More Useful or Not So Bad? Examining the Effects of Utility Value and Cost Reduction Interventions in College Physics

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Abstract

This study compared two expectancy-value-theory-based interventions designed to promote college students' motivation and performance in introductory college physics. The *utility value intervention* was adapted from prior research and focused on helping students relate course material to their lives in order to perceive the material as more useful. The *cost reduction intervention* was novel and aimed to help students perceive the challenges of their physics course as less psychologically costly to them. Students (n = 148) were randomly assigned to the utility value intervention, cost reduction intervention, or a control condition. Participants completed intervention or control activities online at two points during the semester. Their motivational beliefs and values were measured twice, once immediately after the intervention or control activities ended and again at the end of the semester. Both interventions improved students' grades and exam scores relative to the control group (*d*'s from 0.24-0.30), with stronger effects for students with lower initial course exam scores (*d*'s from 0.72-0.90). Unexpectedly, both interventions effects were explained in part by initially lower performing students reporting higher competence-related beliefs and lower cost immediately after they received either intervention, compared with lower performing students in the control condition. Results suggest that cost reduction and utility value interventions are both useful tools for improving students' STEM course performance.

Keywords: expectancy-value theory, utility value, cost, intervention, STEM

Educational Impact and Implications Statement

This study assessed the effectiveness of two different types of brief motivational interventions for promoting student motivation and performance in a college physics class. Both were based in the expectancy-value theory of motivation. One intervention focused on enhancing students' perceptions of the usefulness of physics (i.e., a utility value intervention) and was based on similar interventions done in other subject areas. The second was a novel intervention designed to reduce students' perceptions of the negative aspects (or costs) of engaging with physics coursework (i.e., a cost reduction intervention). Results showed that both interventions improved students' performance in the course. The effects were strongest for those who had lower initial course performance, and thus were most likely to drop out of STEM majors. Findings suggest that there are at least two different types of motivational intervention techniques that can promote college students' performance in introductory STEM courses.

More Useful or Not So Bad? Examining the Effects of Utility Value and Cost Reduction Interventions in College Physics

A variety of different occupations require individuals to be proficient in skills such as numeracy, data analysis, or analytical reasoning, which are grounded in the fields of science, technology, engineering, and mathematics (STEM; National Science Board, 2014). However, many students do not take the necessary STEM courses they need to develop these skills, and only about half of students who enter college intending to pursue a STEM major complete one (Chen, 2013). Two primary factors that cause students to opt out of STEM coursework during college are poor performance in introductory STEM courses and a loss of interest in STEM fields (Chen, 2013; Crisp, Nora, & Taggart, 2009; Lent et al., 2003; Seymour & Hewitt, 1997)

One way to promote increased interest and performance in STEM subjects is to develop interventions to enhance students' motivation for STEM courses. Researchers have demonstrated that brief interventions targeting students' motivational beliefs or valuing of achievement can improve their performance in STEM courses and interest in STEM subjects (e.g., Brown, Smith, Thoman, Allen, & Muragashi, 2015; Harackiewicz Canning, Tibbetts, Priniski, & Hyde, 2016; Hulleman & Harackiewicz, 2009; see Rosenzweig & Wigfield, 2016, for a review). Many researchers have tested *utility value interventions* (e.g., Hulleman & Harackiewicz, 2009), which ask students to connect what they are learning in a course to their lives. These interventions are grounded in Eccles and colleagues' expectancy-value theory (Eccles-Parsons et al., 1983), which posits that the extent to which students perceive their coursework has value for them is one major factor that affects their motivation and performance in a given course. Utility value interventions have impacted positively students' motivation, performance, and course-taking in biology and psychology (see Harackiewicz & Priniski, 2018; Lazowski & Hulleman, 2016, for reviews).

However, more work is needed to understand whether utility value interventions benefit students in other STEM subject areas. Additionally, it is important to examine the specific processes by which utility value interventions promote course performance, because initial evidence suggests that these interventions can sometimes affect motivational constructs besides utility value.

More broadly, most interventions based in expectancy-value theory have focused on promoting positively-valenced motivational beliefs and values like utility value. An alternative intervention approach is to reduce students' perceptions of negatively-valenced beliefs and/or values that might impede learning. The primary negatively-valenced motivational construct in the expectancy-value framework is *cost*, which refers to students' perceptions of the negative aspects of engaging with an academic task (Eccles-Parsons et al., 1983; Wigfield, Rosenzweig, & Eccles, 2017). In the present study, we developed and tested the effectiveness of a cost reduction intervention and compared it to a utility value intervention in college physics.

Expectancy-Value Theory

In their expectancy-value theory, Eccles and colleagues (1983) posit that students' motivation to pursue different achievement tasks is determined most directly by their expectancies for success on the task and the extent to which they value the task (see Wigfield, Tonks, & Klauda, 2016, for review). In this study, consistent with other recent studies using expectancy-value theory, we consider students' expectancies for success together with their beliefs about their current ability to complete a task, calling this broader variable "competence-related beliefs" (e.g., Simpkins, Davis-Kean, & Eccles, 2006; Wigfield et al., 1997). Eccles and colleagues posited that individuals' overall task value is positively influenced by three main factors: students' inherent enjoyment of a task (i.e., intrinsic value), beliefs about whether the task is important to one's sense of self (i.e., attainment value), and beliefs about whether the task is useful (i.e., utility value). Many researchers have shown that students' competence-related beliefs and task values predict their performance and course-taking in STEM fields (e.g., Meece, Wigfield, & Eccles, 1990; Musu-Gillette, Wigfield, Harring, & Eccles, 2015; Simpkins et al., 2006).

Eccles and colleagues (1983) also proposed that when students perceive that there are negative aspects of engaging with a task, called cost, their overall valuing of the task decreases (see also Wigfield et al., 2017). This can reduce the likelihood that students will continue to take STEM courses and can lower their STEM course performance (see Barron & Hulleman, 2015; Wigfield et al., 2017, for reviews). Cost has always been part of expectancy-value theory, but it did not receive much research attention by empirical researchers until recently (Barron & Hulleman, 2015; Flake et al., 2015; Wigfield & Cambria, 2010). However, a growing number of recent studies have confirmed that students who perceive higher cost of learning show lower course performance and have a lower likelihood of engaging with courses or career paths related to a given subject in the future (Conley, 2012; Jiang et al., 2018; Perez et al., 2014).

Researchers and theorists who have studied perceived cost (e.g., Flake et al., 2015; Gaspard et al., 2015; Perez, Cromley, & Kaplan, 2014; Wigfield, Rosenzweig, & Eccles, 2017) generally agree that students perceive different types of cost, which represent different types of negative aspects of task engagement. These researchers have focused primarily on three types of cost: Students' perceptions of the negative emotional or psychological consequences of engaging with an activity, or threats to one's self-worth that come from failure at the activity (i.e., emotional cost), perceptions of the effort required by a task (i.e., effort cost), and perceptions of the alternative activities or opportunities that one must give up in order to complete a given task (i.e., loss of valued alternatives cost) (Wigfield et al, 2017). To study cost, researchers either conceptualize and measure it as an overall construct that includes these different types of cost (e.g., Jiang et al., 2018) or measure each type of cost separately (e.g., Flake et al., 2015). Because this was the first intervention to try and reduce perceived cost in college physics, we focused on students' perceptions of the overall cost of physics in this study.

Utility Value Interventions to Improve STEM Participation and Course Performance

As noted earlier, most expectancy-value-based interventions implemented in STEM courses have focused on enhancing perceived utility value (see Harackiewicz & Priniski, 2018, for review), primarily by asking students to generate connections between the material they are studying in a course and their own lives. This is typically done either by having students complete writing activities (e.g., Harackiewicz et al., 2016; Hulleman & Harackiewicz, 2009) or by asking students to evaluate quotations from other students (e.g., Gaspard et al., 2015; Kosovich, Hulleman, Phelps, & Lee, in press; Rosenzweig et al., in press). At the college level, utility value interventions have improved students' interest and course performance in biology and psychology (e.g., Canning et al., 2018; Harackiewicz et al. 2016; Hulleman, Godes, Hendricks, & Harackiewicz, 2010; Hulleman, Kosovich, Barron, & Daniel, 2017; see Tibbetts, Harackiewicz, Priniski, & Canning, 2016, for a review). These interventions often are most effective for students with lower perceived or actual competence (Harackiewicz et al., 2016; Hulleman et al., 2010; 2017). Such a result is especially important because low-achieving students are particularly likely to switch out of STEM majors (Chen, 2013).

Although utility value interventions have been successful in improving students' outcomes in some STEM areas, there are still many issues to be addressed as this work moves forward. First, given the success of utility value interventions in college biology and psychology, researchers should examine whether such interventions would also be successful in other STEM subjects. It may be easier to relate STEM course material to one's life in subjects such as biology and psychology compared with subjects such as college-level physics or mathematics, which focus on solving computational problems that may seem quite disconnected from one's everyday experiences (Murphy & Whitelegg, 2006). In this study we implemented a utility value intervention in physics, a STEM subject area not previously examined, and which is both computationally-intensive and perceived less favorably than other science subjects (Barmby & Defty, 2006). An additional reason to test intervention efficacy in physics was because physics courses are often required for a variety of STEM majors that have particularly high rates of attrition during college, such as engineering and computer science (Chen, 2013).

