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Goals for the Undergraduate Instructional Inorganic Chemistry Laboratory When Course-Based Undergraduate Research Experiences Are Implemented: A National Survey

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ABSTRACT: Course-based undergraduate research experiences (CUREs) are a promising approach for incorporating inquiry-based instruction into the undergraduate chemistry laboratory curriculum. This study used data from a national survey of inorganic chemistry faculty members ($n = 142$) to investigate CURE implementation in the inorganic chemistry instructional laboratory. Results indicate that faculty members who implement CUREs place greater emphasis on a distinct set of instructional goals when compared to faculty members who do not implement CUREs. CURE implementation was further associated with a range of instructional and departmental characteristics, including group-only student work, independent course development by faculty instructors, limited graduate TA support, and ACS certification of degree programs. Findings from this investigation point toward (1) a need for increased efforts focused on supporting CURE implementation, (2) productive avenues through which curriculum designers and communities of practice can provide this support, and (3) needed areas of research that will further inform these efforts.

KEYWORDS: *Second-Year Undergraduate, Upper-Division Undergraduate, Inorganic Chemistry, Curriculum, Laboratory Instruction*

■ INTRODUCTION

Our understanding of how individuals learn across the undergraduate chemistry curriculum has prompted a rise in inquiry-based instruction.[1] As evidenced by this *Special Issue* and numerous articles within the *Journal*, a body of chemistry educators are now committed to developing and implementing inquiry-based laboratory experiences.[2−6] Course-based undergraduate research experiences (CUREs) constitute one means of incorporating inquiry into the instructional chemistry laboratory.[7−10] The CURE pedagogy involves embedding real chemistry research experiences within the undergraduate curriculum, providing an opportunity for students to design experiments, collect and analyze novel data, and produce results relevant to the scientific community.[11,12] Participation in undergraduate research is associated with increased levels of retention,[13] greater pursuit of graduate education,[14] and learning gains for key research skills;[15] by incorporating research within a course, CUREs have the potential to increase access to undergraduate research opportunities and ultimately make associated benefits available to a larger number of students.[16] Furthermore, the CURE pedagogy can bridge the disconnect between research and teaching for faculty instructors that feel they cannot amply devote the necessary time to both, allowing them to advance their own research interests while fulfilling their instructional role.[11]

CUREs afford a range of benefits for students and educators,[11,12] suggesting that increasing adoption of the pedagogy within our community is a productive avenue for promoting inquiry-based instruction. Most recently, education research on CUREs has focused on how the pedagogy impacts students' learning in the chemistry laboratory;[17] results suggest that CUREs result in similar content-based learning gains when compared to traditional laboratory instruction.[17] Evidence of this efficacy provides additional support for their adoption. However, implementation poses a challenge, as faculty members report that implementation of CUREs requires financial resources, additional time and work effort, and logistical planning.[18] These resources can be scarce for many instructors. Additionally, facilitating inquiry within a CURE setting also requires pedagogical knowledge and skills not necessarily held by chemistry instructors.[19] Given these challenges, understanding drivers of CURE adoption is essential for supporting use of the pedagogy.

CUREs are implemented across scientific disciplines with the general goal of supporting students' development as scientists;[11] this development includes learning about the

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Table 1. Factors and Exemplar Items from the Faculty Goals for Undergraduate Chemistry Laboratory Instrument Developed by Bruck and Towns[24a]

Factor	Exemplar Items
Research Experience	• Preparing students for research experiences is a goal for the laboratory. • How often are students conducting experiments that mimic research experiences?*
Group Work and Broader Communication Skills	• Students need to learn to work together in laboratory to succeed in their future careers. • Group work in laboratory encourages students to use their peers as information sources.
Error Analysis, Data Collection and Analysis	• Laboratory is a place for students to learn to analyze data. • How often are students required to carry out an error analysis?*
Connection between Lab and Lecture	• The goal for laboratory instruction is to reinforce lecture content. • There is a strong connection between the lecture and the laboratory.
Transferable Skills (Lab-Specific)	• Laboratory activities and experiments selected for this course are designed to develop students' mastery of laboratory techniques. • Laboratory activities and experiments selected for this course are designed to focus on skills that are transferrable to research-oriented laboratories.
Transferable Skills (Not Lab-Specific)	• Laboratory activities and experiments selected for this course are designed to teach students to build logical arguments based on their data. • Laboratory activities and experiments selected for this course are designed to foster an appreciation for science in students.
Laboratory Writing	• Teaching students how to write scientific reports is a goal for laboratory. • Writing laboratory reports helps students to communicate what they know about chemistry.

