

Efficacy and Insights Gained from a Utility Value Intervention with Inorganic Chemistry Students

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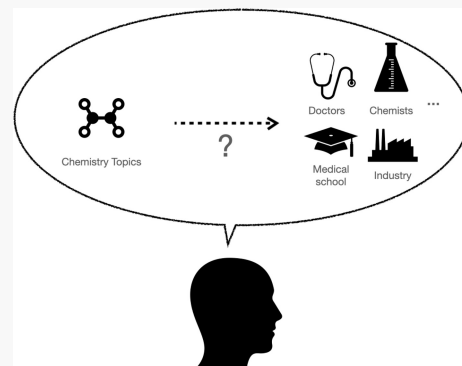
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ABSTRACT: Utility value interventions (UVIs) are brief assignments designed to promote students' perceived utility value of the content they are learning. UVIs have been shown to improve students' academic performance in varying STEM courses; however, the use of UVIs in either chemistry courses or upper-level courses has not been well explored. This study evaluated a UVI in an upper-level chemistry course on student performance using an experimental design. Students were randomly assigned to either a utility value group or a content summary group. The first group received prompts asking students to describe the utility of what they are learning toward their career plans; the second group received prompts asking students to summarize what they are learning. Each student received three prompts over the semester and was tasked to write a short essay in response to each prompt. To evaluate the UVI, independent sample *t* tests were conducted on exam scores between the two groups, and effect sizes indicated that the UVI has no impact on one exam and a positive impact on two exams. In addition to the quantitative evaluation, the study qualitatively characterized student engagement in the intervention, namely how students' responses demonstrated an internalization of the perceived utility value of chemistry topics. The results suggest that the majority of students perceived a personal utility of chemistry topics as the intervention intended. Furthermore, students' responses provided details on their career plans, which can provide instructors' insight in designing curricula responsive to students' plans. In summary, enacting UVIs has low instructional costs and may benefit student performance and provide valuable insights for the instructors. Therefore, UVIs are recommended for consideration in instructional practices of upper-level chemistry courses.

KEYWORDS: Upper-Division Undergraduate, Inorganic Chemistry, Chemical Education Research, Communication/Writing, Applications of Chemistry



Utility value interventions (UVIs) are brief assignments designed to help students find value in the course materials. In doing so, the interventions drive students' motivation to engage with the materials and thus improve students' performance in the course.¹ The effectiveness of this intervention has already been demonstrated in introductory STEM courses; however, only limited work is found in chemistry settings or in upper-level STEM courses.² The current study advances the literature by evaluating the effectiveness of UVIs in inorganic chemistry, an upper-level chemistry course. Furthermore, several prior works have characterized student engagement with the intervention to determine if student engagement moderates the impact of the intervention; however, no study has explored the variations in engagement, which can inform enacting an intervention. The current study conducts a qualitative analysis on students' responses to characterize variations in how students internalize perceived utility of the topics. The qualitative analysis also generated insight into inorganic chemistry students' career choices and perceived utility of chemistry topics selection, which can inform inorganic chemistry instruction while

demonstrating the instructional insights gained by enacting UVIs.

■ BACKGROUND

Expectancy Value Theory and Perceived Utility Value

UVIs are grounded in expectancy-value theory.³ The theory posits that individuals' performance, persistence, and choices are related to their beliefs about how they will do on the activity (expectancy) and the extent to which they value the activity (task value). Task value can be further delineated into four components: intrinsic value, utility value, attainment value, and cost, which are described within Table 1. The distinction between utility value and attainment value is subtle

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Table 1. Components, Definitions, and Examples of Task Value

Component	Definition by Wigfield and Eccles	Example
Intrinsic value	The enjoyment one gains from doing the task	A student finds learning a chemistry topic interesting
Utility value	How a task fits an individual's future plans	A student sees using a chemistry topic in her future career
Attainment value	The importance of doing well on a given task	A student thinks a chemistry topic will appear on a graduate entrance exam
Cost	How engaging an activity limits access to other activities	A student misses an event to study chemistry

as both components may relate to an individual's personal goal, depending on the extent an individual's planned occupation is central to one's core values. The theory predicts that students who perceive value in the task they are engaging with and perceive a high likelihood of achieving the task are more likely to persist in the face of challenges and ultimately succeed. Thus, the delineation between attainment and utility value may be less important as either value offers a means for recognizing task value. In recognizing task value, it is essential that an individual recognizes the importance of the task to one's own plans, as opposed to recognizing how important a task may be for someone else.