Second, researchers need to assess more fully the motivational processes by which utility value interventions affect students. Utility value interventions are designed to help students perform better by helping them think about the value of their course material. However, their effects may be more complex than simply promoting students' perceptions of value. Indeed, only Hulleman et al. (2010) demonstrated empirically that utility value was the primary process driving intervention effects on college students' course performance (see Shin et al., 2019, for evidence of mediation on academic outcomes through utility value for younger students). It is possible that interventions targeting utility value might sometimes impact other beliefs and values instead of, or in addition to, promoting perceived utility value. In particular, some recent studies have found that some utility value interventions promote students' competence-related beliefs (Brisson et al., 2017; Canning & Harackiewicz, 2015; Hulleman et al., 2017). Many motivational theorists have argued that students' perceptions of competence are central forces that drive motivation, and competence concerns are particularly salient in school (e.g., Bandura, 1997; Deci & Ryan, 2000; White, 1959; see Elliot, Dweck, & Yeager, 2017 for review).

Furthermore, Jacobs et al. (2002) found that students' perceptions of competence explained the development of their task values over time. It is possible that when students are asked to think about course material as more useful to them, they perceive this task as giving them information about their competence in a subject. Given this focus on competence concerns, if students think that they completed the intervention task successfully, or they read quotations from other students about how those students used course material successfully, they may come to perceive higher competence-related beliefs as a result of receiving the intervention (Bandura, 1997). We explored this possibility in the present study.

Finally, a third way to extend previous work is to examine whether interventions that target other constructs within the expectancy-value framework besides utility value may also be effective ways to enhance students' motivation and STEM course performance. Many expectancy-value constructs could be useful targets for interventions (e.g., attainment value, intrinsic value). One particularly powerful approach may be to try and reduce students' beliefs and values that might cause them to avoid learning, by helping reduce their perceptions that learning STEM is too costly.

Intervening to Reduce Perceived Cost

Intervention approaches that aim to reduce students' perceptions of cost may be an alternative yet effective means of promoting course outcomes compared with an intervention approach that aims to increase students' perceptions of utility value. However, to the best of our knowledge, Perez and colleagues (2019) are the only researchers to have tested a cost reduction intervention, in the subject area of college biology. The intervention did not lower students' self-reported perceptions of cost.

However, other researchers have developed interventions that are relevant to designing cost reduction interventions. Walton and Cohen (Walton & Cohen, 2007, 2011) have examined *social-belonging interventions* designed to reduce underrepresented students' perceptions that they did not belong in college. Uncertainty about belonging is related to emotional cost in that both involve negative affective reactions to engaging with a given activity (Hulleman, Barron, Kosovich, & Lazowski, 2016). Walton and Cohen based their interventions in part in attribution theory (Weiner, 1985), which has to do with how people understand and interpret various kinds of outcomes in their lives. The social-belonging interventions focused on helping underrepresented students re-interpret their uncertainties about belonging as (a) short-term, and (b) something that other students also experienced, in order to make the uncertainties seem more manageable. They found that underrepresented ethnic minority students in the intervention group had higher college GPAs and better health outcomes up to three years after receiving the intervention. This evidence suggests that one way to reduce students' perceptions of cost in a course might be to have them re-interpret their challenging course experiences in a more positive way.

The Present Study

The overarching goal of this study was to test the efficacy of a newly-developed cost reduction intervention and a utility value intervention in the college physics context. By testing the utility value intervention we hoped to examine whether effects found in prior studies would generalize to the subject area of physics. To that end, we adapted closely utility value intervention materials that have been used in previous studies (e.g., Dicke, Hulleman, & Kosovich, 2016; Gaspard et al., 2015; Kosovich et al., in press; Rosenzweig et al., in press; Truong, Beardsley, Getty, & Hulleman, 2016). Our goal in testing the cost reduction intervention was to examine whether it was possible to reduce students' perceptions of cost using a newly-developed intervention, as a path to promote their course performance.

Our outcomes of interest were students' self-reported utility value, competence-related beliefs, and perceptions of cost in physics, measured once after the second session of the intervention ended (to examine short-term effects), and again at the end of the semester (to examine long-term effects). We also examined the effects of the interventions on students' exam scores and final course grades.

We had three primary research aims. We first examined whether students in either intervention had higher scores on any outcomes (and/or lower perceptions of cost) compared with students in a control group. We predicted that students receiving the utility value intervention would report higher utility value and competence-related beliefs, and earn higher course grades and exam scores, compared with students in the control condition. We predicted that students receiving the cost reduction intervention would report lower perceptions of cost and have higher course performance compared with students in the control condition.

The second research issue was whether the effects of either intervention would be moderated by students' initial exam scores in physics prior to the intervention. Our hypotheses were that in the utility value intervention, all effects would be larger for students who began the intervention with lower initial physics course examination scores. Given the lack of previous research on cost, we did not have a hypothesis for the cost reduction intervention.

The third issue was whether the effects of receiving either intervention versus the control condition on course grades or exam scores would be explained by effects on students' motivational beliefs and values. We predicted that the utility value intervention's positive effects on students' subsequent grades and exam scores would be explained in part by its positive effects on perceived utility value and competence-related beliefs. For the cost reduction intervention we hypothesized that any positive effects on students' subsequent grades and exam scores would be explained in part by its negative effects on perceived cost.

Method

Participants

Participants (n = 148) were enrolled in an introductory physics course at a large mid-Atlantic U.S. university during Fall 2016. Participants were 72% male, 51% European American, 25% Asian or Asian American, 8% African American, 3% Hispanic or Latinx, 1% Middle Eastern, and 11% other ethnicities or multiple ethnicities. Students were 49% first-years, 390% second-years, 9% third-years, and 3% fourth-years or other. This course was the first in a three-semester introductory sequence; 86.4% of participants indicated that the course was required for their major or intended major. Almost all participants (94.6%) planned to pursue majors in the university's college of engineering (69.4%) or computer, mathematical, and natural sciences (25.2%).

All students in the course (N = 179) were sent links to the study activities by the course professor, who agreed to embed the activities into his curriculum for the semester. Participants could opt in or out of releasing their data to the research group. Of the 162 students that completed the first study session, 148 opted to release their data and thus comprised the sample for this study (utility value intervention = 52 students, 72% male, 54% European American; cost reduction intervention = 48 students, 70% male, 45% European American; control condition = 48 students, 75% male, 54% European American)**.** Of the 148 consenting students 129 (87.2%) also received the second session of intervention or control materials. One hundred thirty two students completed Session 3, which was a follow-up measurement session (i.e., 88.5% of the original sample). Ten students did not give permission for researchers to access their exam scores and/or final course grades.

Design and Procedure

This study used a randomized control trial design and the course professor was blind to students' condition. Students were randomly assigned (via the Qualtrics survey system) to one of three conditions: utility value intervention, cost reduction intervention, or control. The study unfolded over three sessions: the initial intervention or control activity (Session 1), a second "refresher" dose of the intervention or control activity (Session 2), and a follow-up measurement session (Session 3). Approximately six weeks into the Fall, 2016 semester, and one week after the first course exam, students completed a homework assignment that contained an online link directing them to the Session 1 activities. Immediately afterwards, they completed the post-intervention demographic and participation questionnaires. Four weeks after Session 1, and one week after their second course exam, students again clicked on an online link as part of their weekly homework to complete the Session 2 activities. Afterwards, they completed a questionnaire assessing their perceived utility value, cost, and competence-related beliefs. Six weeks later, on their final homework assignment of the semester (Session 3), students were sent a link to the questionnaire assessing utility value, cost, and competence-related beliefs. At the end of the semester the researchers obtained students' exam scores and course grades. There were no barriers to implementing the manipulations as designed.

Intervention Structure, Content, and Development

The utility value and cost reduction interventions were delivered online in two brief sessions (each lasted 10-15 minutes total). Both interventions had a similar structure in which students read and evaluated quotations from other students and then wrote their own quotation to a future student (see the online supplement for full text of intervention prompts). We chose quotation evaluation tasks for the interventions because three prior utility value intervention studies have reported that a quotation ranking and evaluation task works the same or better than an essay task (Gaspard et al., 2015; Kosovich et al., in press; Rosenzweig et al., in press).

Intervention development. To create the intervention instructions and quotations, we conducted pilot work with approximately 250 students enrolled in the target physics course during the year prior to intervention implementation. We first developed drafts of the quotations that would be used in the two intervention conditions. We tried to ensure that the quotations in each intervention had face validity to their targeted motivational constructs, because students spent the majority of the time during the intervention sessions reading and evaluating the quotations. Then, we administered the quotations to six focus groups of 5-10 students each to get feedback aimed at improving the quotations iteratively. This process helped us discover and then change any aspects of the materials that students perceived as boring, inaccurate, or unnatural-sounding. Through this process we created final intervention materials and prompts that we hoped would be engaging and likely to produce either neutral or positive responses. We also revised the quotations in consultation with experts in motivational theory and motivational interventions, to ensure that they targeted the appropriate motivational constructs.