[a] Participants responded to 27 items using a six-point Likert scale ranging from strongly disagree to strongly agree and to two frequency items (indicated by *) using a five-point scale ranging from 0% to 76–100%.

nature of research and cultivating skills requisite to scientific thinking, communication, and collaboration.[11] CUREs are further implemented across content areas in the undergraduate chemistry curriculum, including the inorganic chemistry instructional laboratory.[20−23] Understanding the unique goals of inorganic chemistry faculty members implementing CUREs in the instructional laboratory, along with instructional and departmental characteristics that facilitate their implementation, will allow curriculum designers and communities of practice to better aid faculty members in developing and implementing their own CUREs. It will further allow inorganic chemistry instructors to compare their own goals, instructional contexts, and departmental contexts with those of faculty members implementing CUREs as they consider adopting this pedagogy within their own courses.

■ RESEARCH QUESTIONS

Our study is guided by two research questions:

1. How do faculty members' goals in inorganic chemistry instructional laboratories implementing CUREs differ from those in inorganic chemistry instructional laboratories not implementing CUREs?
2. How do inorganic chemistry instructional laboratories implementing CUREs differ from those not implementing CUREs?

■ METHODS

A survey-based approach was used to address our research questions. The survey focused on faculty goals for, and the format of, inorganic chemistry instructional laboratory courses in the United States. Survey items comprising an instrument on faculty members' goals for the instructional chemistry laboratory were psychometrically evaluated.[24] Lastly, survey responses were analyzed using descriptive and inferential statistics.

Data Collection

Faculty members from the Division of Inorganic Chemistry (DIC) of the American Chemical Society ($N \approx 6{,}000$) and registered users of the Virtual Inorganic Pedagogical Electronic Resource Web site (VIPEr; $N = 1{,}467$) were invited via email to complete a survey on CURE implementation and goals for inorganic chemistry instructional laboratory courses in October 2019. Data from this convenience sample were collected anonymously through November 2019. Comprehensive institutions, two-year institutions, and institutions serving minoritized populations are likely undersampled due to our sampling strategy. The survey contained items about the inorganic chemistry instructional laboratory curriculum, departmental and institutional contexts, and respondent demographics as part of a larger investigation (see Raker et al.).[25] The study was approved by the University of South Florida's Institutional Review Board on September 24, 2019 (Application Pro00042058).

A total of $n = 294$ individuals consented to participate in the study, and a subsequent $n = 142$ individuals provided information on CURE implementation and goals for the inorganic chemistry instructional laboratory. Participants completed the survey in reference to a single undergraduate inorganic chemistry instructional laboratory course they had taught and had the most control over in the last three years. Specifically, we asked respondents about their familiarity with CUREs, whether they had implemented a CURE in their inorganic chemistry instructional laboratory course, and their likelihood of implementing a CURE in a future offering of their inorganic chemistry instructional laboratory course. Respondents also completed the Bruck and Towns instrument on faculty goals in undergraduate chemistry laboratory courses;[24] this 28-item instrument uses a six-point Likert scale, ranging from strongly disagree to strongly agree, to measure goals across seven factors: Research Experience; Group Work and Broader Communication Skills; Error Analysis, Data Collection and Analysis; Connection between Lab and Lecture; Transferrable Skills (Lab-Specific); Transferrable Skills (Not Lab-Specific); and Laboratory Writing (see Table 1). Two of the 28 items assess the frequency of laboratory activities; these items use a five-point scale ranging from 0% to 76–100%. Each factor has 3–5 items; exemplar items for each factor are provided in Table 1, and the complete instrument is provided in the Supporting Information.

Additional survey items focused on instructional resources used to develop experiments, organization of student laboratory work, departments' ACS-certification status and terminal chemistry degree (bachelor's or graduate), and funding sources for improving undergraduate chemistry courses. Survey items were informed by previous research on the inorganic chemistry lecture curriculum,[26] the American Chemical Society's Committee on Professional Training's Supplement on the Inorganic Chemistry Instructional Laboratory Curriculum,[27] and discussions with inorganic chemistry educators.[28,29]

Of the 142 respondents providing information on CURE implementation and instructional laboratory goals, 65% were from institutions with a terminal bachelor's degree and 35% were from institutions with a terminal master's or doctoral degree. Additionally, 79% of respondents were from institutions offering an ACS-certified bachelor's degree, 20% were from institutions that did not offer an ACS-certified bachelor's degree, and 1% reported they did not know this information.

Psychometric Evaluation of the Bruck and Towns Instrument

The internal structure of the Bruck and Towns instrument was evaluated using confirmatory factor analysis (CFA), and reliability was evaluated using McDonald's omega (ω). Additionally, Mann−Whitney *U* tests were used to corroborate the characterization of the factor structure. This is the first reported use of CFA and McDonald's ω to evaluate data from this instrument; initial reporting of the instrument used exploratory factor analysis to identify factors and Cronbach's alpha (α) to evaluate reliability.