UVIs are designed to improve students' utility value, which is expected to generate increased student persistence, and result in improved students' performance in a course. The effectiveness of the intervention is dependent on the intervention's ability to promote student perception of utility value. According to the theory, a successful UVI should lead students to find the link between the provided content and their personal goals (future career plan). Therefore, in their responses to the intervention prompts, when describing the future career plan, they are expected to use personal pronouns. The use of second- or third-person pronouns to describe a future plan indicates a lack of internalization of utility value and may represent a less effective response to a UVI. For example, a student may frame their response to describe an unidentified person who finds the provided content relate to a career plan or that an external factor requires the provided content. A check on whether students articulated utility value in the intervention was conducted among psychological studies to explore the extent to which students perceive personal utility values during the intervention.^{4–7} The most common strategy to explore the articulated utility value is rating students' responses on a scale designed to measure how personal and specific the connections were that students made. Harackiewicz and colleagues operationalized a scale to characterize student responses from general utility, which is applicable to all humanity, to specific connections that show personalized, deep appreciation or future application of the course material.^{5,7,8} Another strategy characterized personal connection through the use of personal pronouns such as I, me, us, or our.⁶ The purpose of coding for articulated utility value in these studies is to demonstrate the extent UVIs work as intended or to explore the reasons why UVIs are effective. One study quantified the codes and used these values to determine whether students receiving a UVI articulated more utility value compared to a control group.⁷ Other studies quantified personal connections within student responses to explore if forming personal

connections is a mediator in a theoretical model on the mechanism of UVIs.^{4,5} While these studies sought to index student responses in terms of describing personal connections with the course content, an additional opportunity is available to explore the variations in how students engage in a UVI. That is, one goal of the current work is to qualitatively investigate students' perceived utility value in their responses to the intervention prompts. Such an investigation can guide instructor feedback to students' responses and inform instructors enacting UVIs.

UVIs in Chemistry

An extensive literature base supports the effectiveness of UVIs in terms of improving students' course achievement, persistence, and affective outcomes (e.g., students' interest).^{2,9–11} The settings vary from high school to college level classes including courses such as psychology, physics, algebra, biology, and chemistry.^{2,4,9,12,13} Recently, the effectiveness of UVIs in several studies conducted in college level STEM courses was summarized by Wang et al.² However, only two studies have implemented UVIs within chemistry courses. Linnenbrink-Garcia and colleagues¹⁴ embedded UVIs within a summer science gateway course. The intervention focused on a pharmacology topic that highlighted the real-world relevance of topics in chemistry and biology. The study embedded the UVI within a suite of other motivational components and did not seek to evaluate the isolated impact of the UVI. Second, Wang and colleagues² implemented a UVI in second-semester general chemistry courses where students were randomized to a utility value group and a content summary group, serving as a comparison group. Each group of students was assigned a brief prompt, spaced to occur three times throughout the semester. The UVI prompt tasked students to select from recently covered topics in the course and either connect the chosen topic to their daily life or future plans. The content summary prompt tasked students to summarize the content from the topic that is important to succeed in the course. The UVI was associated with an improvement in students' exam scores relative to the content summary group. Further, students' emotional satisfaction and utility value among those who had lower attitudes toward chemistry were improved with the UVIs over the course of the semester. The results suggest that UVIs have potential as a practical and effective tool for instruction, supporting a recommendation for instructors to employ UVIs in their own chemistry instruction. To date, only one study has evaluated UVIs within a chemistry course, and it is unknown the extent these findings would generalize to other chemistry courses.

UVIs in Upper-Level Courses

As with the prior chemistry studies, other existing studies on UVI in STEM field are exclusively located within introductory-level courses.^{5,7,8} The closest example to looking beyond introductory courses was an evaluation of the long-term impact of UVI that was given to introductory biological sciences students.⁸ The researchers collected data regarding students' persistence in the biomedical major and found that a UVI in an introductory biology course had a lasting impact on students' persistence two years after the intervention. UVIs have yet to be evaluated with upper-level STEM courses. Upper-level courses may pose a unique challenge to the effectiveness of UVIs as upper-level courses usually have a higher level of abstraction and require students' ability to synthesize a broad range of concepts from introductory courses. As a result,

students may struggle to find real-world relevance of upper-level course content and link the content to their personal plans. For example, Canning and colleagues⁵ found that the impact of UVI could decrease if the students are struggling with the content of the course. Alternatively, students enrolled in upper-level courses may be more committed to their major than students in lower-level courses, and thus, students in upper-level courses may already have a high perceived utility value of the content, thereby diminishing the impact of a UVI. Owing to the lack of studies and reasons advanced for why UVIs may function differently with upper-level course work, it is unclear if a UVI in an upper-level STEM course would function as intended and improve students' course performance.

Given the lack of prior research on UVIs in upper-level STEM courses, and a national call for more education research within upper-level STEM courses,¹⁵ the present study investigates a UVI implemented within an intermediate inorganic chemistry course. Previous studies on inorganic chemistry courses focus on improving curriculum designs^{16,17} and proposing a framework to facilitate development of inorganic chemistry courses.¹⁸ Recent studies have explored inorganic chemistry students' affective experiences. Nennig and colleagues¹⁹ evaluated the effectiveness of an online inorganic chemistry course, in terms of improving students' attitude toward the course and course performance, in comparison with a face-to-face course. The results suggest that students in both formats found the course emotionally satisfying and intellectually accessible. Pratt and Raker²⁰ explored students' achievement emotions (experiences of anxiety and enjoyment) in inorganic chemistry courses. The study demonstrated a negative, significant correlation between students' anxiety during examinations and final exam scores. This work highlights the important role of affect in students learning inorganic chemistry courses and supports the possibility to improve students' performance through intervening with their affective experiences as UVIs are designed to do.