For the utility value intervention, we developed an initial draft of the quotations by adapting materials from prior utility value intervention studies (e.g., Gaspard et al., 2015; Hulleman et al., 2010; Kosovich et al., in press; Rosenzweig et al., in press). We tried to write quotations that reflected the ways many past students had articulated using course material (i.e., for their hobbies, for careers in science and math fields). Students in the focus groups gave us feedback regarding which specific careers, hobbies, and course concepts they related most readily to their lives. They also gave us information about *how* they related course material to their lives, informing us that they did not do this spontaneously but they could do this if they were prompted. We added language to this effect into our quotations.

For the cost reduction intervention, before developing an initial draft of quotations we administered open-ended surveys asking 187 physics students to describe their challenges in physics class and to write about specific challenges they experienced that were related to each dimension of cost. Our primary goal was to understand, in students' own words, how they experienced cost in physics. To the extent possible, we used students' own words in writing the cost quotations to ensure that the quotations accurately reflected the cost experiences students had in physics (see Table 1 for a depiction of how we translated students' quotations into the intervention quotations).

Final intervention materials. The text of the instructions and quotations from both intervention conditions can be found in the online supplement. The general structure of each intervention was as follows: In Session 1, participants read four quotations from prior physics students. After reading, in order to ensure that participants engaged deeply with the material presented, they ranked the quotations in order from most- to least-liked, evaluated whether they had a similar experience to each quotation, and evaluated how interesting each quotation was. Next, they wrote down what about the top-ranked quotation caused them to rank it highest. Finally, they wrote their own quotation as an example for a future student. These procedures are adapted closely from prior utility value intervention studies (e.g., Gaspard et al., 2015; Kosovich et al., in press; Rosenzweig et al., in press). In Session 2, students were asked what they remembered about the prior session, in order to try and improve their memory for the information (Roediger & Karpicke, 2006). Students were reminded of the purpose of the task and then read two more quotations. They wrote about how their thinking about the task had changed (or not) since the first activity, and then wrote another quotation to a future student.

The utility value intervention asked students to reflect on how the content from their physics course related to their lives. The quotations in Session 1 expressed the following: (a) engineers used physics to innovate machines and help the environment; (b) computer scientists used physics to make video games more realistic; (c) physics was helpful to understand blood pressure readings; and (d) people thought about physics when watching action movies to see if scenes were plausible. In Session 2, students re-read two of these quotations. When writing their own quotation, students were asked to write about how what they were learning in physics related to their lives.

The cost reduction intervention asked students to reflect on how they had overcome challenges in their physics course. Consistent with the work of Walton and Cohen (2007; 2011), the intervention tried to help students to interpret their course challenges in a more positive way in order to make the challenges seem less costly. The quotations focused on challenges related only to effort and emotional cost, because pilot work had demonstrated that loss of valued alternatives cost was not particularly salient to the physics students in our target sample. We asked students to think about and read about how they could address course challenges head on, how some experiences might not seem as challenging over time, or how the challenges were normal parts of college rather than something reflective of students' own low abilities. The quotations included at Session 1 expressed the following: (a) physics homework was effortful, but once the student knew what to expect the effort did not feel as tiring; (b) studying for exams was effortful, but the student reminded herself that it was temporary; (c) juggling physics with other courses was challenging, but others were going through the same thing and over time the student realized he might have overestimated how much effort this took; (d) working very hard and not receiving a good grade was frustrating, but the frustration was temporary and other students had the same experience. The Session 2 quotations were new but expressed similar sentiments. When writing quotations, students were asked to write about how they overcame a challenge in the physics course.

Control Conditions

The control condition was comprised of students who were assigned randomly to one of two sub-conditions. In the survey sub-condition, students (n = 25) responded to the same baseline and post-test motivation surveys as did the other students in the study, but did not do anything else. In the summary sub-condition, in Session 1 students (n = 23) were asked to list a topic about which they had been learning, write about the steps needed to solve a problem related to that topic, then write a sample problem and solution regarding that topic. In Session 2, students were asked to write about what they chose to summarize in the prior session and why, and then to reflect on how their thinking about the topic had changed over the course of the semester. Both conditions are consistent with control groups utilized in previous utility value intervention research (Gaspard et al., 2015; Harackiewicz et al., 2016; Hulleman et al., 2010; 2017; Kosovich et al., in press). We assigned students to two sub-conditions within the overall control condition because we were interested in whether a summary condition might benefit students more than a survey control condition, but our primary goal in the study was to maximize power to detect differences for each intervention compared with a control group. Ultimately, course enrollment was lower than we expected, so we not obtain enough students to assess how the two sub-conditions compared with one another. We report all results using an overall control condition which collapsed across these two sub-conditions, rather than reporting results for each control sub-condition separately. As is reported in the online supplement, analyses treating the control sub-conditions separately produced similar interaction effects to those reported in the results section.

Measures

Initial exam scores. We measured initial physics course performance using students' scores from the first course exam, administered one week prior to the beginning of the intervention. Scores were measured in terms of percentage correct.

Post-intervention motivation questionnaire. All items were randomized and the full text of the items can be found in the online supplement.

Utility value. Perceptions of utility value for learning physics were measured using two items from a questionnaire that has been validated in prior expectancy-value research (Eccles & Wigfield, 1995; sample item: "In general, how useful is what you learn in Physics?"). Students responded using a 7-point Likert scale ranging from *not at all useful* to *very useful*. We computed an average score across the two items (Session 2 $\alpha = .86$; Session 3 $\alpha = .90$).

Perceptions of cost. Perceptions of cost in physics were assessed using fifteen items from a questionnaire developed and validated by Flake et al. (2015) with college students. Their measure was developed in a multi-phase process consisting of a literature review, focus groups with college students, item ratings by experts, and empirical validation. Flake et al. showed that the items on this questionnaire formed separate but highly correlated factors. We computed an average score across types of cost rather than examining each type of cost as an outcome separately, because we designed our intervention to reduce multiple types of cost. This approach is consistent with that of prior researchers (e.g., Jiang et al., 2018; Conley, 2012). Students responded using 7-point Likert scales ranging from *strongly disagree* to *strongly agree.* To represent total cost, we computed an average score for all items measuring effort cost (we included Flake et al.'s measures of task effort cost and outside effort cost in this measure) and emotional cost (Session 2 $\alpha = .95$; Session 3 $\alpha = .91$).[1] Flake et al.'s (2015) original cost scale also includes items measuring loss of valued alternatives cost, but we did not design quotations in the cost reduction intervention to target this dimension of cost. We therefore did not include this dimension of cost in our measure.

Competence-related beliefs. Students' beliefs related to their competence to learn physics were measured using five items from the Eccles and Wigfield (1995) questionnaire. Three items related to students' current ability beliefs (sample item: "How good in Physics are you?") and two related to students' future expectations for success (sample item: "How well do you expect to do in Physics this semester?"). Students responded to items using a 7-point Likert scale with anchor terms that differed for each question. We created an average score across the five items (Session 2 $\alpha = .93$; Session 3 $\alpha = .94$).

Physics course performance outcomes. Students' exam scores were computed by taking the average score from the two exams that occurred after the intervention or control activities: Exam 2 occurred three weeks after the first session, and Exam 3 occurred at the end of the semester, approximately 6 weeks after the second session and 2.5 months after the first session. Students' final course grades represented a composite score based on in-class exercise participation, homework participation, quiz scores, and exam scores. Both outcomes were scored as a percentage of total points correct.

[1]Using factor analysis, we confirmed that a model treating cost as a higher-order factor, with sub-factors for the different types of cost, fit the data from each session well (Session 2, χ^2 (203) = 341.93; CFI = 0.96; RMSEA = 0.07; SRMR = 0.05, and Session 3, χ^2 (203) = 408; CFI = 0.93; RMSEA = 0.09; SRMR = 0.06).

Intervention fidelity. Intervention fidelity is the extent to which the intervention is implemented as intended (O'Donnell, 2008). All intervention materials were delivered through the online survey system, but an important aspect of intervention fidelity is participant responsiveness to intervention materials (Murrah, Kosovich, & Hulleman, 2017). In order to measure student responsiveness, we assessed several variables to address whether students engaged with intervention or control activities to a sufficient amount and responded to intervention prompts in the way that we intended within each condition.

Engagement check. We collected two overall measures assessing whether or not students seemed to engage sufficiently with the activities, finding that students did indeed engage with them. A more complete description of these measures can be found in the online supplement.

Time spent reading, ranking, and evaluating the quotations. We designed Session 1 of the cost reduction and utility value interventions to include two tasks: (1) quotation ranking and evaluation, and (2) students writing their own quotations. Students were expected to engage meaningfully with both portions of the intervention, so we assessed measures of fidelity related to both. To assess whether students engaged adequately with the quotation ranking and evaluation task, we created a composite score reflecting the amount of time students spent reflecting on the quotations (i.e., reading quotations, evaluating them, ranking them, and answering short-answer questions about them). We also measured the proportion of time students spent doing the quotation ranking and evaluation task compared to the total time students spent on intervention activities (excluding questionnaires).