CFA was conducted in MPlus version 8.7 using the published factor structure.[24] The weighted least-squares mean and variance adjusted (WLSMV) estimator was used to estimate model parameters, as it accommodates ordinal data.[30] Model fit was evaluated using the χ^2 statistic, comparative fit index (CFI), Tucker−Lewis index (TLI), and root-mean-square error of approximation (RMSEA). For acceptable model fit, χ^2 should be nonsignificant, the CFI and TLI should be $\geq$0.90, and the RMSEA should be <0.05.[31,32] Factor scores for each respondent were calculated using the lavaan package in RStudio, as this package calculates factor scores for ordinal data.[33]

CFA results provided sufficient evidence of the instrument's structural validity. Model fit statistics exhibited a borderline fit of the seven-factor structure when compared to published cutoff criteria: χ^2 (N = 142, df = 329, p < .001) = 775.65, CFI = 0.89, TLI = 0.88, and RMSEA = 0.10. Item loadings ranged from 0.42 to 0.96. A complete set of item loadings is provided in the Supporting Information. This is the first psychometric evaluation of the instrument beyond its original development;[24] while our results are near ideal thresholds, these results are acceptable for using the instrument in the context of our study. We note that any potential misinterpretation of scores would also not result in severe unintended consequences, for example, the loss of opportunity for marginalized groups;[34] thus, these results are acceptable for use in the context of our study. We reaffirm previous calls for researchers to similarly evaluate the consequential validity associated with their own study before using this instrument. As we discuss in our Implications sections, specific further work is necessary to affirm the seven-factor structure; however, the current sample and sample size are insufficient for such analyses and potential instrument or factor-structure revision.

Internal consistency was evaluated using Cronbach's α and McDonald's ω. Cronbach's α was evaluated for the purpose of comparing with α coefficients published by instrument developers.[24] McDonald's ω is conceptually like Cronbach's α; however, McDonald's ω is the more appropriate reliability coefficient when item loadings are unequal and data are ordinal, as with our data set. McDonald's ω was calculated using the psych package in RStudio.[35]

McDonald's ω values for each factor exceeded, or were near, the recommended minimum acceptable value of 0.70; Cronbach's α values approached those found by instrument developers (see Table 2). The factors Transferrable Skills (Lab-Specific) and Transferrable Skills (Not Lab-Specific) had coefficients below 0.70. Results from the CFA further demonstrated that these factors exhibited collinearity with the Research Experience factor, suggesting that these factors may jointly be measuring a broader construct. As mentioned previously, future work with a larger sample size is necessary to identify any persistence of these correlations and to consider possible implications of these correlations for recharacterizing the factor structure of the instrument.

Table 2. Reliability Coefficients for Factors in the Faculty Goals for the Undergraduate Chemistry Laboratory Instrument[a]

Factor	ω	α	α_{dev}
Research Experience	0.83	0.78	0.84
Group Work and Broader Communication Skills	0.90	0.83	0.83
Error Analysis, Data Collection and Analysis	0.87	0.79	0.82
Connection between Lab and Lecture	0.89	0.88	0.86
Transferable Skills (Lab-Specific)	0.67	0.63	0.81
Transferable Skills (Not Lab-Specific)	0.62	0.55	0.67
Laboratory Writing	0.70	0.67	0.77

[a] All values exceed or are near the recommended minimum value of 0.70. Cronbach's α values also approach those published by the instrument developers (α_{dev}).[24]

Lastly, a series of difference tests were conducted to further evaluate the instrument. These tests demonstrated that results of the instrument are associated with external variables.

First, Mann−Whitney *U* tests were used to evaluate differences in factor scores between respondents who described the inorganic chemistry laboratory curriculum at their institution as "one stand-alone/independent inorganic chemistry laboratory course" (n = 59) versus those who indicated "the inorganic chemistry laboratory course is incorporated into an inorganic chemistry lecture course" (n = 70). A difference in the Connection between Lab and Lecture factor is considered evidence of functionality, as instructors teaching laboratory courses that are incorporated into lecture courses would be expected to place greater emphasis on making connections between the two. Significance was set at α = .05 for these analyses, and effect sizes (r) were calculated post hoc. Analyses were completed using the stats and rcompanion packages in RStudio. Small, medium, and large effects corresponded to values of 0.10, 0.30, and 0.50, respectively.[36]

Results of the Mann−Whitney *U* evaluation showed a difference in scores on the Connection between Lab and Lecture factor between respondents who described their inorganic laboratory course as "incorporated into an inorganic chemistry lecture course" (Mdn = 0.320) and those who indicated it was "stand-alone/independent" (Mdn = −0.177): $U(N_{\text{incorp}} = 70, N_{\text{indep}} = 59) = 2641$, $z = 2.720$, $p = .007$, and $r = 0.24$. For all other factors, *p*-values exceeded .05. Additional values are provided in the Supporting Information.

