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UTILITY VALUE INTERVENTION TO SUPPORT UNDERGRADUATE STUDENT INTEREST, ENGAGEMENT, AND ACHIEVEMENT IN CALCULUS AND CALCULUS-BASED PHYSICS

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The purpose of this study was to help undergraduate STEM students at a Hispanic-serving institution make connections between calculus and physics content and their lives using a utility-value intervention. As part of either a Calculus II or a calculus-based Newtonian Physics course, 471 undergraduate students were randomly assigned to either read essays written by peers emphasizing the usefulness of their coursework in their daily life or to a control group. We found that students in the intervention condition reported significantly higher levels of utility value, midterm grades, and earned higher course grades. A path analysis revealed that utility value indirectly improved achievement through interest and engagement factors. Findings support predictions stemming from Expectancy-Value theory and offer practitioners with principles for leveraging perceived utility value, interest, engagement, and achievement.

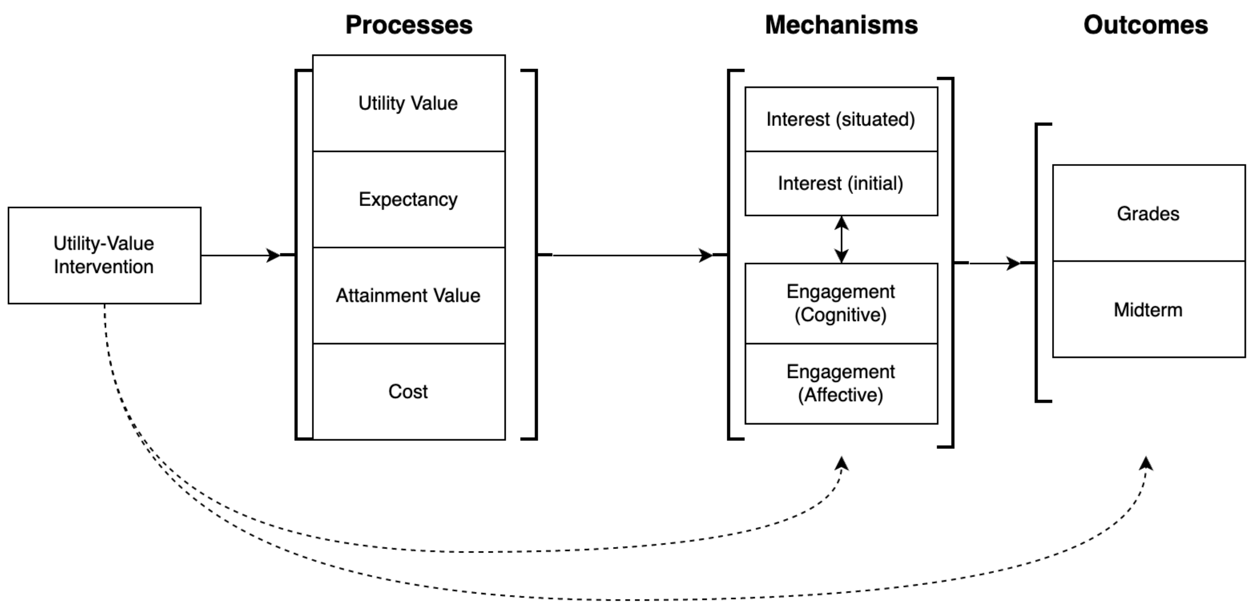
Keywords: expectancy-value theory, utility value, calculus, physics

A wealth of research in education shows that student motivation is a key variable in fueling learning and successful academic performance (e.g., Gottfried et al., 2013; Vu et al., 2022). Student motivation is augmented when students place *value* on the content that they are learning (Wigfield et al., 2017). The expectancy-value theory (Eccles et al., 1983) underlines three ways that value is related to student motivation. First, students may be motivated by experiencing the *intrinsic value* of what they are learning or finding an activity enjoyable for its own sake. Second, they could be motivated by *attainment value*, which is viewing the learning as important to their identity. Finally, learning may be motivated by *utility value* or finding the learning experience useful now or in the future.