Identifying Students' Future Career Plans

Because of a growing demand for a trained workforce in STEM, there is a trend of research studying factors that influence students' career choice in STEM.²¹ A study reports that there might be two junctures that influence people's future career plan: (1) transition from high school to college and (2) transition from academia to industry.²² Additionally, previous research shows that students' choosing a career could be influenced by the value students attach to a specific discipline.²³ UVI prompts that seek students relating course content to future career plans can offer insight into upper-level chemistry students' career interests. This information can serve instructional adaptations to incorporate students' career plans that may also aid students with unclear career goals by highlighting potential career plans. To demonstrate the potential for the adoption of a UVI to offer insight into students' career plans at the setting where adoption takes place, this work will explore students' responses to characterize their career plans to demonstrate how this information or process could serve future instruction.

RATIONALE

Prior work shows the potential for UVIs as an effective instructional intervention that can improve students' attitudes and academic achievement in introductory STEM courses but

has not explored UVIs within upper-level coursework. The current study seeks to expand these findings by implementing and evaluating a UVI within inorganic chemistry. The results have the potential to directly inform instruction within inorganic chemistry. Therefore, the first goal of this study is to explore the generalizability of prior research by quantitatively evaluating the effectiveness of a UVI in an intermediate inorganic chemistry course.

Furthermore, prior studies suggested that UVI did not demonstrate the same effect for everyone,²⁴ which highlights the importance of understanding how students respond to UVI prompts. On the basis of Expectancy Value Theory, UVIs are intended to promote internally framed connections. For example, a student response that describes how that particular student intends to apply the content would be more effective than a student response that describes how a hypothetical individual would apply the content. Past efforts investigating this phenomenon quantified student responses in terms of their alignment with the intended process. The second goal is to explore the variations in how students frame their responses to better understand how students may engage in processes other than what was intended. The results of such an investigation may inform follow-on efforts with UVIs for example through purposeful feedback to student responses to promote internally framed connections.

Student responses to UVI prompts offer a unique opportunity to explore upper-level chemistry students' career plans and perceived utility of inorganic chemistry topics. Characterizing students' career plans and perceived utility of inorganic chemistry topics can inform the chemistry education community on the perspectives of near graduates from an undergraduate chemistry program and serve discussions on curriculum design. This characterization can also model for would-be adopters the additional insight gained from student responses to a UVI as a benefit beyond the intended gains in student attitudes and achievement. Additionally, with knowing the topics that students select or do not select, an instructor can utilize this information by making the utility of topics that were seldom selected more explicit in future iterations of the course. Therefore, the third goal of the study is to characterize students' career plans and selected topics in their responses to the UVI prompts.

To meet these goals, this study is guided by the following research questions:

Research question 1: What is the effectiveness of a UVI for improving intermediate inorganic chemistry students' academic performance?

Research question 2: What are the variations in students' framing of perceived utility within their responses to the UVI prompts, as informed by Expectancy Value Theory?

Research question 3: What are the self-identified future career plans of inorganic chemistry students and what topics are identified as relevant to these future career plans within students' responses to the UVI prompts?

METHODS

Setting

This study was conducted in an intermediate inorganic chemistry course at a large research-intensive university in the southeastern United States during Spring 2021. This course has a prerequisite requirement of passing second-semester general chemistry, is required for students majoring

in chemistry, and satisfies an upper-level elective requirement for students majoring in biomedical sciences. Academic advising at the research setting recommends chemistry majors enroll in this course during their fourth year of studies and biomedical science majors in their third or fourth year of study. The lectures were prerecorded and delivered completely online. The course covers fundamental principles of inorganic chemistry including atomic structure, bonding theories and structural consequences, transition metal chemistry, and illustrative laboratory work using "Shriver & Atkins Inorganic Chemistry, 6th Edition" as the textbook.²⁵ There were three interim tests and a cumulative final test, which were synchronized and only available for the designated class time. Each interim test weighed 20% of the overall grade and a cumulative final test weighed 40%. The tests contained multiple choice questions randomly selected from a preset question bank. Therefore, due to the uniqueness of the test each student took, the Cronbach's alpha was not calculated for the tests. Instead, the Pearson correlations among the tests were calculated and presented in Table 2. The correlation results show positive and moderate correlations among the tests, which provide evidence for the convergent validity of the tests.

Table 2. Correlation Values among the Tests

	Test 2	Test 3	Final Test
Test 1	0.554 ^a	0.556 ^a	0.473 ^a
Test 2		0.593 ^a	0.640 ^a
Test 3			0.567 ^a

^aCorrelation is significant at the 0.01 level (2-tailed).

Study Design

Students were randomly assigned to either a content summary or utility value group. To randomize the students, their ID number was divided by 6 and grouped based on the remainders from the division operation; remainders equal to 1/6, 2/6, or 5/6 were assigned to the content summary group and the rest to the utility value group. Group assignment was maintained throughout the semester. Random assignment to groups was enacted to avoid potential conflating explanations for any differences observed between the two groups when answering the first research question. Each group received a set of three prompts, delivered via survey on Canvas. Students were awarded an extra 1% toward their total course grade for each complete response to a prompt. The three prompts were spread with one each on week 9, week 12, and week 15 of the

Box 1. Prompt Used with Content Summary Group

Select **one or two** of the following topics covered in lecture. Describe what you need to know on the topic(s) to be successful in this class. Summarize the main parts of the topic(s).