Finally, a Kruskal−Wallis test, followed by a post hoc Tukey HSD test, were used to evaluate differences in factor scores for respondents who indicated that students in their course worked individually ($n = 32$), in groups ($n = 76$), or a combination thereof ($n = 34$). A difference for the Group Work and Broader Communication Skills factor is considered additional evidence of instrument functionality, as those employing only group work would be expected to place the greatest emphasis on those related goals. Significance was set at $\alpha = .05$ for these analyses, and effect sizes (*r*) were calculated for the post hoc Tukey HSD test.

A difference in scores was observed for the Group Work and Broader Communication Skills factor for respondents who indicated their students worked exclusively in groups (Mdn = 0.270), individually only (Mdn = −0.296), or a combination of the two (Mdn = −0.011): $H(2) = 7.36$ and $p = .025$. A post hoc Tukey HSD test resulted in a significant difference in scores between respondents indicating their students worked in groups versus individually ($p = .039$, $r = 0.25$). All *p*-values exceeded .05 for all other factors and the individual−combination and group−combination comparisons; complete analyses, including additional *p*-values and effect sizes, are provided in the Supporting Information.

Data Analysis

To address the first research question, Mann−Whitney *U* tests were used to evaluate differences in factor scores between the two groups across all seven factors. Bonferroni adjusted significance was set at .007 ($\alpha = .05/7$) for these analyses, and effect sizes (*r*) were calculated post hoc.

To address the second research question, two-sided Fisher's exact tests were used to identify instructional and departmental characteristics associated with courses implementing CUREs. Significance was initially set at $\alpha = .05$, with an appropriate Bonferroni correction applied for each analysis. Odds ratios were calculated post hoc as a measure of effect size: small, medium, and large effects corresponded to odds ratios equaling 1.68, 3.47, and 6.71, respectively.[37]

■ RESULTS AND DISCUSSION

Descriptive statistics are presented for implementation of CUREs in inorganic chemistry instructional laboratory courses. Next, inferential statistics are reported for the Faculty Goals for Undergraduate Chemistry Laboratory instrument by use and nonuse of CUREs in inorganic chemistry instructional laboratory courses (Research Question 1).[24] These results are followed by inferential statistics on instructional and departmental characteristics associated with courses implementing CUREs (Research Question 2).

CURE Implementation in Inorganic Chemistry Instructional Laboratories

Descriptive statistics were used to characterize faculty members' self-reported familiarity with CUREs, use of a CURE in their own course, and self-reported likelihood of implementing a CURE in their course in the future. Most respondents (82%) indicated that they did not currently use a CURE in their course (see Table 3). A large proportion of respondents (41%) further indicated limited familiarity with this pedagogy, with 21% of respondents reporting that they have never heard of CUREs and 20% reporting that they know the name but not much more (see Table 3). However, most respondents (72%) indicated some likelihood of implementing a CURE in the future, with self-reports of such likelihood ranging from possibly (37%) to definitely (17%; see Table 4).

Table 3. Inorganic Chemistry Faculty Members' ($n = 142$) Self-Reported Familiarity and Use of CUREs

Response	*n*	% Respondents
I have never heard of this before now.	30	21%
I know the name, but not much more.	29	20%
I know about this but have never used it in my course.	52	37%
I have tried it in my course, but no longer use it.	6	4%
I currently use it in my course to some extent.	25	18%

Table 4. Inorganic Chemistry Faculty Members' ($n = 142$) Self-Reported Likelihood of Implementing a CURE in Their Course in the Future

Response	*n*	% Respondents
Definitely	24	17%
Very probably	13	9%
Probably	10	7%
Possibly	55	39%
Probably not	36	26%
Definitely not	2	1%
No response	2	1%

A minority of respondents reported discontinued use of CUREs (4%) or unlikelihood of using the pedagogy in the future (27%), with self-reports ranging from probably not (26%) to definitely not (1%; see Tables 3 and 4).

Limited use of CUREs, combined with instructors' general likelihood of implementing the pedagogy, suggests a need for increased efforts focused on supporting CURE adoption. Limited familiarity with CUREs among these instructors suggests that increasing knowledge of the pedagogy and its associated benefits may serve as a productive avenue for promoting its adoption. Future research could also focus on perceived barriers to implementing CUREs, especially among instructors who have either discontinued CURE use or report an unlikelihood of future CURE implementation.