Drawing on utility value component of expectancy-value theory (Eccles et al., 1983), Utility Value (UV) interventions have been designed by social psychologists as interactive classroom-based assignments to help students make connection between their lives and the content they are learning (Hulleman & Harackiewicz, 2022). The assignments ask students to write an essay (e.g., Harackiewicz et al., 2016), a letter (e.g., Aron et al., 1991) or read quotations (e.g., Kosovich et al. 2019) about the utility of the course material. The interventions should be personal, specific, and context relevant to be effective. Overall, a recent meta-analysis of randomized field experiments shows that UV interventions significantly increase student learning and interest (Hulleman et al., 2018) and may be particularly effective for underrepresented students in higher education (Harackiewicz et al., 2016).

Hulleman and Harackiewicz (2022) propose a logic model that outlines the processes and mechanisms through which UV interventions influence grades, persistence, and career intentions. Drawing on the variables from this logic model, we put together a UV intervention model (Figure 1) that we tested using path model analyses with specific process and mechanism variables that could explain the relationship between UV intervention and outcomes. Specifically, drawing from expectancy-value theory (Eccles et al., 1983), the model predicts that the UV intervention would elicit higher levels of perceived utility value and expectancy, and lower cost (process variables). These processes variables, in turn, should predict student interest and engagement (mechanisms) which are predicted to increase learning outcomes such as grades.

Figure 1. Hypothesized Utility-Value Intervention Logic Model



Note. Model was inferred from the Hulleman & Harackiewicz (2022). All dependent variables used in the model were posttest scores. Not shown in this figure are pretest scores which were included in the model as covariates predicting each posttest value (namely, this pertains to utility value, expectancy, value, cost, situated and initial interest, cognitive and affective engagement, and midterm grades).

In this model, interest and engagement are viewed as important mechanisms that are signaled by values and predict learning outcomes. *Interest* is defined as stable tendencies to engage with a subject over time (individual interest), or as a short-term phenomenon that is aroused by context (situational interest; Durik & Harackiewicz, 2007; Rotgans & Schmidt, 2017). Similarly, *Engagement* is multidimensional and is regarded in the literature as having behavioral, emotional, and cognitive dimensions (Fredricks et al., 2004). Behavioral engagement includes actions such as attendance and participation. Positive emotional (or affective) engagement is characterized by experiencing joy or excitement. Cognitive engagement is the willingness to engage in effortful tasks, purposiveness, strategy use, and self-regulation.

Despite theory that predicts relationships between processes, mechanisms, and academic outcomes, few, if any, empirical studies have synthesized these constructs and tested this model.

Current Research

The current study involves a randomized controlled trial examining the efficacy of a UV intervention in math and physics courses at a Hispanic-Serving Institution. It contributes important insights to the literature on UV interventions in three important ways. First, the current study seeks to test the effectiveness of UV interventions in critical transition *math* (Calculus II) and *physics* (Newtonian Mechanics) courses at a Hispanic-Serving Institution in the Western United States. This allows us to examine whether the intervention is effective with diverse populations (particularly Latino/a/x) which is a gap in the UV literature. Second, the current study examines the efficacy of quotations as a variation of the UV intervention. Rather than write essays themselves, students read 4-6 quotations from students who have previously completed the course. Previous research supports the efficacy of quotation utility value in math courses (Gaspard et al., 2015; Kosovich et al. 2019), but no previous research has examined quotations in a four-year university context. Third, this study empirically includes both process and mechanism variables outlined in the Utility-Value Intervention Logic Model (see Figure 1), which, to our knowledge, have not been simultaneously tested in a single model.

Research Questions

1. Will the UV intervention improve students' achievement outcomes (reported midterm grades, course grades) compared with a control?
2. Will the hypothesized relationships between task value processes and achievement outcomes be mediated by mechanisms of interest and engagement? (see Figure 1)

Based on predictions posed by the UV Intervention Logic Model (Hulleman et al., 2021), we hypothesized that the UV intervention would significantly improve students' achievement outcomes and this effect would be mediated by situated and initial interest as well as cognitive and affective engagement (see Figure 1).

Methods

Study Context

To answer our research questions, we initially recruited 518 undergraduate students from a general, calculus-based physics course (Newtonian Mechanics) and a Calculus II course. Five different instructors taught five sections of the physics course. One calculus instructor taught two sections of Calculus II and one instructor taught one section. We excluded 48 students from the study, 40 who did not meet our inclusion criteria because they were enrolled in two participating courses (both physics and mathematics), and 8 who opted not to participate. After these restrictions, our analytic sample was $N = 471$. Of this group, 5 were excluded from analyses when course grade was the main outcome because their grades were either unavailable, students did not consent to our using their grade, or they received a non-traditional course grade. Furthermore, 67 students did not complete a posttest, so were excluded from analyses where the main outcome was captured at posttest (i.e., midterm grades, career interest, and utility value).