Select the relevant information from class notes and the textbook and **use your own words to write at least 200 words.**

semester. The first prompt was administered after Test 1 but before Test 2. Therefore, Test 1 scores are considered a preintervention measure for student academic performance. The second prompt was administered a week before Test 3 and the third one a week before the Final Test.

The content summary and utility value groups received different prompts. Each prompt includes a list of topics and tasked students to write a 200-word essay based on the prompt. For each group, the prompt was the same in all three iterations but changed by referencing different topics. The prompt for the content summary group is shown in Box 1. The topics varied matching the key concepts presented in class from the previous test up until date of the prompt and are shown in Table 3. The topics were suggested by the instructor of the course. The prompt for the utility value group is shown in Box 2 with the same list of the topics shown in Table 3.

Box 2. Prompt Used with Utility Value Group

Select **one or two** of the following topics covered in lecture.

How might the topic(s) be useful to your future career plans?

Select the relevant information from class notes and the textbook and **use your own words to write at least 200 words.**

Scoring was based on the submission of the responses instead of the scientific accuracy of students' responses. Students received a full score if they submit a response that fulfilled the word requirement in the prompt. No individualized feedback was provided to students, but general feedback was provided as comments on students' responses such as a reminder of the word count expectation for students or the need to link the topic to students' career plans for utility value students who talked about the topics without mentioning anything about their personal plans.

All students in the class were assigned to one of the two groups and given the set of prompts; however, the data

Table 3. Topic List Used with Boxes 1 and 2

Phase 1 Topics (Week 9)	Phase 2 Topics (Week 12)	Phase 3 Topics (Week 15)
• Electron geometry, molecular geometry, and bond angles of compounds • Emission and absorption spectrum • Expression of first and second K_a for the dissociation of an acid • Prediction of the bond forms between two atomic orbitals • Identification and strength of the Lewis acids and conjugate bases • Calculation of pH in a solution • Ionization energy • Hard–soft acid and base	• Identifying operation symmetry elements • Finding point group of the molecule • Application of symmetry/point group • Metal–ligand coordination • High coordination metal complexes (tetrahedral/octahedral)	• Metal ligand orbital repulsion • Metal ligand interaction • Reaction rate measurement (e.g: NMR, UV, mass spec, EPR...) • Ligand stability field energy • Inert and labile complex • High coordination metal–ligand compound

Table 4. Descriptive Statistics of Outcome Measures by Groups

Variables	Test 1	Test 2	Test 3	Final Test
UVI (SD, N)	65.1% (17.7%, 60)	74.5% (13.9%, 56)	68.2% (14.0%, 59)	63.5% (23.4%, 60)
Content summary (SD, N)	68.7% (17.7%, 58)	73.1% (15.9%, 57)	69.5% (18.7%, 58)	61.6% (15.0%, 58)
<i>t</i> test statistic	−1.102	0.492	−0.411	0.745
Significance	0.273	0.623	0.682	0.458
Cohen's <i>d</i>	−0.20	0.09	−0.08	0.13

presented here are only for students who consented to participate in the study. The inorganic chemistry course had an enrollment of 198 students of which 144 consented to participate in the study. Of the consenting students, 24 either dropped the class during the study or missed two or more surveys and they were excluded from the data analysis. As a result, data from 120 students, with 61 in the utility value group and 59 in the content summary group, were analyzed. The data comprised students' test scores used to answer the first research question and students' written responses to the UVI prompts to answer the second and third research questions. The reliance on three prompts and the design of the utility value and construct summary prompt were similar to Wang et al.;² however, the use of extra credit as an incentive differed from the prior work which integrated the prompts into homework assignments.

Qualitative Analysis

Expectancy value theory of achievement motivation describes the utility value as how a task fits into an individual's future plan (e.g., a career plan). Previous studies have found that students referencing oneself when they are learning new materials could lead to learning gains.^{26,27} Therefore, students are expected to relate the task to their personal plan and frame their responses in the first person (e.g., I, we, me, us etc.), in other words, use internal agents in their responses. To understand students' engagement in this intervention, particular attention was paid to the agents that the students employed in the responses. An initial code list was constructed after researchers' cursory review of the responses through an open-coding process. The initial code list included various agents employed by students. Two researchers independently employed the code list to the responses to the first prompt, compared their coding and discussed discrepancies. The definitions of some codes evolved during the discussions. When a new code list was constructed, the two researchers employed the updated code list to the responses to the second and third prompts. Similar to the first round, the code list was refined by application, discussion, and revision during the coding process until the two researchers were both satisfied with the code list. Once the final code list was constructed, consensus coding was applied where two researchers independently coded all the responses to the utility value prompts, compared the codes, and reconciled each discrepancy until an agreement was reached.²⁸ The final code list includes two types of internal agents, utility value perspective and attainment value perspective; three types of external agents, hypothetical, external, and anthropomorphic; an irrelevant code for responses that do not describe topics relating to students' personal career plans; and a not useful code for responses that stated an inability to find the usefulness of the topics. The code book and exemplar codes are included in the [Supporting Information](#).

Two researchers independently coded the topics that each student selected in their responses based on the topic list

provided in [Table 3](#). If a student identified a particular topic relevant to their future career plan that did not explicitly mention any of the topics provided in the topic list, a topic from the topic list was inferred based on the entirety of the student's response. Each researcher coded all of the responses, and any discrepancies were reconciled using the aforementioned consensus coding approach. Some responses identified more than one topic, and those responses were coded for all the topics utilized.