For the purposes of subsequent analyses based on CURE use and CURE nonuse, only instructors ($n = 25$) who use CUREs in the course for which they are responding to the survey are considered users of CUREs; the remaining $n = 117$ instructors comprise the nonusers of CUREs category.

RQ1: How Do Faculty Goals in Inorganic Instructional Laboratories Implementing CUREs Differ from Those in Laboratories Not Implementing CUREs?

Mann−Whitney *U* tests resulted in differences in scores on five of the seven factors for CURE users and CURE nonusers: Research Experience; Group Work and Broader Communication Skills; Error Analysis, Data Collection and Analysis;

Table 5. Mann–Whitney *U* Test Comparisons of Factors Scores between CURE Users (n = 25) in Inorganic Instructional Laboratory Courses and CURE Nonusers (n = 117)[a]

Factor	*U*	*z*-score	*p*-value	*r*	$\mathrm{Mdn}_{\mathrm{users}}$	$\mathrm{Mdn}_{\mathrm{non}}$
Research Experience	780	3.66	<.001*	0.307	0.5081	−0.1860
Group Work and Broader Communication Skills	828	3.40	.001*	−0.285	0.4691	−0.1059
Error Analysis, Data Collection and Analysis	900	3.01	.003*	−0.253	0.1986	−0.0065
Connection between Lab and Lecture	1695	1.25	.214	0.105	−0.1762	0.3005
Transferrable Skills (Lab-Specific)	820	3.44	.001*	−0.289	0.2456	−0.0528
Transferrable Skills (Not Lab-Specific)	825	3.41	.001*	−0.286	0.2962	−0.0809
Laboratory Writing	1182	1.50	.134	−0.126	0.1240	0.0399

[a] Initial significance was set at $\alpha = .05$, and the Bonferroni adjusted significance level was set at .007 (.05/7). *corresponds to $p < .05$.