Participating students were about 20.5 years old, first-generation college students (40%) female (30%), male (70%), Hispanic (39%), Asian (33%), Black (4%), Native American (5%), Pacific Islander (11%), White (41%), Other race (6%). Most completed the intervention as part of a calculus-based Newtonian Physics course (86%), the remaining from a Calculus II course (14%). Over the course of the Fall 2020 semester, students were emailed four survey links 1–4 weeks apart. Students were emailed a pretest survey at the beginning of the semester, two waves of intervention links, and a posttest survey that was nearly identical to the pretest near the end of the semester. Below we provide details about the intervention, pretest, and posttest surveys.

The Utility Value Intervention

As part of their regular coursework, on two separate weeks, students were given a link to a survey where they completed an assignment that was required for a small portion of course credit. Students were assigned to either the UV intervention group or a control group for both assignments. Students in the control group were also asked to process and evaluate textbook excerpts from either a Newtonian physics textbook or from a Calculus II textbook depending on the course that the student was enrolled in. Students in the treatment group were similarly presented with texts presenting student quotations, but in this case, they emphasized the utility value of topics specific to either Newtonian Physics or Calculus II, depending on the course that the student was enrolled in, and asked a series of questions encouraging students to process and evaluate the student quotations (see Table 1 for examples).

Students in the intervention group engaged with a total of six student quotations (3 quotations X 2 waves) written from the perspective of peers at their university explaining how a particular topic they learned in their Calculus II or Physics course "is relevant in [their] own life." The quotations were developed in a separate study over the course of several iterations of focus group interviews and were intended to pertain to topics they had recently covered in class. Some of the quotations were written by actual students (and edited by the research team) and some were created by the researchers. In all cases, students in the utility value intervention were asked to reflect on and engage with the student quotations by rating whether they "liked" them, explained why or why not, and then they ranked the quotations from their most to least favorite.

Table 1. Sample Student Quotations from Utility Value Intervention and Control Group

Course	Example Utility Value Narrative
Calculus-Based Physics	I loved playing soccer in high school. We had a great team in my senior year and were fighting really hard to win our final tournament game. I got the ball and saw an opening so I was taking the ball down the field as fast as I could and when I kicked the ball to my teammate, my ankle just gave out. I had to be carried off the field without being able to finish my last soccer game. Turns out I had torn the ligament in my ankle. I took me weeks to recover and a lot of physical therapy. At CPP, when I was studying for Physics 1510 one night, it hit me that the rotational forces could explain my ankle injury. The movement of the ankle is connected to work and energy, momentum and rotational motion. The ligament in my ankle was bent in a direction approximately perpendicular to the long bones of the leg. This tore my ligament because of the rotation of the bones beyond what was physiologically allowed. My doctor had me wear ankle wraps for a few weeks after the injury to provide some extra pressure to support my ankle, so it endures less force during recovery. It was not fun being injured and I hated being in crutches but now I know that I going to pursue a career in biomechanics so I can work on technologies to help athletes with injuries. (Jenna, Age 20, major: Mechanical Engineering)
Calculus II	A lot of people will say that you never need high level math in real life. This is true for most people, but if you are taking calc 2 then you're probably going to take harder math classes in the future and you WILL need what you learn. I am a mechanical engineering major and I use calc 2 all the time. I use integration by parts in my physics classes. Calc 2 is also the foundation for three variable calculus, which is basically 3D math. Any real-life object is going to be 3D so calc 2 and 3 is really important for modeling real things. I also know that other high level math courses like linear algebra, differential equations, even statistics all involve integration and sequences and series. It's like calc 2 is another step on the mathematical ladder. Without it, you can't get to the next step. (*Esmeralda Lopez, 20, major: Mechanical Engineering*).

Note. All student names shown were pseudonyms.

Materials

As noted, the pretest was identical to the posttest, both of which consisted of 9 questionnaires (Utility value, expectancy, attainment value, cost, interest, cognitive engagement, affective engagement, STEM career interest, and a demographics questionnaire). The posttest also included a demographics questionnaire, which included self-reported grades for course exams and a question requesting permission to use students' course grades in our analyses.