All three responses for each student were considered in coding for students' future career plans. An initial code list of career plans was developed by one of the two researchers based on a review of students' responses and was iteratively refined by two researchers independently applying the codes, discussing discrepancies to modify or clarify the code list, combining similar codes, and then recoding the data. The two researchers then coded the entire data set and reconciled any discrepancies. Some students identified multiple career plans throughout the semester and were therefore assigned multiple codes. The complete code list is provided in the [Supporting Information](#).

Ethical Considerations

The efficacy of UVIs to promote student performance has been shown in some studies^{6–8} but has not been consistently demonstrated.⁵ This study sought to explore the efficacy of UVI in an upper-level course, which has not been previously investigated, and reasons have been advanced for why UVI may perform differently in this setting. The research design thus considered that the potential for advancing knowledge on the efficacy of UVIs outweighed the potential risk for disproportionate benefits based on group assignments. Further, the risk was potentially mitigated by enacting an active comparison group via the content summary prompts. Finally, this study design was approved by the institutional review board at the research setting as an external judgment on the ethical implications.

RESULTS

Research Question 1: Effectiveness of UVI for Improving Students' Academic Performance

Descriptive statistics on test performance are presented in [Table 4](#). The content summary group overperformed the UVI group on Test 1 by 3.6%, which was given prior to any intervention. The mean differences between the two groups on Test 2 and Test 3 were smaller compared to Test 1, with UVI leading by 1.4% with Test 2 and trailing by 1.3% with Test 3. The UVI group overperformed the content summary group on the Final Test by 1.9%. To evaluate the statistical significance of the impact, an independent *t* test was conducted to compare the two groups for each test. No significant results were found between the two groups likely due to insufficient statistical power. A posthoc power analysis indicates that with the sample size in this study, an effect size of 0.52 (approximately a

medium effect size) would be needed to determine statistical significance with 80% power at a 5% Type I error,²⁹ while the effect sizes observed herein were notably smaller than this threshold. In terms of effect size, the comparison group began with higher scores on Test 1 that had a small effect size ($d = 0.2$) while afterward the utility value group had higher scores on Test 2 and the Final Test that were below a small effect size.

The effect size with Test 1 indicates that there is a gap between the two groups on student knowledge before the intervention implemented. To account for this difference, a separate linear regression was conducted for Tests 2, 3, and the Final Test using Test 1 as a predictor variable. The average residuals from the regression were calculated for each group, which showed the extent a group overperformed their predicted score (positive residual) or underperformed (negative residual). The descriptive statistics of the standardized residuals by group are listed in Table 5. The results

Table 5. Standardized Residuals by Groups

Variables	Test 2 Residual	Test 3 Residual	Final Test Residual
R^2	0.295	0.306	0.218
UVI (SD, N)	0.10 (0.98, 57)	0.007 (0.87, 60)	0.12 (0.96, 61)
Content summary (SD, N)	-0.10 (1.00, 58)	-0.007 (1.11, 59)	-0.12 (1.02, 59)
t test statistic	1.104	0.080	1.393
Significance	0.272	0.936	0.166
Cohen's d	0.21	0.01	0.25

showed that after accounting for Test 1 scores, the UVI group overperformed content summary group on each of the later tests. An independent t test comparing the two groups for residuals found no significant differences between the two groups. The Cohen's d values indicated that the effect sizes for Test 2 and Final Test were small, while the effect size for Test 3 was negligible, each of which was below the threshold for sufficient statistical power to demonstrate statistical significance. The observed impact of the UVI in inorganic chemistry is less consistent than the results observed in general chemistry. The observed effect sizes herein range from negligible to small with Cohen's d ranging from 0.01 to 0.25 while the previous study observed effect sizes ranging from 0.10 to 0.31.²

To further explore whether the results were impacted by outliers in the data set, an outlier screening was performed for each test, and any residual outside a range of -2 to 2 was removed from each Test (representing observed scores more than 2 standard deviations away from the predicted score in the regression). This resulted in 5 students removed from each of Test 2 and Test 3, and 4 students were removed from the Final Test data. The results presented in the Supporting Information indicate that after removing the outliers, the effect size for Test 2 became small to negligible (Cohen's $d = 0.10$), was still negligible for Test 3 (Cohen's $d = 0.01$), and for the Final Test the effect size was still small (Cohen's $d = 0.20$).

Research Question 2: Variations in Students' Framing of Perceived Utility

Student responses to the set of UVI prompts framed the utility value from differing perspectives, which articulate differing versions of who or what finds the material useful. The term "agent" is operationalized here to describe the person or object

that has perceived or caused the usefulness of the material. The full code book and exemplar quotes are presented in the Supporting Information. The proportion of students coded for each agent appear in Table 6; many student responses included multiple agents within a prompt so it was possible for a student to be assigned multiple agents.