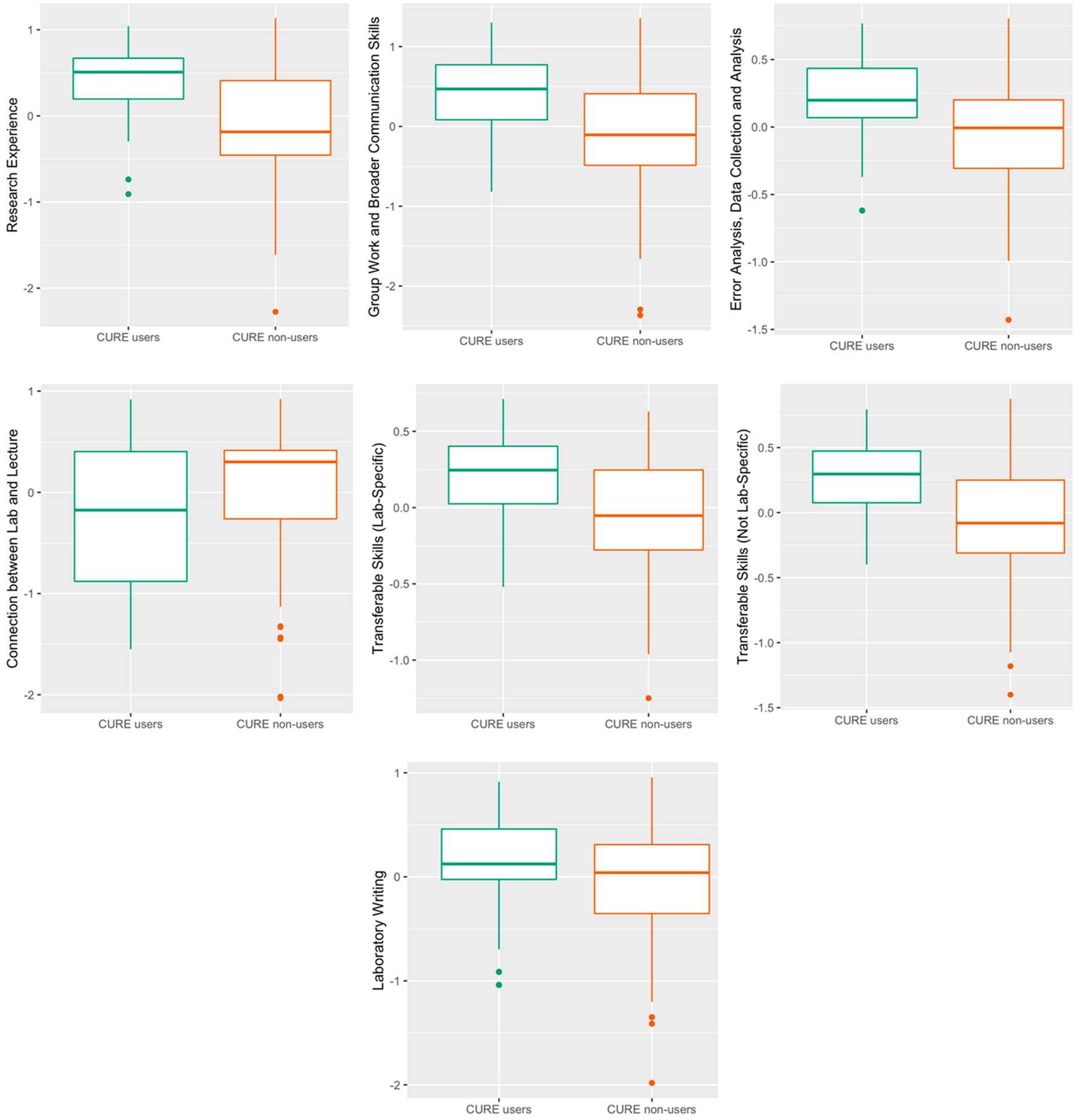

Figure 1. Factor scores on the Faculty Goals for Undergraduate Chemistry Laboratory instrument for CURE users (n = 25) versus CURE nonusers (n = 117). Respondents implementing CUREs scored higher on the following factors: Research Experience; Group Work and Broader Communication Skills; Error Analysis, Data Collection and Analysis; Transferrable Skills (Lab-Specific); and Transferrable Skills (Not Lab-Specific).

Transferrable Skills (Lab-Specific); and Transferrable Skills (Not Lab-Specific); see Table 5 and Figure 1).

Observed differences suggest that, for inorganic chemistry instructional laboratories where CUREs are implemented, faculty members place greater emphasis on goals relating to Research Experience; Group Work and Broader Communication Skills; Error Analysis, Data Collection and Analysis; Transferrable Skills (Lab-Specific); and Transferrable Skills (Not Lab-Specific) when compared to faculty members teaching inorganic chemistry instructional laboratories where CUREs are not implemented. Faculty members' greater emphasis on goals relating to Research Experience aligns with the central objective of CUREs, i.e., to provide undergraduates with authentic research experiences. For example, goals corresponding to the Research Experience factor include having students use laboratory techniques also used by professional chemists, having students conduct experiments that mimic research experiences, preparing students for research experiences, developing students' scientific reasoning skills, and increasing students' understanding of the usefulness of laboratory techniques (see the Supporting Information for the complete Bruck and Towns instrument).[24] Emphasis on goals relating to Research Experience is further reflected across multiple reports of CURE implementation in the inorganic chemistry instructional laboratory.[21−23]

Goals associated with the other four factors for which a difference was observed between users and nonusers of CUREs include teaching students to work together, communicating orally, presenting data in multiple formats (e.g., posters, PowerPoint, laboratory reports, etc.), collecting data via proper techniques, analyzing data and conducting error analysis, carrying out laboratory techniques, and constructing arguments from data. Again, these goals align with the CURE objective of cultivating skills requisite to scientific thinking, communication, and collaboration.[11] They are further reflected in reports on CURE implementation in the inorganic chemistry instructional laboratory; for example, specific goals include teaching students to use spectroscopic techniques,[20] analyze IR, NMR, and ultraviolet−visible spectral and X-ray crystallographic data,[23] safely handle chemical reagents,[20] and orally present results.[21,23]

Faculty members who do not implement CUREs, and yet have these goals for their inorganic chemistry instructional laboratory, may wish to consider adoption of the pedagogy, as the alignment with general CURE objectives suggests adoption may help them accomplish their instructional laboratory course goals. Further, efforts to increase knowledge of CUREs and their associated benefits among this instructor population could highlight these goals, providing additional avenues for disseminating the CURE pedagogy.

RQ2: How Do Inorganic Instructional Laboratories Implementing CUREs Differ from Those Not Implementing CUREs?

Fisher's exact tests are used in our analyses to indicate association between courses implementing CUREs and several instructional and departmental characteristics. These characteristics are primarily related to course organization and development. Results provide practitioners with insights into implementing CUREs, and they provide researchers with an understanding of the potential barriers to CURE adoption and opportunities for supporting the use of this pedagogy within inorganic chemistry education.

Courses Implementing CUREs Are Associated with Group-Based Student Work. An association was found between CURE implementation in instructional laboratories and the format of student work (i.e., individually only, group only, or a combination; see Table 6). Post hoc Fisher's exact tests across three possible comparisons of student-work format indicated that courses in which CUREs were implemented tended to employ group-only student work and not individual-only student work when compared to non-CURE courses (see Table 7). Use of group-only student work is also reflected in multiple reports of CURE implementation in the inorganic chemistry laboratory.[20−23]

Table 6. Two-Way Fisher's Exact Test Comparing Student Work Format between Inorganic Instructional Laboratories Implementing CUREs ($n = 25$) and Those Not Implementing CUREs ($n = 117$; $p = .043$)[a]

Student Work Format	Frequency of Courses Implementing CURE	Frequency of Courses Not Implementing CURE
Individual only	2	30
Combination (group and individual)	4	30
Group only	19	57

[a] Significance was set at $\alpha = .05$.