Outcome Measures

Grade. With students' consent, their course grades were accessed for use as a main outcome in our study. Grades were on a four-point scale (e.g., 4.0 = A+, 2.19 = C-).

Self-Reported Midterm Grades. In the posttest given near the end of the semester, we asked students to report a percentage score for their first and second midterm. The second midterm score was used as a main outcome and the first midterm as a covariate, when applicable.

Utility Value. UV was measured using four items adapted from Hulleman et al. (2010). This scale asked students to report their feelings that what they were learning was relevant to their life, and consisted of four items that differed depending on which course the student was taking (e.g., "[Calculus II/Physics] can be useful in everyday life." Responses were on a five-point agreement scale and were reliable at conventional levels (α = .84 pre, .90 post). Given that the interventions target UV, we used this variable as an outcome in a manipulation check, but also used the variable as a covariate in central analyses predicting academic performance.

Predictors

Expectancy. Expectancy was measured using three items adapted from Kosovich et al., (2015) at pre- and posttest. Items asked participants to rate their agreement on a five-point scale to statements about their expectancy for success (e.g., "I believe that I can be successful in my [Calculus II/Physics] class"). The scale was reliable at conventional levels (α = .92 pre, .93 post).

Attainment Value. Attainment value was measured at pre- and posttest using three items from Kosovich et al., (2015) measuring perceived importance of the class on a five-point agreement scale (e.g., "I think [Calculus II/Physics] class is important."; α = .92 pre, .92 post).

Cost. Perceived cost was measured at pre- and posttest using four items from Kosovich et al., (2015) measuring on a five-point agreement scale, the perceived cost of time and effort required for success (e.g., "I have to give up too much to do well in my [Calculus II/Physics] class." α = .86 pre, .85 post).

Interest (situated and initial). STEM interest was measured at pre- and posttest with a scale adapted from Hulleman et al., (2010) that assesses both situational and initial interest. The initial interest scale consisted of eight items assessing interest in the subject (e.g., "I think [Calculus II/Physics] is an interesting subject.") on a seven-point agreement scale (α = .93 pre, .94 post). The situated interest subscale consisted of five items measuring interest as situated in the course (e.g., I think that what we're learning in this class is fascinating." α = .89 pre, .88 post) on the same response scale.

Cognitive Engagement. Cognitive engagement was measured at pre- and posttest using 16 adapted items from two cognitive engagement scales (Greene & Miller, 1996; Pintrich et al., 1991). Items assessed participants' reported levels of cognitive effort when learning (e.g., "I make sure I understand material that I learn in [Calculus II/Physics]", α = .89 pre, .90 post).

Affective Engagement. Affective engagement was measured at pre- and posttest using four items adapted from Thompson (2007). The items asked participants to report on a five-point scale (1 = *Never* to 5 = *Always*) how often they felt "inspired," "determined," "attentive," and "active" (α = .79 pre, .81 post).

Demographic Factors. Lastly, participants completed demographics items. In the current study, we included factors of race/ethnicity, gender, and first-generation status as covariates. For analyses, we recoded gender as a dichotomous variable (1 = *Female*, otherwise 0), as well as race/ethnicity (1 = *African/African American/Black or Hispanic/Latino*, 0 = otherwise), and First-Generation College student status (coded as 1 for students who reported that neither of their parents received a degree from a four-year college or graduate degree, and 0 otherwise).

Results

Independent samples t-tests revealed that there were no significant differences in pre-test scores between control or treatment groups with the analytic sample for all outcomes (all *p*s > .31) and many predictors (*p*s > .060). The exceptions were that pre-test situated interest ($M_{control}$ = 5.12; $M_{treatment}$ = 4.84; p = .03), pretest expectancy ($M_{control}$ = 4.92, $M_{treatment}$ = 4.68; p = .014), and cognitive engagement ($M_{control}$ =4.71, $M_{treatment}$ =4.51, p = .028) were higher in the control group than in the treatment group. To account for these differences and to improve power, we included pre-test scores as covariates in all models.

Effects of our Intervention on Utility Value and Academic outcomes (RQ1)

To test the effects of the intervention, we ran linear regressions with academic achievement outcomes and utility value as main outcomes. We also included instructor fixed effects to account for classroom-level differences (e.g., to account for differences in teachers' grading patterns). In separate models, the outcomes were course grade, reported second midterm grades, and utility value. To improve power, we included pre-intervention scores as covariates in all models, with the exception of course grades because course grades were not assigned prior to the intervention. To assess the effectiveness of the math versus physics intervention, we also tested models after including course type (physics or math) as a moderator of the intervention effects. See Table 2 for a summary of all regression models with all relevant coefficients.

