nearly 75% lower). Students in this study were in one of eight lecture sections of the course (six in Fall semester, two in Spring); taught by one of five instructors. All students were also enrolled in one of 140 lab sections (109 in Fall, 31 in Spring).

Participants. In total, 2,941 students were enrolled in the course. Of those students, 2,505 were assigned to one of two intervention conditions or the control condition, were at least 18 y of age, consented, and completed the course. These students comprise the sample for the current study (1,995 in Fall, 510 in Spring)[‡]. Although the Fall and Spring sections of the course differed in terms of students' characteristics (with proportionally more FG and URM students in Spring), the content and structure of the course were the same, and we combined all sections of the course for analytic purposes. Of the 2,505 students, 487 were FG students (19%) and 2,018 were CG students (81%). There were 256 URM students (10%; 168 Hispanic or Latinx, 80 Black, 15 American Indian or Alaska Native, and 10 Pacific Islander) and 2,249 racial/ethnic majority students (90%; 1,974 White, 343 Asian or Asian American). Regarding gender, 1,402 identified as women (56%), 1,100 as men (44%), and three as nonbinary ($<1\%$)[§]. The average age was 18.8 y (SD = 0.9) at the beginning of the study.

Writing Assignments. All students were given three writing assignments over the course of the semester as graded homework, each corresponding to a section of the curriculum that culminated with an in-class exam. This schedule of three assignments was implemented to expose students to a UVI repeatedly throughout the semester, consistent with previous research (14, 16, 18). All but 14 students in the sample (99.4.%) completed at least one essay. A total of 2,234 students (89.2%) completed all three essays. Essays were graded by a team of advanced undergraduate students who had been successful in this introductory chemistry course, but they were not teaching assistants in the course and had no direct contact with students. These graders were recruited by the chemistry instructors and were trained and supervised by the research team. Each team member graded only one type of assignment, using a rubric.

Students were randomly assigned to one of three conditions: a control condition or one of two UVI conditions ("standard" or "prosocial-combined"). In each condition, students completed three writing assignments (500 to 600 words) for course credit throughout the semester. Students in the control condition were asked to summarize course material, as in Harackiewicz, Canning et al. (16), whereas in the two UVI conditions, students were asked to summarize course material and describe its usefulness to themselves and/or for helping others. Students received assignments through the course's learning management system, such that instructors and teaching assistants remained blind to condition.

For each assignment, students were provided with a condition-specific prompt, delivered via online course software. Students were asked to formulate and answer a question, and examples of scientific questions were provided (e.g., "Why does the polarity of a molecule matter?"). In the control condition, students were asked to provide references for the scientific content of their essays. In the three UVI conditions, students were asked to explain how the scientific content of their essays could be applied, either to 1) their own life (standard UVI) or 2) their own life and to helping others (prosocial-combined UVI). In each UVI condition, the assignment instructions provided three short examples of potential applications. Sample questions and examples were developed in conjunction with course instructors.

Experimental Design and Assignment to Condition. Students were blocked on FG status, URM status, and gender and then randomly assigned to condition, within lecture sections. Despite a large overall sample size ($N = 2{,}505$), CG-majority students made up 75% of the sample ($N = 1{,}867$) whereas the numbers of FG-majority ($N = 382$), CG-URM ($N = 151$), and FG-URM ($N = 105$) students were low. We therefore needed to consider the implications for statistical power when deciding how many versions of the UVI to test with each group. There were too few URM students to test two UVIs against control in a three-cell design with sufficient power. Accordingly, we developed a procedure for assigning participants to condition within two independent experimental designs.

Three-Cell Design with Majority Students. We randomly assigned CG-majority and all FG-majority students in both Fall and Spring (N = 2,249) to one of three conditions. This allowed us to compare the effects of two versions of the UVI (standard and prosocial-combined) relative to control in a three-cell design and to explore how these effects varied for different subgroups (e.g., FG students) of majority students.