Table 7. Post Hoc Fisher's Exact Tests Across Three Possible Comparisons of Student Work Format between Inorganic Instructional Laboratories Implementing CUREs ($n = 25$) and Those Not Implementing CUREs ($n = 117$)[a]

Post Hoc Comparison	*p*-value	Odds Ratio (OR)
Combination−Individual	.673	1.98
Group−Combination	.135	2.48
Group−Individual	.032*	4.95

[a] Initial significance was set at $\alpha = .05$, and the Bonferroni adjusted significance level was set at .016 (.05/3). *corresponds to $p < .05$.

This association aligns with faculty members' greater emphasis on Group Work and Broader Communication Skills in courses where CUREs are implemented, suggesting that instructors may use group-only student work to accomplish these goals. In addition, the group-work format has been identified as a strategy for reducing instructors' time spent assessing projects in CUREs and, in turn, expanding the CURE model across the physical sciences.[38] These findings further suggest that contexts restricting group-only student work (e.g., limited space for collaboration in the instructional laboratory) may serve as a barrier to CURE adoption. Research that identifies how group-only student work can be used in restrictive contexts serves as a potential avenue for supporting adoption of the CURE pedagogy. Instructors could also consider the feasibility of using group-only student work when seeking to implement a CURE; while limited ability should not deter adoption, the group-work format may be important for accomplishing related goals and overcoming challenges with assessment.

Developing Experiments in CURE Courses Is Associated with Independent CURE Development by Faculty Instructors and Development Not Involving

Textbooks. Associations were found between CURE implementation and experiment development by faculty instructors (i.e., themselves) and not textbooks (see Table 8). Other developmental resources, including the *Journal of Chemical Education (JCE)*, the VIPEr Web site, and colleagues were not associated with CURE implementation (see Table 8).

Table 8. Two-Way Fisher's Exact Tests Comparing Resources for Developing Experiments between Inorganic Instructional Laboratories Implementing CUREs (n = 25) and Those Not Implementing CUREs (n = 117)[a]

Resource	Frequency of Courses Implementing CURE	Frequency of Courses Not Implementing CURE	p-value	Odds Ratio
JCE	22	106	.713	1.31
No JCE	3	11		
VIPEr	14	77	.367	1.51
No VIPEr	11	40		
Textbook	9	76	.012*	3.27
No textbook	16	41		
Colleague	4	38	.147	2.51
No colleague	21	79		
Self (independent)	23	82	.040*	4.67
Not self	2	34		
Other	5	19	.769	1.29
No other	20	98		

[a] Initial significance was set at α = .05, and the Bonferroni adjusted significance level was set at .008 (.05/6). *corresponds to p < .05.

The association between CURE implementation and development involving faculty instructors aligns with the notion that instructors typically implement CUREs related to their own research and research interests.[11] Other research has noted that instructors report implementing CUREs in order to integrate their teaching and research, publish both research and educational practice papers, broaden the impact of their research, and identify, recruit, and train students to join their own research laboratories.[18,39,40] Further, authentic and relevant scientific discovery is inherent to CUREs;[12] the association between CURE implementation and development not involving textbooks may therefore be due to the limited novel information afforded by this resource but requisite to such discovery. Our results suggest that faculty instructors are the primary developers of experiments and learning materials for inorganic chemistry instructional laboratories that implement the CURE pedagogy.

To support adoption of the CURE pedagogy, faculty instructors likely need intensive support in developing these elements via guideline-style materials, professional development opportunities, or communities of practice aimed at implementing CUREs. Further, community-based support has been identified as an essential resource for both the initial and long-term planning of CUREs in the physical sciences.[38] Instructors may also benefit from department-level, college-level, or multi-institutional CURE programs in which students work across courses on a shared research goal; development of experiments and learning materials would then be a collaborative effort rather than a task done in isolation.[10,17,39,41,42] The Center for Authentic Science Practice in Education (CASPiE) serves as one example for broadly implementing course-based research experiences in chemistry.[41,43]

CUREs Are Implemented Across Inorganic Chemistry Curriculum Types. No association was found between CURE implementation and common inorganic chemistry curriculum types (i.e., a curriculum including one stand-alone, independent inorganic chemistry instructional laboratory course and a curriculum including an inorganic chemistry instructional laboratory course that is incorporated into an inorganic chemistry lecture course; p > .999 and OR = 0.896; see Table 9). This lack of association suggests that CUREs are implemented across curriculum types and that curriculum type does not pose a barrier to implementation. It further suggests that, for instructors seeking to implement a CURE within their own curriculum, they can find support from a community of inorganic chemistry educators implementing CUREs in a range of instructional contexts. In addition, various curriculum types are described in reports on CUREs within the inorganic chemistry instructional laboratory.[20,22] Implementation materials and professional development opportunities should emphasize the curricular context in which CUREs have and can be implemented (i.e., within all curricular contexts).