Table 2.
OLS Regression Analyses After Adjusting for Teacher Fixed Effects (N = 471)

	Course Grade		**Reported Midterm 2 Grade**			**Utility Value**		
Treatment	**0.188~**	**0.255***	**3.523***	**3.445***	**4.875****	0.087	**0.271****	**0.279***
	(0.105)	**(0.113)**	**(1.702)**	**(1.670)**	**(1.817)**	(0.136)	**(0.101)**	**(0.110)**
	p = .077	**p = .025**	**p = .040**	**p = .040**	**p = .008**	p = .525	**p = .008**	**p = .012**
Pretest Score				0.081***	0.073**		0.731***	0.731***
				(0.022)	(0.023)		(0.043)	(0.043)
				p < .001	p = .002		p < .001	p < .001
Treatment * Math Course		-0.5			-9.088~			-0.054
		(0.308)			(4.653)			(0.278)
		p = .105			p = .052			p = .847
Observations	465	465	321	321	321	361	330	330
R-Squared	0.007	0.013	0.014	0.053	0.065	0.001	0.479	0.479

Note: Reference group for "Treatment" variable is "Control," and for "Math Course" is "Physics Course" ~*p* < .1; **p* < .05; ***p* < .01; ****p* < .001

We found that post-test **utility value** was significantly higher in the treatment condition when compared with the control condition (*d* = .08) after adjusting for pre-test utility value. This finding remained significant after including course type as a moderator. These findings serve as a manipulation check to ensure that the intervention was working as expected.

We found a marginally significant effect of treatment on **course grades** (*d* = .17). This effect became significant after adjusting for the treatment's interaction with course type. This suggests that the treatment was slightly less effective in the math class, but not significantly so.

We found that reported **midterm grades** were significantly higher among individuals in the treatment condition (*d* = .26) before and after adjusting for prior midterm scores. That is, individuals in the intervention condition reported scoring about 3.4 percentage points higher than those in the control condition. The effect remained significant after including course type as a moderator, revealing marginally stronger effects ($p = .052$) of the treatment in the physics courses when compared with the math courses.

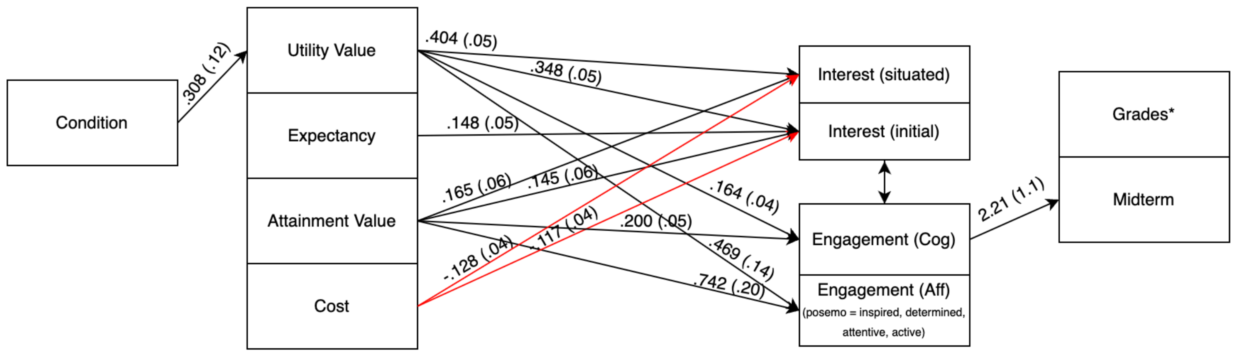
We also ran exploratory analyses in which we reran the previous models but with race, gender, first generation college student status, and number of treatments as moderators of the effects of the intervention. We found no significant moderation effects (all $p > .087$).