Table 6. Agents Employed by Students among the Interventions

Agents	Time 1	Time 2	Time 3	At Least Once at Any Time Point
Internal agent, utility value	73%	65%	52%	91%
Internal agent, attainment value	15%	6%	4%	16%
Hypothetical agent	22%	7%	16%	40%
External agent	9%	3%	6%	13%
Anthropomorphic agent	9%	3%	3%	15%
Irrelevant	7%	12%	18%	29%
Not useful	2%	3%	2%	4%

Over the course of the semester, nearly all students (91%) had at least one prompt that described an internal agent that perceives utility value. For example, a student wrote: "I intend on doing work in the biochemical field, so the topic identification and strength of Lewis acids and bases has importance because it describes how and why certain reactions occur within organisms." Responses varied by the amount of specificity in how the chemistry topics were used. Examples of responses that offer chemistry topics used in specific instances include, "...I would need to know a molecule's symmetry to make sure I do not create the wrong drug. If a reflection of a certain compound was made instead of the original, that drug could be completely different or cause different or worse side effects..." or "I could also use metal-ligand coordination as a physician when working with diagnostic imaging such as MRI. MRI uses magnetism to produce its images, and paramagnetic metal complexes can be used to produce imagery in MRI scans." Alternatively, less specific responses described how chemistry topics were present without detailing a specified use, for example, "Metal-ligand complexes are also found throughout the human body, one main example would be hemoglobin as it has an Iron, Fe, and there are many other metal-ligand complexes that assist in various biological processes." While the more specific application of the topics demonstrates a greater internalization, both paths portray a perceived relevance of the topic in line with expectancy value theory.

Alternatively, a minority of responses (4–15% of responses to each prompt) responded with an internal agent that perceives attainment value. In these responses, the topic(s) relevance is linked to a task (e.g., an entrance exam) needed to gain access to the career. For example, a student who mentioned a plan to attend medical school stated, "It is vital for me to understand and keep up with these two topics so I can successful <sic> recognize the answers to these questions if they pop up on my real MCAT exam or even the practice exams/questions as well." As mentioned, attainment value is an alternative means to perceive task value and may serve as motivation depending on the extent an individual's planned occupation is central to one's core values.

Another minority of responses (7–22%) described a hypothetical agent, such as an undefined “you”, as perceiving relevance of a topic. Example responses include, “That’s why knowing the details on the molecules you are working with is so important” or “This (being able to identify operation symmetry of molecules) could be a useful skill for a variety of reasons, like if you need to create a 3D model which could be useful if 3D printing ever becomes integrated into standard medical procedure.” In these cases, the students did not specify how the topic is relevant to oneself but instead described how a hypothetical subject would apply the topics to a certain field. These responses indicate that students see potential use of chemistry knowledge but have yet to identify as a user of this knowledge or have an individualized connection with the content.

Infrequently, students’ responses (3–9%) cited an external agent that requires certain knowledge. Unlike attainment value, where students perceived using chemistry topics to open opportunities for future career, these responses describe being compelled to learn by an external factor. For example, “As a medicinal organic chemistry researcher, I will have to utilize reaction rate measurements, such as Nuclear Magnetic Resonance (NMR), Ultraviolet Spectroscopy, mass spectroscopy, and electron paramagnetic resonance spectroscopy (EPR).” The use of the phrase “I will have to” implies that the utility of the topic is not by choice but rather a requirement of the career path. External agent also co-occurred with a hypothetical agent, as this student continued, “Medicinal organic chemists perform various organic reactions to try to make a “hit” compound...” Seeing the knowledge as required by an external entity and used by a hypothetical individual was also indicative of not identifying a personal connection with the content.

Another infrequent response pattern (3–9%) was students ascribed anthropomorphic qualities to the topics wherein the content was the driving agent for its own utility. For example, “This material helps prepare me for my career path that will either include medical school or pharmacy school” or “Just this knowledge (acids and bases) alone can allow for us to eliminate the likelihood of certain reactions occurring.” Instead of the student being the active agent in the learning process, these responses imply that the content could help or permit them to do a certain activity. This perspective also falls short of the intended process of finding personal connections between content and one’s future plans.

The most frequent combination of agents involved internal agent utility value with hypothetical agent. These responses often explicitly portrayed the student’s connection with a career plan but when it came to identifying the utility of the chemistry topic the response portrayed a hypothetical user engaging in the task. Similarly, utility value was also combined with attainment value or external agent, each describing a student identifying with a career plan but the chemistry topic only serving as a means to reach the career plan (attainment value) or as being required by the career plan (external agent). In each of these cases, the individualized connection between the student and the chemistry content is likely not fully realized.

In a minority of responses (7–18%), the application of the topics in a specific field was described without indicating the students’ future career plans, and thus, the relevance to future career plans could not be established. For example, “Plastics are made with transition metal catalysts as well as detergents

and paints.” While these responses describe how chemistry is used, there was no indication of an individualized connection with the topic and thus these responses fell short of the intention of UVI. Despite the lack of personal connection, students may still potentially benefit from the intervention by generating different ways to apply the topics in a real-life context.³⁰

Rarely (2–3%) students explicitly mentioned difficulties perceiving the usefulness of any of the provided topics in their desired career. One student offered: “In all honesty, my future career plans are still in limbo, so I cannot be completely sure that any topic here can apply to me without a doubt.” For students with unclear career plans, it may be an opportunity to present potential career plans for the student’s consideration. An alternative exemplar, “My desire is to teach within the high school. I hope to be a science teacher, I really desire to teach in chemistry so taking higher level chemistry courses, I feel helps reinforce some of the more fundamental things...inorganic topics...are some topics that will never enter specifically into a high school classroom because of the advanced level of the topics.” For students who see no utility of the content for their future career plans, there is an opportunity for instruction to make a more explicit case for how the content can be used with specific careers, with UVI responses serving as a means to learn about students’ career plans.