Students completed the study online with no researcher or teacher supervision, so it was possible that some students would open the survey page on their computer without actually completing the survey right away, or that students would click through the survey questions quickly without reading them. These students were included in the primary regression models for the present study as is consistent with an intent-to-treat approach to intervention data analysis (Shadish & Cook, 2009). However, to avoid skewing the mean scores for students' time data we standardized students' scores regarding time spent on each portion of the intervention, and we excluded students from time-data-related analyses if their scores were more than three standard deviations above the mean. We also excluded students who took less than one minute of time combined across the quotation reading, ranking, and evaluating activities (prior to writing).

References to utility value, cost, and competence-related beliefs when writing quotations. To assess fidelity for the writing portion of the intervention, we measured whether students in the utility value or cost reduction intervention conditions wrote about the targeted motivational constructs when writing their own quotations. Two trained coders evaluated whether or not students referenced utility value, cost, or competence concerns in their quotations from each intervention session. This coding was intended to be maximally inclusive of motivationally-relevant topics. For example, if students referenced coursework being hard for them without explicitly referring to their competence-related beliefs, this was coded as being relevant to competence; if students referenced it being challenging to manage their coursework for different classes without explicating that time spent on one subject prevented them from doing another course's assignments, this was coded as being related to cost; if students referenced course material as being relevant to their lives without explicating that it was useful, this was coded as being related to utility value. Disagreements were resolved by consensus (interrater agreement: for cost, 77.3% - 98.1%; for competence concerns, 81.1% - 87.0%; for utility value: 88.9% - 96.2%; see online supplement for more information).

Demographic questionnaire. Students completed a questionnaire after Session 1 in which they reported their gender, ethnicity, year in school, and major or intended major. [2]

Analysis Strategy

We used linear regression with orthogonal contrast codes to assess the three research aims, consistent with much previous utility value intervention research (e.g., Canning et al., 2018; Harackiewicz et al., 2016; Hulleman et al., 2010). All regression analyses were done in MPlus version 7, with full information maximum likelihood estimation used to address missing data (maximum missingness on any variable was 14.2%). This estimation method is considered to be appropriate when data are missing at random (Enders, 2001) which we expected our data to be given the theoretical relationships being explored. Our analytical model included seven terms: (a) two contrast codes: intervention (each coded as +1) versus control (coded as -2); cost reduction intervention (coded as +1) versus utility value intervention (coded as -1); (b) covariates of gender (contrast-coded, male = -1; female = +1) and prior competence-related beliefs in physics (standardized); (c) students' initial exam scores (standardized), (d-f) two terms representing the interactions between initial exam scores and each of the contrast codes. Sensitivity analyses based on this proposed model using G*Power software ($\alpha = .05$; power = .80) determined that the study was powered to detect main effects of the intervention versus control contrast at an effect size of $d = 0.50$ or greater, and main effects of the cost reduction versus utility value intervention contrast at an effect size of $d = 0.44$ or greater. This corresponds to the average effect size that would be expected for a motivational intervention (Lazowski & Hulleman, 2016).

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[2] In addition to the measures reported here, we collected additional measures of students' participation, beliefs about their physics course, and engagement with the course in order to understand more fully students' participation and responsiveness to intervention materials. We do not report all of these measures in the present study to focus on those which were the most clearly aligned with our theoretical predictions and hypotheses.

To test the first research aim concerning the interventions' main effects, we examined the results of the two contrast codes on each outcome. For the second research aim, which concerned moderation of intervention effects by initial exam scores, we examined the results for the interaction terms between the contrast codes and initial exam scores. In the case of significant interaction effects, we used the "model constraint" function in MPLUS to test the significance of the simple slopes for the intervention versus control contrast at representative high and low levels of the moderating variable (Aiken & West, 1991). To address the third research aim, which concerned whether students' motivational beliefs and values mediated any intervention effects on course grades or later exam scores, we used path analysis in MPlus.

Results

Descriptive Statistics and Correlations

Descriptive statistics and correlations are reported in Table 2. As expected, students' utility value and competence-related beliefs in physics correlated significantly and positively with one another (and negatively with cost) and with grades and exam scores. Students' perceptions of cost correlated significantly and negatively with grades and exam scores. There were two exceptions: the correlations of students' utility value at session 3 and their cost perceptions at Session 3, and utility value at Session 3 and exam scores, were not significant.

Descriptive statistics by condition are reported in Table 3. To test whether there were significant baseline differences in initial exam scores or baseline competence-related beliefs across conditions, we conducted a one-way ANOVA in SPSS version 24. Results showed that the conditions did not differ significantly from one another on baseline competence-related beliefs, F (2, 144) = 1.08, p = .34, or on exam 1 scores, F (2, 133) = 2.45, p = .09. We concluded that there were no significant baseline differences by condition, but given that there was a marginally significant difference in exam scores we wanted to ensure as much as equivalence across groups as possible. Therefore we adjust all effects in the remainder of the manuscript to control for students' initial exam scores, gender, and baseline competence-related beliefs. See the online supplement for unadjusted mean scores by condition.

Intervention Fidelity

Engagement checks. Several pieces of evidence confirmed that students were engaged while completing the intervention activities and completed the tasks that were asked of them (see the online supplement for more information).

Time spent reading, ranking, and evaluating quotations. Before examining timing data, we excluded two students (one from each of the cost reduction and utility value intervention conditions) whose scores were more than three standard deviations above the mean on any time indicator, and seven students who took less than one minute on the quotation reading, ranking, and evaluation portion of the intervention activities combined (4 in the cost reduction condition, 3 in the utility value intervention condition). Among the students who provided meaningful time data, there was much variability in the time it took students to complete both intervention tasks. In the cost reduction intervention students spent an average of 222.40 s (SD = 128.98 s) reading, ranking, and evaluating the quotations, which represented approximately 70.8% of the time spent on quotation-related intervention activities. In the utility value intervention, students spent an average of 180.29 s (SD = 85.44 s) reading, ranking, and evaluating quotations, which represented approximately 55.7% of the time spent on quotation-related intervention activities.

Writing about cost reduction or utility value in quotations. As predicted, most students (Session 1: 75.0%; Session 2: 67.3%) who completed the quotation-writing activity in the utility value intervention condition wrote about topics related to utility value. Additionally, students in the utility value intervention condition did not often write about topics related to cost (Session 1: 1.9%; Session 2: 7.7%). A larger percentage of students referenced topics related to competence (Session 1: 25.0%; Session 2: 15.4%), but this was a smaller percentage than the percentage of students writing about utility value. Most students who referenced these topics wrote about how course material was useful because it would help them to be more competent in their future pursuits (e.g., jobs). Logistic regression analyses showed that students who wrote quotations in the utility value intervention condition referenced utility value more often than did students in the cost reduction intervention condition at Session 1 and 2 (b's < -1.88, p's < .005).

In the cost reduction intervention condition, as expected, students who completed the quotation-writing activity did not often reference topics related to utility value (Session 1: 6.3% of students; Session 2: 2.1%). However, fewer students than expected wrote about topics related to cost (Session 1: 39.6%; Session 2: 25.0%). Instead, a large proportion of students referenced competence-related topics (Session 1: 60.4%; Session 2: 47.9%). Most students in the cost reduction intervention who referenced competence-related topics wrote about how they addressed issues that were difficult for them in physics (e.g., learning how to study for exams better in order to get a good grade). Logistic regression analyses confirmed that students in the cost reduction intervention referenced cost and competence-related beliefs significantly more often than students in the utility value intervention did (b's > 0.63, p's < .049). These results show that competence-related beliefs may have been equally to or more salient than perceived cost during the writing portion of the intervention (see Discussion).

Aim 1: Effects of the Interventions on Students' Competence Beliefs, Utility Value, Cost, and Course Performance

Results of the regression models predicting each motivational outcome are reported in Table 4, and results predicting each course performance outcome are reported in Table 5. Importantly, there were no effects of the contrast testing the cost reduction intervention versus the utility value intervention on any outcomes. However, in support of our hypotheses there were positive main effects of the intervention versus control contrast on students' grades, $\beta = 0.14$, $z = 2.94$, $p = .003$, $d = 0.24$, and exam scores, $\beta = 0.17$, $z = 2.84$, $p = .01$, $d = 0.30$, after adjusting for students' initial exam scores, competence-related beliefs, and gender.[3] Students receiving either intervention earned higher subsequent grades and exam scores than did students in the control condition. Additionally, there was a positive main effect of the intervention versus control contrast on students' competence-related beliefs at Session 2, $\beta = 0.10$, $z = 2.04$, $p = .04$, $d = 0.15$; students in either intervention condition had higher competence-related beliefs than students in the control condition. These results support the hypothesis that the utility value intervention would promote students' competence-related beliefs. We had not made a similar hypothesis about whether the cost reduction intervention would affect this outcome because of a lack of previous research on it. Contrary to our hypotheses concerning students' utility value and perceived cost, there were no main effects of the contrasts on students' perceptions of utility value or cost at Sessions 2 or 3.