Path Analysis (RQ2)

We ran a path model to investigate which relationships hypothesized by the UV Intervention Logic Model were significant for our intervention. Specifically, we tested the hypothesized model shown in Figure 1, which depicts the intervention condition predicting process variables (UV, expectancy, attainment value, and cost), followed by mechanism variables (STEM interest [initial and situated]), and engagement (cognitive and affective), followed by academic outcomes (course grades and midterm grades). In all cases, scores at posttest were of primary interest, although pretest scores were included as covariates predicting each posttest value whenever available (namely, pertaining to UV, expectancy, attainment value, cost, situated and initial interest, cognitive and affective engagement, and midterm grades). We allowed for all variables at each of the process, mechanism, outcome stages to correlate and initially included pre-intervention variables to covary with their post-intervention counterpart whenever available in all models. See Table 3 for intercorrelations between variables. All analyses were done with the "lavaan" package in R version 4.0.2 (Rosseel, 2012).

As is typical of path modeling, we underwent model modifications to improve the model fit. The initial model had fit statistics that were not satisfactory at conventional levels (Chi-sq = 802, *df* = 129, CFI = .816, TLI = .73, AIC = 16534, RMSEA = .141; Hu & Bentler, 1999). As such, we computed the modification indices and included additional paths between pretest scores with all modification indices larger than 45. Fit improved (Chi-sq = 359, *df* =113, CFI = .93, TLI = .89, AIC = 16023, RMSEA = .091). Figure 2 shows the full path model with all coefficients.

Figure 2. Path Model with Significant Paths Shown



Note. Only paths that are significant at the .05 level are shown, red paths are used when coefficients are negative. All variables shown represent values at posttest. Not shown in this figure are pretest scores which were included in the model as covariates predicting each posttest value

Interventions influenced processes. As depicted in the figure, there was a significant effect of UV condition on reported UV (p = .008), with no significant effects on expectancy, attainment value, or cost (ps = .573, .473, .692 respectively).

Processes predicted mechanisms. These four process variables were significantly associated with mechanism variables. Namely, UV was significantly and positively associated with situated and initial interest, and cognitive and affective engagement (all ps < .001). Expectancy positively predicted initial interest (p = .004), but not situated interest, or cognitive or affective engagement (ps = .139, .062, .957 respectively). Attainment value positively predicted situated and initial interest and cognitive and affective engagement (all ps = .009 and .015, and less than .000 and .000 respectively). Cost negatively predicted situated and initial interest (both ps = .001), but did not significantly predict cognitive or affective engagement (ps = .156 and.724 respectively).

Mechanisms predicted outcomes. Of the process variables, reported midterm grades were significantly and positively predicted by cognitive engagement (p = .047), but not by situated or initial interest, or affective engagement (ps = .386, .160, and .750 respectively). Grades were not significantly predicted by any of the mechanism variables of situated / initial interest or cognitive / affective engagement (ps = .737, .290, .747, and .976 respectively).

Significance

We sought to investigate whether a UV intervention would improve a diverse group of students' achievement outcomes in advanced calculus and physics, and whether such relationships were mediated by student interest and engagement in course content. We found that students who were asked to engage with student quotations emphasizing useful applications of content they were learning in their course (either relating to calculus 2 or Newtonian physics) indeed significantly improved perceptions of utility value of course content compared with a control group. Students in the UV intervention condition also had higher end-of-course grades compared with the control group (d = 0.17) and reported scoring about a quarter of a standard deviation higher on their second midterm exams (d = 0.26). These findings are consistent with prior research showing that utility value interventions can support achievement outcomes for undergraduate students in STEM (c.f., Hulleman et al., 2021) and support the idea that, to improve motivation and achievement, it is important for practitioners to remind students how concepts they are learning will be useful for their lives (c.f. Thacker et al., 2022).

Furthermore, we tested predictions that interest and engagement may be important mechanisms underlying relations between utility value and achievement outcomes. We found that the relationships predicted by the Utility Value Intervention Logic Model had satisfactory fit. Indeed, psychological processes of value perceptions were significant predictors of psychological mechanisms (such as individual/situated interest and affective/cognitive engagement) which significantly predicted achievement outcomes (grades and self-reported midterm scores). Although we did not find significant *indirect* effects of the intervention on achievement through process and mechanism variables (likely due to only modest effects of the intervention), our findings provide emerging evidence that interest and engagement may be important underlying mechanisms by which utility value operate.

Although our findings span a semester of growth, future research might investigate more long-term effects of UV interventions using longitudinal methods. Future research might also use qualitative methods to further illuminate why UV interventions lead to improved achievement outcomes, and in particular, explore to what extent students perceive such interventions to support their interest and engagement.

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