Research Question 3: Future Career Plans of Inorganic Chemistry Students

Among the 61 students in the utility value group, 8 students did not specify their career choice across the three responses, as described with the irrelevant code. And 53 students identified at least one career plan; 31 of them mentioned a career as a medical practitioner including doctors, physicians, physician assistants, surgeons, or perfusionists. For example, “my career plans involve becoming a physician and practice medicine for several years before possibly going into academic medicine” or “My goal is to become a physician and I can see these topics being on the MCAT, a necessity to get into medical school and thus achieve my career plans.” Five students identified preparing for or being a dentist, such as “Covering these topics in class has already helped me to prepare for my Dental Admissions Test along with some of the other general chemistry topics we have touched on. As a dentist being able to understand bonding on a chemical level will contribute to my understanding of bonding used when doing a filling or cementing a crown on a patient.” Among the 36 students aspiring for medical or dental professions, “Calculation of pH in a solution” (67% of responses), “metal–ligand coordination” (69%), and “Reaction rate measurement” (64%) were discussed most frequently. These topics were found useful mostly in patient treatment scenarios or doing research in medical school. For example, knowing how to calculate pH was seen as useful for doctors to know “the amount of acidic and basic drugs to be used during sedation”. Other students described career plans related to the medical field: two students aspired to be a pharmacist, two students an anesthesiologist, and one student an epidemiologist.

After medical and dental professions, the next most popular career plan was chemist ($n = 14$), namely a material chemist or analytical chemist. Student responses describe a desire to develop, or discover a new product, including medicinal or skincare products. Other plans include performing chemical

analyses within a lab or earning a master's degree. Similar to students who want to be medical practitioners, aspiring chemists most frequently chose the same three topics: "Calculation of pH in a solution" (57% of responses), "metal–ligand coordination" (57%), and "Reaction rate measurement" (71%).

The rest of the student responses described a variety of career plans including a teacher ($n = 2$), a food scientist ($n = 1$), an environmental field technician ($n = 1$), a crime scene investigator ($n = 1$), or a lawyer ($n = 1$). Student responses that identified these career plans offered unique insight into the applicability of chemistry topics. The aspiring crime scene investigator wrote that measurement tools, such as NMR and UV, can be used to "identify unknown compounds that could be possibly found at a crime scene to better help the investigators determine what sort of crime was committed". The aspiring lawyer admitted difficulties in perceiving the utility values of the topics; however, the student depicted a scenario where the topics could be used: "I am considering patent law, and I could use my chemistry degree to specialize in biotechnology." These responses are particularly helpful as they indicate difficulties students perceive with linking the topics to their career plan yet provide a potential path forward that instruction may be able to develop further.

Although most of the topics presented were used in student responses, there are a few topics discussed by fewer than 10% of the students. These topics include "Expression of 1st and 2nd K_a for the dissociation of an acid" ($n = 3$), "high coordination metal–ligand compound" ($n = 3$), "prediction of the bond forms between two atomic orbitals" ($n = 2$), "ionization energy" ($n = 2$), and "metal ligand orbital repulsion" ($n = 2$). These topics are more abstract and fundamental, which could be the reason why students were less likely to choose these topics. Instruction that links these foundational topics to more applied topics could be useful in helping students form a perceived utility value for these topics.

RESEARCH IMPLICATIONS

The effectiveness of UVI in STEM courses has been demonstrated in several studies; however, it has not yet been studied within upper-level courses. This work addresses this gap by evaluating a UVI in an intermediate inorganic chemistry course. The results show that after controlling for the first test, compared to content summary, UVI led to a 0.21 standard deviation gain on Test 2 and 0.25 standard deviation gain on the final test; however, the impact of UVI on Test 3 was negligible (0.01 standard deviation gain). The combined results indicate that the true effect of UVI probably ranges from negligible to small in the current setting. These results were somewhat lower than an earlier study in an introductory-level chemistry course where UVI gains relative to the content summary group were approximately 0.3 standard deviation on two tests in and the impact was negligible on one test. Combined, these two studies suggest that the best estimate of the true effect of UVI with chemistry students is a small, positive impact on student achievement given that four of the six measurements from the two studies show a small effect over a content summary group and the random assignment to groups rules out many competing explanations. However, it should be acknowledged that statistical noise (unexplained variance) is also present in these measurements, which means the true effect may range from no impact to a small, positive impact. More research would be needed to narrow this

observed range or offer insight into the variability in measurements observed.

The current work sought to explore whether students engaged in UVI as intended according to Expectancy-Value Theory, which is a necessary step to understand why any academic gains occurred. By a qualitative analysis of the students' responses, most responses to each prompt (52–73%) employed an internal agent with a utility value perspective, indicating that a majority of students found utility value in the topics they selected and engaged in the intervention as intended. The proportion of student responses portraying perceived value in the content is also augmented by those who were marked as showing attainment value along with the infrequency by which students mentioned perceiving no value. Thus, the UVI appears to work as intended within an inorganic chemistry class at the research setting, and future research can explore the efficacy of UVIs at other research settings or with different chemistry subdisciplines.