Aim 2: Testing for Moderation of Intervention Effects by Initial Physics Exam Scores

We hypothesized that in the utility value intervention, effects would be stronger for students beginning the intervention with lower course performance; we did not hypothesize this for the cost reduction intervention given the lack of previous research. In fact, this pattern of

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[3] To compute *d* values we used the estimated adjusted mean scores from Table 3 along with unadjusted standard deviations for the conditions of interest.

results occurred for both interventions. There were interactions between the intervention versus control contrast and initial exam scores on final grades, $\beta = -0.19$, $z = -3.99$, $p < .001$, and average post-intervention exam scores, $\beta = -0.25$, $z = -4.01$, $p < .001$. Students with initially lower exam scores earned significantly higher course grades and average postintervention exam scores if they received either intervention versus the control condition (the estimated unstandardized effects on grades and exam scores for initially lower performing students were eight and 11 points out of 100, corresponding to *d*s of 0.72 and 0.90, respectively). Students with initially higher exam scores did not show significant differences between conditions (see Figure 2).

Also in support of the hypotheses for the second research aim, we found interactions between the intervention versus control contrast and initial exam scores on Session 2 cost, $\beta = 0.20$, $z = 2.51$, $p = .01$, and Session 2 competence-related beliefs, $\beta = -0.15$, $z = -2.72$, $p = .01$. Students with initially lower exam scores (one standard deviation below the mean) reported significantly higher competence-related beliefs at Session 2 and lower cost at Session 2 if they received either intervention versus the control condition. Students with initially higher exam scores (one standard deviation above the mean) did not differ across conditions (see Figure 1). No effects of the intervention versus control contrast by initial exam scores were significant at Session 3, and there were no differences between the cost reduction and utility value interventions.[4]

[4] In addition to the analyses using orthogonal contrast codes, we also ran our central regression analyses using dummy codes testing the effects of each intervention condition compared with control. The results of the dummy-coded analyses corresponded almost exactly to the results of the contrast codes (see the online supplement for output). Both intervention conditions showed significant, positive effects on students' course grades and exam scores compared with the control condition, with stronger effects for students who began the intervention with lower initial course exam scores. We also found the same interactions on Session 2 cost and Session 2 competence-related beliefs as in the contrast-coded analyses. The only differences were the following: (a) The main effects of both interventions versus the control condition on Session 2 competence-related beliefs were marginally significant using

Aim 3: Testing the Motivational Processes by Which the Interventions Affected Physics Course Performance

We did not find overall effects of the utility value intervention on utility value or the cost reduction intervention on cost. Thus neither of our primary hypotheses concerning motivational processes were supported, and we did not conduct further mediation analyses to test these hypotheses. However, we did find that receiving either intervention promoted intervention group students' competence-related beliefs overall compared with control students, as well as course grades and exam scores. We conducted overall mediation analyses to test whether the effects of receiving either intervention versus the control condition on grades or exam scores could be explained by students' improved competence-related beliefs at Session 2; however, the mediation effect was not significant (estimates < 0.36, *SE*s < 0.20, *p*s > .06).

As discussed in the previous section, we also found interaction effects suggesting that among lower performing students in the course, receiving either intervention versus the control condition promoted competence-related beliefs, exam scores, and grades, and reduced perceived cost. We therefore conducted conditional mediation analyses to test whether either intervention's effects on lower performing students' competence-related beliefs or perceptions of cost explained, in part, intervention group students earning higher grades and exam scores. Results are reported in Table 6. The analyses produced estimates of conditional indirect effects (i.e., in this case, indirect effects of receiving either intervention versus control on grades or exam scores), modeled at different levels of the moderator, initial exam scores. We modeled indirect effects at one standard deviation above and below the mean on initial exam scores. As can be

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dummy codes; and (b) There was an additional interaction effect suggesting that the cost reduction intervention raised utility value at Session 3 for initially lower performing students compared with the control condition.

seen in Table 6, for initially lower performing students, the effects of being in either intervention condition (versus the control condition) on their subsequent grades and exam scores were mediated by their higher Session 2 competence-related beliefs and by Session 2 perceptions of cost. For initially higher performing students, the relations between being in the intervention versus control condition and subsequent grades and exam scores were not mediated by either construct.

Discussion

Results of this study extend the growing body of evidence showing that brief motivational interventions can promote STEM course performance. In particular, this study replicated the positive effect of previous utility value intervention studies on course performance in a new subject area, college physics. The results also provide encouraging support for the effectiveness of a new cost reduction intervention as another way to promote college students' physics course grades and course performance. At the same time, the interventions' effects on students' motivational beliefs and values did not fully support our hypotheses. We discuss the effects of each intervention in turn and then the broader implications of the results.

The Utility Value Intervention: Extending to College Physics

Previous research has shown that utility value interventions improve students' performance in college biology and psychology (e.g., Canning et al., 2018; Harackiewicz et al., 2016: Hulleman et al. 2010; 2017). Results of the present study extend these findings to college physics, which potentially is a subject area in which students may have more difficulty finding relevance in their course material. Furthermore, as predicted the utility value intervention had particularly strong effects for students with lower initial exam scores. Initially lower performing students in the intervention groups earned an estimated eight percentage points higher on final course grades, and 11 percentage points higher on average exam scores, compared with lower performing students in the control group. These results are of great significance to researchers and educators who are concerned with helping students achieve their best in STEM courses.

Contrary to our hypotheses, students receiving the utility value intervention did not report higher utility value compared with students in the control condition. This finding differs from three prior utility value field intervention studies, done in fifth and sixth grade science (Shin et al., 2019), high school math (Gaspard et al., 2015), and college psychology (Hulleman et al., 2010) which did find effects on students' self-reported utility value, but it is similar to the findings of some other utility value interventions which failed to affect self-reported utility value as expected (Hulleman et al., 2017; Rosenzweig et al., in press).

We believe that the intervention activities were successful in having students *reflect* on utility value as we intended; our coding of students' written responses showed that most students in the utility value intervention wrote about utility value, and students spent at least several minutes engaging with the utility value quotations. However, in this study the activities did not seem to be sufficient in leading students to *report* more utility value than at pretest. Self-reported utility value was measured using general items (e.g., "In general, how useful is what you learn in physics?"). Most students in our sample already reported high utility value prior to the intervention, likely because the targeted physics course was required for most participants' majors. Reflecting on the utility of course material may not have led students to report any higher general utility value of physics, because they already perceived that physics was useful for their majors or careers.

Despite not affecting utility value, the utility value intervention promoted students' competence-related beliefs as predicted. Both Brisson et al. (2017) and Canning and

Harackiewicz (2015) reported similar findings with respect to competence beliefs in utility value intervention studies, and Hulleman et al. (2017) found that a utility value intervention improved low-achieving male college students' competence-related beliefs. Results suggested that the effects of the intervention on competence-related beliefs were strongest among initially lower performing students, so we focus our discussion on them. Lower performing students are highly sensitive to information about their perceived competence (Covington, 2009). As noted in the introduction, different motivation theorists agree on the central role of perceived competence in guiding human motivation, particularly in school settings where evaluation is prevalent (e.g., Bandura, 1997; Deci & Ryan, 2000; Elliot, Dweck, & Yeager, 2017; White, 1959). Students therefore are likely to think about most academic activities in the context of their own competence. Given this fact, there are several reasons why the intervention activities may have primarily affected lower performing students' perceptions of competence. First, making connections to course material typically requires that students understand the material on some level, so that they can articulate how it relates to their lives. Being able to write about how they could use physics in their lives may have indicated to lower performing students that they had more mastery of the course material than they had thought, providing a success experience (Bandura, 1997). Second, the quotations reflected students' descriptions that even though they did not typically use physics in their day-to-day lives, when prompted they could see the utility of physics. Reading such messages from other students may have helped lower performing students perceive themselves as similar to others taking physics in terms of how they thought about course material; in turn, reading about the students' successes could have been a vicarious experience that helped lower performing students perceive themselves as more competent.

We also found that initially lower performing students' Session 2 cost perceptions were lower after receiving the utility value intervention. Cost and competence-related beliefs correlated negatively and moderately with one another in this study, and other researchers also have found negative correlations of these variables (e.g., Flake et al., 2015; see Barron and Hulleman, 2015 for discussion of reciprocal relations of cost and competence-related beliefs). It is possible that these constructs influence each other, with lower performing students' cost perceptions decreasing in this study because their competence-related beliefs were increasing, and vice versa. It is also possible that lower performing students perceived their own course challenges as less costly as a result of identifying with their peers featured in the quotations. Although we did not design the utility value quotations with a goal to help students perceive themselves as similar to their peers, we did take great care to write quotations that would sound realistic to our target students. Thus, reading quotations from similar peers may have reassured lower performing students that they were not alone in how they thought about course material (Walton & Cohen, 2007). This could have helped students perceive less cost for the course.

The effects of the utility value intervention on lower performing students' motivational beliefs and values were limited to Session 2. It may be that the intervention's effects on students' perceptions of cost and competence-related beliefs were eventually overshadowed by other experiences shaping these beliefs more strongly, such as receiving exam grades. The relatively short-term effects of the utility value intervention in this study are inconsistent with some prior utility value intervention work (e.g., Gaspard et al., 2015), but they are consistent with Canning et al.'s (2018) suggestion that utility value interventions be administered in multiple doses to be most effective for a variety of students. It is important to try and ensure that future utility value interventions have longer-lasting effects on students' motivational beliefs and values, perhaps by implementing interventions at a higher dosage. However, it is worth noting that the dosage of this utility value intervention was sufficient to affect students' grades, despite not having lasting effects on motivational beliefs and values.