Two-Cell Design with URM Students. We randomly assigned all URM students (N = 256) to a two-cell design. This allowed us to test a single version of the UVI relative to control for the relatively smaller number of URM students in this course. We tested the prosocial-combined UVI vs. control in the Fall, but we switched to testing the standard UVI vs. control in the Spring after a check for adverse outcomes showed that URM students were performing somewhat more poorly in the prosocial-combined UVI condition.

Measures.***Confidence about performance.*** Confidence about performance was measured at the beginning of the intervention semester with three items on a one to seven Not at all true–Very true scale: "I am confident that I will do well in this course," "I expect to get a good grade in this course," "I believe that I can be successful in [course name]" ($\alpha = 0.84$, $M = 5.3$, SD = 1.1).

Prosocial chemistry motivation. Prosocial chemistry motivation was measured at the beginning of the intervention semester with three items in response to the prompt "I want to study chemistry because…". These three items, "I want to make a contribution to society," "I want to give back to my community," and "A background in chemistry will allow me to help other people" were measured with a one to seven Unimportant reason for me–Very important reason for me scale. ($\alpha = 0.87$, $M = 5.0$, SD = 1.4).

STEM degree plans. At the end of the intervention semester, students responded to the prompt "Do you intend to obtain a degree or certificate in the chemical and health sciences?" on a one to seven Definitely will not–Definitely will scale ($M = 4.4$, $SD = 2.1$).

Engagement with UVI Assignments. We used the average length (i.e., word count) of students' intervention or control essays as an indicator of their engagement with the assignments ($M = 554.6$, $SD = 47.7$)

Interest in chemistry. Interest in chemistry was measured with ten items at the end of the intervention semester on a one to seven Not at all true–Very true scale: "I think the field of chemistry is very interesting," "I'm really looking forward to learning more about chemistry," "To be honest, I just don't find chemistry interesting" (reversed), "Chemistry fascinates me," "I'm excited about chemistry," "I think what we're learning in this course is important," "[Course name] is important to my future," "The study of chemistry is personally meaningful to me," "The study of chemistry is personally important to me," "Learning about chemistry will help me become the person I want to be" ($M = 4.5$, $SD = 1.4$, $\alpha = .92$).

Chemistry Grades. At the end of the intervention semester, instructors provided grades for students in the course (A = 4.0, AB = 3.5, B = 3.0, BC = 2.5, C = 2.0, D = 1.0, F = 0.0). Students' grades in the course were curved to approximately a B average ($M = 2.90$, $SD = 0.92$).

[‡]174 CG-Majority students, in the fall semester, were assigned to a third utility value intervention condition for a study focused on utility value writing and are not included in the present sample.

[§]In all analyses, the three students who identified as nonbinary were not assigned a score on the gender variable; their remaining data were retained using full information maximum likelihood estimation.

Self-reported STEM major. At the beginning and end of the intervention semester, all students reported their intended major(s) and academic plans. We classified all students with clear STEM plans (e.g., an intended STEM major or prehealth plans) as "STEM" (92.4% at the beginning of the semester, 91% at the end of the semester). If a student did not list clear STEM plans or stated a non-STEM plan we classified them as "undecided/non-STEM."

Long-term STEM persistence. To measure long-term STEM persistence, we obtained students' majors from institutional records at the end of the Spring semester approximately 2.5 y after the beginning of the study. This timepoint represents the end of junior year for most students in the sample. We classified all majors as STEM or non-STEM using the classification system detailed in "STEM Major Classification System S1" (*SI Appendix*).

STEM course taking. To measure whether students were pursuing STEM-related plans in each semester following the intervention (during a time that official major is often not yet declared), we coded whether students were enrolled in two or more STEM courses each semester after the intervention (Spring Year 1–Fall Year 3 for Fall chemistry students, and Fall Year 2–Fall Year 3 for Spring chemistry students). When we compare students' course taking to their institutional majors 2.5 y postintervention, this measure correctly classifies 87% of STEM majors and 87% of non-STEM majors.

Data, Materials, and Software Availability. All study data and analysis scripts are included as supporting information for this article and described in the *SI Appendix*.

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