INSTRUCTIONAL IMPLICATIONS

Considering the current study and past literature, UVIs in inorganic chemistry appear feasible and beneficial. Instructors interested in UVIs may want to consider the potential costs and benefits of adoption. In terms of instructional cost, the UVI in this study was implemented by posting one question three times throughout the semester. In this study, scoring the prompt was based on checking responses for the word requirement given in the prompt, and thus, one researcher graded all the responses to one prompt in about 1 h. The instructional costs would scale up with larger class sizes, more prompts, and more individualized scoring or feedback; however, the instructional costs can also be shared or distributed with teaching assistants if available. In terms of benefit, the intervention may lead to an improvement in students' academic performance and it provides instructional insight into students' career plans and perceived topic relevancy, which can inform both current and future instruction. By knowing students' career plans, an instructor could link each topic in the course to one of these career plans and provide a rationale as to why a student should learn the topics.

Additionally, this study points to promising adaptations for instructors' future implementation of UVI, particularly as instructor engagement in UVI also impacts intervention outcomes.³¹ The exploration of agent in student responses provides a guideline to how instructors can give feedback to students' responses for UVI. Students who cite an external agent may benefit from feedback that asks the student to elaborate on why the external agent, such as an entrance exam or admissions, was designed to require content related to these topics. Students who cite a hypothetical agent can get feedback asking whether the student envisions doing the same task as the hypothetical individual in the response. In addition, an instructor can provide exemplar responses to the class as a whole and demonstrate how this exemplar response fits the instructors' expectation, particularly in advance of the first prompt. Students who find topics not useful might also benefit from seeing exemplar responses to help the students perceive the varying ways in which utility value of the topics has been perceived. Lastly, students who only described a general application of the topics (coded as "irrelevant") may not have a clear idea about their future career plans. In class, an instructor can review differing career plans that have been brought forth

in past student responses, and in the prompt, an emphasis can be made that the student can pick any career plan they would consider pursuing in the future.

The inclusion of exemplar responses has shown promise in previous research studies. Gaspard and colleagues³² included sample quotes from students who have already taken the course as a component of UVI. The prompt with quotes serves as a scaffold and has a stronger effect on students' personal utility value compared to the pure text prompt. Harackiewicz and colleagues⁷ provided students with more structured instruction, including examples of applications and an emphasis via bold text to connect content to "your own life" and a suggested structure of the essay that explicitly requires students to make the essay personal (e.g., explain why this information is relevant to your life or useful for you and give examples). Their study found that the prompt with structured instruction helps students to perceive utility value. Neither of these adaptations have been tried in a chemistry setting; future work may benefit by incorporating these elements when implementing a UVI in chemistry.

Student responses to UVI also gave insight into the career choices of students in an upper-level chemistry course. The career choices at this setting are not thought to generalize to other settings; however, the method for analyzing student's career choices demonstrates a path whereby future adopters of UVI's can gain insight into their own students' career plans while promoting perceptions of utility value. This study found the strong majority of students in such a class endeavored to enter the medical profession, and among those students, most were able to find utility among the chemistry topics for their chosen profession. One implication from this study is that UVI can serve to inform instructors about their students' career interests and informed discussions on how to make the curriculum relevant to these interests.³⁰ Importantly, as this study shows, students pursuing a medical field can find utility in chemistry concepts, and thus, curriculum discussion can focus on how to promote these links with existing topics further instead of abandoning topics that may not be considered directly related to a medical field.

LIMITATIONS

This study represents an intervention given in one class at one research setting, and thus, claims of generalizability cannot be supported at this time. While an effort is made to place these results within the context of results reported in the literature, the creation of a more substantive literature base evaluating UVIs within chemistry settings will be necessary to support broader claims of generalizability. Students' perceptions of utility are likely dependent on the topics covered within the inorganic chemistry course. Nationally there is a large variability in the material taught within inorganic chemistry¹⁷ so it is unknown the extent other inorganic topics may be perceived by students. Additionally, students' career plans are likely dependent on the placement of the course within the curriculum and which majors incorporate the course into their degree progression. At the research setting, the inorganic chemistry class was required for students majoring in chemistry and served as an upper-level elective for students majoring in biomedical sciences. Other curriculum alignments will likely bring a different distribution of career plans and may affect students' perceived utility of topics.

CONCLUSIONS

This study found that UVI had a positive impact on student performance, although future work is needed to better substantiate the stability of the observed impact across different measures of academic performance. The UVI was relatively low cost compared to many instructional interventions as it can be adopted via the incorporation of three questions spaced throughout the semester. Coding student responses by the agent who perceives utility of chemistry topics found most students perceived a personal utility of chemistry topics as the intervention intended. This insight has supported a case of the intervention working as planned and offers paths for developing student feedback in future UVI implementations. Coding student responses also provides details on students' career plans, which can serve both current and future instruction in designing instruction and curriculum responsive to students' plans. Owing to the observed benefit in student performance and the additional insights gained in student responses compared to the low cost in instructional effort to enact, UVIs are recommended for consideration in instructional practices of upper-level chemistry courses.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at <https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00045>.

Code lists, exemplar quotes, outliers sensitivity analyses (PDF, DOCX)

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Notes

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