The intervention's effects on grades and exam scores can be explained by considering the motivational processes by which the intervention affected students. Mediational analyses indicated that effects on lower performing students' grades and exam scores were explained in part by these students having lower perceptions of cost and higher competence-related beliefs at Session 2 of the intervention. Because the intervention promoted lower performing students' competence-related beliefs and reduced their perceptions of cost, this likely helped these students approach their subsequent course activities (e.g., homework assignments, quizzes) with more confidence, engage in less avoidance behavior, and ultimately earn higher grades on their mid-semester course exams (Bandura, 1997; Flake et al., 2015; Jiang et al., 2018; Wigfield et al., 2016). These results are important because they contribute to a small but growing body of studies suggesting that utility value interventions do not always affect students' course grades and exam scores solely by promoting utility value (Harackiewicz et al., 2016; Hecht et al., 2019; Hulleman et al., 2017). Future studies should continue exploring the contexts in which these interventions promote competence-related beliefs and/or perceptions of cost instead of perceived utility value.

The Cost Reduction Intervention: A Novel Approach to Motivational Interventions

The positive effects of the cost reduction intervention suggest that this intervention is a resource-efficient tool to enhance the performance of students at risk of dropping out of STEM majors in a gateway college course. Furthermore, this study is the first to show that it is possible to reduce lower performing students' cost perceptions via an intervention. Such findings are promising for educators and researchers looking for effective intervention approaches that can enhance students' motivation and performance in college STEM subjects.

Results partially supported our hypotheses that the cost reduction intervention would reduce students' perceptions of cost in college physics, in that this effect occurred but was limited to initially lower performing students. Lower performing students may have identified more strongly with the challenges expressed by the students in the quotations. Students who perceive their challenges as being caused by their own low ability are the most at risk academically because they often experience negative emotions in achievement settings and so are less likely to put in effort to address these challenges moving forward (Weiner, 1985). When students perceive challenges as being something that others also experience, they may be less likely to perceive the challenges as being caused by their low ability (Walton & Cohen, 2007; 2011). Therefore, reading that other students also struggled with the course could have helped lower performing students perceive their challenges as being less related to their abilities, and hence less costly.

The cost reduction intervention also increased initially lower performing students' perceptions of competence in physics. This may be because the writing portion of the cost reduction intervention asked students to write about overcoming a challenge in the course, which relates to both perceptions of cost and perceptions of competence. Overall during the intervention students spent the majority of their time reading and evaluating the cost quotations, and thus we believe they primarily reflected on topics related to cost reduction. However, the coding of students' written quotations suggested that many students reflected on topics related to competence during the writing portion of the intervention, and thus in this portion of the activities students may have also reflected about their competence. If that occurred, initially lower performing students' thinking about past successes in overcoming course challenges could have promoted their perceptions of competence to learn physics (Bandura, 1997) in addition to reducing their perceptions of cost. However, as in the utility value intervention the effects of the cost reduction intervention on lower performing students' competence-related beliefs and perceived cost were limited to Session 2. The same factors that we discussed for the utility value intervention likely explain why the cost reduction intervention did not affect Session 3 beliefs and values.

Mediational analyses showed that the cost reduction intervention's effects on lower performing students' course grades and exam scores were explained in part by them reporting lower Session 2 cost and higher Session 2 competence-related beliefs. The same motivational processes likely occurred in the cost reduction intervention as in the utility value intervention: lower performing students who perceived themselves as more capable or who perceived that their coursework was less costly as a result of the intervention may have worked harder on their mid-semester assignments, leading to better grades in the course.

Broader Implications of Considering the Effects of the Interventions Together

There are four major implications of considering the results of both interventions together. First, both interventions promoted students' course grades and exam scores. These results demonstrate two different resource-efficient educational intervention approaches that targeted students' motivational beliefs and values as a path to promote STEM course performance. For the utility value intervention, our study supports a growing body of research pointing to the effectiveness of these interventions at promoting course performance across STEM domains. Thus, an important next step is to continue to adapt utility value interventions to different contexts so that their effectiveness can be assessed more broadly (Rosenzweig, et al., in press). For the cost reduction intervention, initial results regarding performance are promising. We suggest that researchers continue to explore the effectiveness of the intervention in different STEM areas to assess further the intervention's effectiveness.

Second, the effects of both interventions were strongest for initially lower performing students. It is perhaps not surprising that both interventions benefitted only those who needed the most support in this context. Students enrolling in the target physics course had relatively high initial competence-related beliefs, as well as fairly high performance on the first exam. Given that prior studies have found that students with lower initial performance and motivation often benefit more from motivational interventions (see Rosenzweig & Wigfield, 2016, for review), it is possible that the utility value and cost reduction interventions would be even more effective in courses where students have lower average initial performance and/or motivation.

Third, utility value and cost reduction interventions are designed to target students' individual motivational beliefs or values. However, results of the present study suggest that such interventions may not always affect only their targeted motivational constructs but instead might affect other motivational constructs. These findings suggest that the same motivational intervention may affect students through different motivational processes when implemented in different contexts (cf. Harackiewicz & Priniski, 2018; Yeager & Walton, 2011). Certain motivational challenges may be more or less salient across different classrooms, different subject areas, or for different students. These factors may cause students to respond differently to the same set of intervention materials. For example, concerns about competence likely are more salient in college physics compared with other subjects, because it is often considered to be a particularly challenging subject (Barmby & Defty, 2006; Williams, Stanisstreet, Spall, Boys, & Dickson, 2003). There are also differences across subjects in terms of student demographics (e.g., at this university, in physics, students were mostly male, whereas in biology courses students were mostly female). Differences in the demographic makeup of students across contexts can affect how students respond to materials on average, given that interventions often show differential effects as a function of student demographic traits (Rosenzweig & Wigfield, 2016).

These findings also suggest that, because students' beliefs and values are correlated (Eccles & Wigfield, 1995), interventions affecting one motivational belief or value can have broader effects than expected by affecting correlated beliefs and values (in this case, the interventions affected both competence-related beliefs and perceptions of cost). Researchers should be sure to assess how utility value, cost reduction, and other motivational interventions influence not only their "targeted" motivational belief or value, but also other correlated constructs in order to explore these possibilities in more depth.

Finally, the findings that competence-related beliefs and perceived cost were moderately correlated with each other are interesting because they are relevant to an ongoing discussion among expectancy-value researchers concerning whether cost primarily acts as a negative influence on students' valuing of an activity, or whether cost and values should be considered as separate but related constructs in the model (see Barron & Hulleman, 2015; Wigfield et al., 2017, for discussions). The results of the present study do not speak directly to this debate, but they do but they do suggest that cost and competence-related beliefs are related to one another closely. Moving forward, it may be important to consider the influence of students' perceptions of the cost of an activity on both task values and competence-related beliefs, in order to understand better the relations among these constructs.

Limitations

The encouraging results of this research should be explored further to address its limitations. The primary limitation is that the sample in this study is small. We had insufficient power to assess whether there were small differences in how the two interventions affected students' competence-related beliefs, utility value, cost, or course outcomes, or to test for all but large interaction effects. We believe that the observed interaction effects point to interesting ideas about the predominant ways by which both motivational interventions affected students. However, we recommend that researchers explore the effectiveness of both interventions with a larger sample.

This study also had limitations associated with measurement. In particular, we used teacher-assigned grades and exam scores as our primary outcomes. Grades and exam scores are the main information that college students obtain regarding their performance and thus we believe these outcomes are meaningful when thinking about college students' decisions to take STEM courses. However, we do not have information about these measures' reliabilities or how they compare to other possible indicators of students performance. In future studies researchers should use other kinds of performance indicators along with grades and test scores. A second measurement limitation is that we measured students' baseline perceptions of competence in physics, but did not measure students' baseline perceptions of cost or utility value. Although we assume that random assignment resulted in these perceptions being similar across conditions, we cannot show definitively whether students across the conditions differed on these constructs prior to implementation of the intervention or control activities.

A third limitation is that the design of our study did not allow for a full exploration of the processes by which the intervention impacted students' motivational beliefs and course outcomes. The mediational analyses suggest that change in students' competence beliefs and cost were two important processes by which students' course grades and exam scores changed. However, we did not explore other possible processes that may have played a role in how students benefitted from the interventions (e.g., engagement). One way to do so in future research would be to use a "think aloud protocol" methodology, in which participants talk about what they are thinking as they are experiencing the intervention (e.g., Azevedo & Cromley, 2004). These methods allow the researcher to determine different processes by which interventions impact students' outcomes that we may not have anticipated.

Conclusion

Overall, our results provide important findings showing the effectiveness of a utility value and a newly-developed cost reduction intervention on students' course grades and exam scores in physics. The interventions also had positive effects on lower performing students' motivational beliefs. We believe that these findings provide important insights into how two motivational interventions could work with students in college physics courses. We encourage researchers to build on our work by examining the effectiveness of these interventions in different STEM educational contexts with materials designed to fit those contexts.

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Table 1

Physics Students' Common Cost Experiences and Their Representation in the Cost Reduction Intervention

Challenge	Student Responses from Pilot Study	Excerpt from Intervention Quotation	Similar Experience
Effort cost (task effort): Homework requires too much effort	"The homework is often tedious … Questions often take a while to work through and aren't consistent with what is on a quiz or a test." "I spend an unusually high amount of time on the homework … This leads to something like 30 minutes spent on one problem."	"I thought the MasteringPhysics homework was challenging because there are so many questions. It felt like way too much work to complete each assignment at first."	75.0%
Effort cost (outside effort): Juggling workload of multiple courses	"Sometimes, given the nature of my exam schedule (such as three major exams in two days), I am not able to commit as much time to studying as I would've liked." "I usually have to juggle studying for physics exams, and studying for other exams that are occurring in the same week, or even on the same day."	"For me it was hard to juggle the work in physics with my other classes. A bunch of times I had assignments, quizzes, and tests due for four classes in the same week. It was hard to commit to working on physics."	72.9%
Emotional cost: Frustration about exam grade not matching the work student put into studying	"The first Physics test I knew would be hard but I believe I was well prepared … I didn't do too well on the test … I believe getting a bad grade and having a lot of anxiety put an emotional toll on me." "I get very sad, frustrated, and stress when I put in a lot of effort and work into the class but do not get the grade that I believe I deserve."	"I got really frustrated after the first physics exam. The material from lectures and homework didn't match the questions on the exam, and I studied really hard but it didn't pay off as much as I thought in my performance."	56.2%
Emotional cost: Anxiety and stress related to studying for exams	"When studying, sometimes I am unsure if I am reviewing all pertinent information. This causes a great deal of stress." "Sometime I stress to the point where I under-prepare for the exam simply because everything is just so overwhelming."	"The biggest challenge my friends and I had in physics was studying for the exams. On the first exam it seemed like there was so much material to learn, and we were overwhelmed talking about whether we would be able to learn everything in time."	54.2%

Note: "Similar experience" category is defined as the proportion of students from Session 1 of the Cost Reduction intervention who rated the situation referenced in the quotation as being at least somewhat similar to their own experiences in physics (response scale ranged from 1 = *not at all similar* to 5 = *extremely similar*. *Somewhat similar* represented a score of 3).

Table 2

Descriptive Statistics and Correlations for Variables Included in the Study

Variable	*n*	*M (SD)*	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Prior competence-related beliefs	147	4.78 (1.28)									
2. Initial exam scores	133	78.71 (19.67)	.67**								
3. Utility value S2	127	5.07 (1.29)	.39**	.24**							
4. Competence-related beliefs S2	127	5.04 (1.23)	.81**	.62**	.55**						
5. Cost S2	127	3.12 (1.25)	-.58**	-.53**	-.33**	-.64**					
6. Utility value S3	132	5.09 (1.29)	.34**	.20**	.72**	.43**	-.33**				
7. Competence-related beliefs S3	132	4.93 (1.24)	.77**	.60**	.52**	.88**	-.58**	.42**			
8. Cost S3	132	3.49 (1.17)	-.52**	-.46**	-.21**	-.49**	.78**	-.15	-.59**		
9. Final grades	134	87.38 (10.80)	.56**	.81**	.25**	.59**	-.53**	.20*	.58**	-.47**	
10. Average exam scores	132	85.05 (11.82)	.44**	.67**	.20*	.53**	-.48**	.17	.55**	-.48**	.84**

Note: *p < .05; ***p* < .01. Unadjusted means and standard deviations shown. All variables' skew and kurtosis statistics were within an acceptable range to assume normality (i.e., between +2 and -2; George & Mallery; 2010). S2 = Session 2 Time Point (immediately after the second session of the intervention or control task was administered). S3 = Session 3 Time Point (at the end of the semester).

Table 3

Descriptive Statistics by Study Condition

	Cost reduction intervention (*n* = 48)		Utility value intervention (*n* = 52)		Control condition (*n* =48)	
Variable	*M*	*SE*	*M*	*SE*	*M*	*SE*
Prior competence-related beliefs[a]	4.57	0.18	4.80	0.18	4.95	0.19
Initial exam scores[a]	73.67	2.87	80.15	2.84	82.54	2.97
Utility value S2	4.96	0.19	5.12	0.18	4.82	0.19
Competence-related beliefs S2	5.06	0.12	5.03	0.11	4.85	0.12
Cost S2	3.02	0.16	3.30	0.15	3.26	0.16
Utility value S3	4.89	0.19	5.11	0.19	5.13	0.19
Competence-related beliefs S3	4.89	0.12	4.87	0.12	4.85	0.12
Cost S3	3.36	0.15	3.59	0.15	3.72	0.15
Final grades	89.28	0.95	88.09	0.93	86.06	0.98
Average exam scores	86.00	1.35	86.64	1.33	82.79	1.38

Notes: Each estimated adjusted mean score was obtained in M*plus* using full information maximum likelihood estimation for missing data, by regressing each variable on condition (dummy-coded with the focal condition as the reference group) with covariates of prior competence-related beliefs, initial exam scores, and gender. S2 = Session 2 Time Point (immediately after the second session of the intervention or control task was administered). S3 = Session 3 Time Point (at the end of the semester).

[a] Indicates that score was a baseline measure and thus was not adjusted for the covariates. Unadjusted mean scores by condition are reported in the online supplement.

Table 4

Regression Results on Motivational Beliefs and Values

	Utility value				Perceived cost				Competence-related beliefs			
Predictor	*b*	*S.E.*	β	*p*	*b*	*S.E.*	β	*p*	*b*	*S.E.*	β	*p*
Session 2												
Intercept	4.94	0.11			3.22	0.10			4.96	0.07		
Int. vs. Control	0.10	0.08	0.10	.22	-0.07	0.07	-0.08	.26	0.09	0.05	0.10	.04
CR vs. UV	-0.10	0.13	-0.06	.45	-0.13	0.11	-0.08	.21	0.00	0.08	0.00	.98
E1 score	-0.05	0.16	-0.04	.76	-0.38	0.13	-0.29	.003	0.23	0.09	0.18	.01
CRB	0.53	0.15	0.41	<.001	-0.52	0.13	-0.40	<.001	0.92	0.09	0.72	<.001
Gender	-0.16	0.12	-0.11	.17	0.06	0.10	0.04	.53	0.04	0.07	0.03	.62
E1 Score x Int. vs. Control	-0.13	0.09	-0.13	.16	0.19	0.08	0.20	.01	-0.14	0.05	-0.15	.01
E1 Score x CR vs. UV	-0.06	0.13	-0.04	.64	-0.06	0.11	-0.04	.61	0.00	0.08	0.00	.96
Session 3												
Intercept	5.02	0.11			3.56	0.09			4.86	0.07		
Int. vs. Control	-0.03	0.08	-0.03	.69	-0.09	0.06	-0.11	.13	0.02	0.05	0.02	.75
CR vs. UV	-0.14	0.13	-0.09	.27	-0.11	0.10	-0.08	.28	0.00	0.08	0.00	.99
E1 score	-0.09	0.15	-0.07	.54	-0.27	0.12	-0.23	.02	0.22	0.09	0.18	.02
CRB	0.49	0.14	0.38	.001	-0.45	0.11	-0.38	<.001	0.82	0.09	0.66	<.001
Gender	-0.04	0.12	-0.03	.73	0.10	0.10	0.08	.31	-0.03	0.08	-0.02	.67
E1 Score x Int. vs. Control	-0.15	0.08	-0.16	.06	0.08	0.07	0.09	.23	-0.07	0.05	-0.08	.19
E1 Score x CR vs. UV	-0.19	0.13	-0.12	.16	-0.08	0.11	-0.05	.46	-0.02	0.08	-0.01	.84

Notes: Regression results based on data from $n = 148$ students. Each model reports the unstandardized regression coefficient (*b*), the standard error of the coefficient (*S.E.*), the standardized regression coefficient (*β*) and the significance of the coefficient (*p*). Int. vs. Control = Intervention v. Control contrast: Either Intervention = +1, Control Condition = -2. CR vs. UV = Cost reduction vs. Utility value intervention contrast: Cost reduction intervention = +1; Utility value intervention = -1. E1 scores = Initial Exam Scores (standardized); CRB = Prior competence-related beliefs (standardized). Gender: female = +1; male = -1.

Table 5

Regression Results on Course Grades and Exam Scores

Predictor	Final course grades				Average exam scores			
	b	*S.E.*	β	*p*	*b*	*S.E.*	β	*p*
Intercept	87.69	0.56			84.96	0.79		
Int. vs. Control	1.07	0.36	0.14	.003	1.45	0.51	0.17	.005
CR vs. UV	0.44	0.61	0.03	.47	-0.54	0.86	-0.04	.53
E1 score	9.10	0.68	0.84	<.001	8.50	0.96	0.72	<.001
CRB	0.51	0.67	0.05	.45	-0.11	0.95	-0.01	.91
Gender	1.25	0.59	0.11	.03	0.61	0.83	0.05	.47
E1 Score x Int. vs. Control	-1.52	0.37	-0.19	<.001	-2.11	0.53	-0.25	<.001
E1 Score x CR vs. UV	0.64	0.61	0.05	.29	0.84	0.86	0.06	.33

Notes: Exam scores and grades are scored as percentage correct between 0 and 100. Regression results based on data from $n = 148$ students. Each model reports the unstandardized regression coefficient (*b*), the standard error of the coefficient (*S.E.*), the standardized regression coefficient (β) and the significance of the coefficient (*p*). Int. vs. Control = Intervention v. Control contrast: Either Intervention = +1, Control Condition = -2. CR vs. UV = Cost reduction vs. Utility value intervention contrast: Cost reduction intervention = +1; Utility value intervention = -1. E1 scores = Initial Exam Scores (standardized); CRB = Prior competence-related beliefs (standardized). Gender: female = +1; male = -1.

Table 6

Results of Conditional Mediation Analyses for the Intervention versus Control Contrast

		Final course grades			Average exam scores		
Mediating variable	Initial performance level	*b*	*S.E.*	*p*	*b*	*S.E.*	*p*
Session 2 competence-related beliefs	Low initial exam scores	0.81	0.32	.01	1.32	0.46	.004
	High initial exam scores	-0.19	0.19	.32	-0.32	0.29	.27
Session 2 cost	Low initial exam scores	0.61	0.29	.04	0.89	0.41	.03
	High initial exam scores	-0.26	0.19	.17	-0.38	0.26	.15

Notes. High and low values of initial exam scores were modeled at +1 and -1 *SD* of the mean, respectively. Unstandardized effects shown (*b*), as well as the standard error of the coefficient (*S.E.*) and the estimated significance of the coefficient (*p*). Exam scores and grades are scored as percentage correct between 0 and 100.

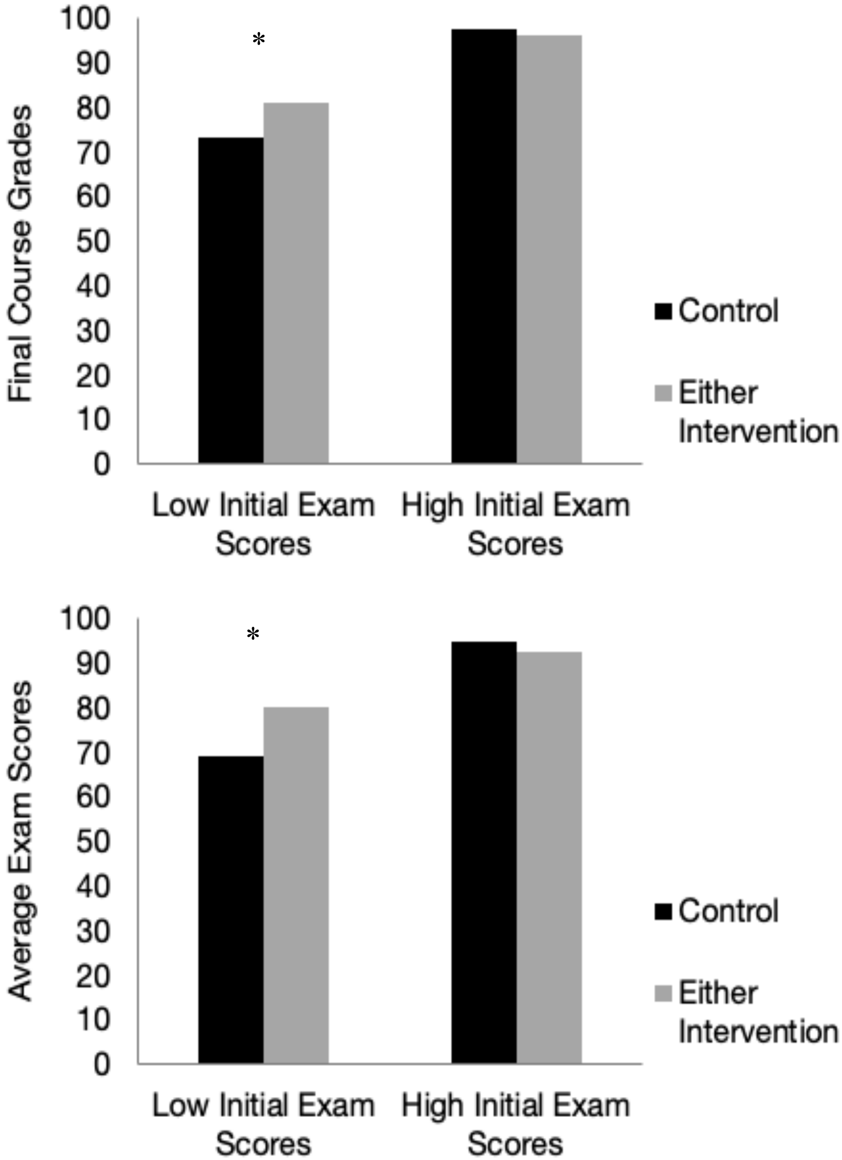
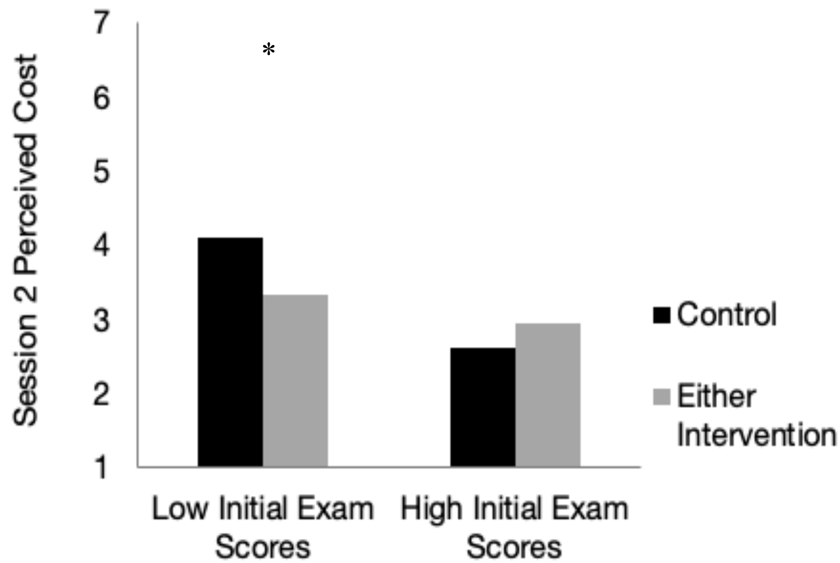


Figure 1. Interactions on course performance variables. Estimated mean scores are shown at each level of the Intervention v. Control Contrast (Either Intervention: +1; Control Condition = -2). Estimated effects control for students' gender and baseline competence-related beliefs in physics. High and low initial exam scores are modeled at one standard deviation above and below the mean, respectively. *indicates that the simple effect for this type of student is significant at $p < .05$.



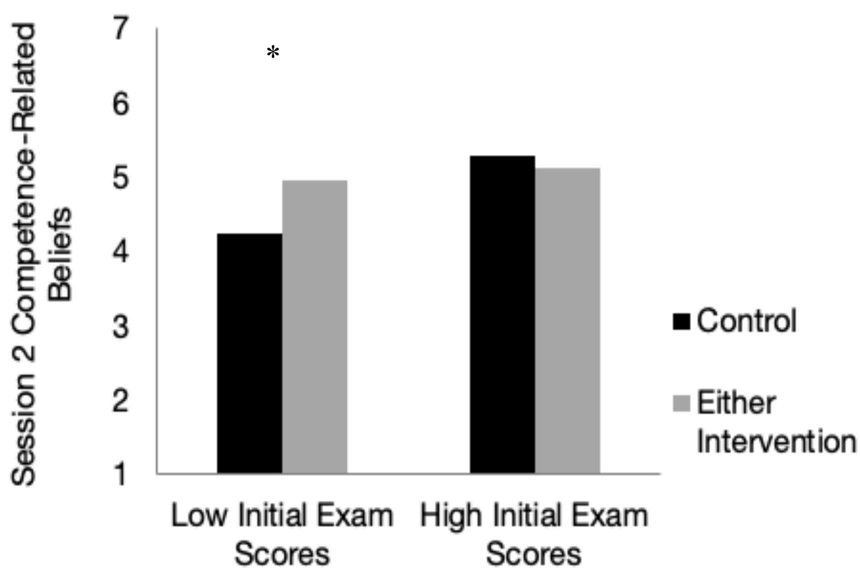


Figure 2. Interactions on Session 2 competence-related beliefs and perceived cost. Estimated mean scores are shown at each level of the Intervention v. Control Contrast (Either Intervention: +1; Control Condition = -2). Estimated effects control for students' gender and baseline competence-related beliefs in physics. High and low initial exam scores are modeled at one standard deviation above and below the mean, respectively. *indicates that the simple effect for this type of student is significant at $p < .05$.