Table 9. Two-Way Fisher's Exact Tests Comparing Curriculum Type between Inorganic Instructional Laboratories Implementing CUREs (n = 25) and Those Not Implementing CUREs (n = 117; p > .999, OR = 0.896)[a]

Curriculum Type	Frequency of Courses Implementing CURE	Frequency of Courses Not Implementing CURE
Stand-alone/independent lab course	10	49
Lab course incorporated into lecture course	13	57

[a] Significance was set at α = .05.

Courses Implementing CUREs Are Associated with Institutions Granting a Bachelor's-Level Terminal Degree and Institutions Granting an ACS-Certified Degree. CURE implementation was associated with institutions granting a bachelor's-level terminal chemistry degree and not with institutions granting a graduate-level terminal degree (see Table 10). Additional research is needed to understand

Table 10. Two-Way Fisher's Exact Tests Comparing Departmental Terminal Degree and ACS Certification between Inorganic Instructional Laboratories Implementing CUREs (n = 25) and Those Not Implementing CUREs (n = 117)[a]

Department Characteristic	Frequency of Courses Implementing CURE	Frequency of Courses Not Implementing CURE	p-value	Odds Ratio
Bachelor's-level terminal degree	21	71	.037*	3.30
Graduate-level terminal degree	4	45		
ACS-certified B.S. degree	23	89	.046*	6.92
Not ACS-certified B.S. degree	1	27		

[a] Significance was set at α = .05. *corresponds to p < .05.

the underlying dynamics of this association, as institutions granting graduate-level degrees have higher research activity and, in turn, more opportunities for incorporating research into the instructional laboratory. CURE implementation may instead be associated with institutions granting a bachelor's-level terminal chemistry degree due to smaller course sizes and faculty members' ability to allocate more time and effort toward undergraduate education. CURE development and implementation is time-intensive;[18] highlighting the potential of CUREs for advancing one's own research agenda may thus be one promising approach for supporting adoption within institutions granting graduate-level chemistry degrees.

CURE implementation was further associated with institutions granting an ACS-certified bachelor's chemistry degree and not with institutions granting a noncertified degree (see Table 10). This association may be due to resources available within ACS-certified programs that are not necessarily available within noncertified programs, such as opportunities for faculty members to engage in professional development focused on pedagogy and the range of chemical instrumentation available for instructional use.[44]

Funding for Improving Undergraduate Courses May Support CURE Implementation. No association was found between CURE implementation and reception of funding for improving undergraduate courses (e.g., internal funding, CCLI, TUES, or IUSE; see Table 11). However, we emphasize that the effect size of 2.65 suggests that funding has a meaningful association with CURE implementation that should not be overlooked; from a methodological standpoint, the p-value for this evaluation is affected by the low n value of the sample. Funding has also been identified as an essential resource for implementing and sustaining CUREs in the physical sciences.[38] There is an opportunity, nonetheless, for funding sources to emphasize CUREs to incorporate chemistry research into the chemistry curriculum. For example, early career grant programs, such as the Faculty Early Career Development Program (CAREER) of the National Science Foundation, could emphasize CUREs as a means to support dissemination of research; we note that CAREER award applications require a research-education integration component that could be achieved through development, implementation, and dissemination of a CURE experience.

Table 11. Two-Way Fisher's Exact Tests Comparing Departmental Funding Status between Inorganic Instructional Laboratories Implementing CUREs ($n = 25$) and Those Not Implementing CUREs ($n = 117$; $p = .062$, OR = 2.65)

Funding Status	Frequency of Courses Implementing CURE	Frequency of Courses Not Implementing CURE
Received funding (internal or external)	16	50
No funding	6	50

Courses Implementing CUREs Are Associated with Not Having Graduate Teaching Assistant Support. An inverse association was found between CURE implementation and graduate teaching assistant (TA) support (see Table 12). Additionally, there were no associations between CURE implementation and undergraduate TA support, TA support in general (graduate or undergraduate), or non-TA support such as preparatory staff (see Table 12). This finding suggests that graduate TAs are not used in CURE implementation; this result is congruent with the number of instructors at primarily undergraduate institutions implementing CUREs, a context that does not have access to graduate TA support.

Table 12. Two-Way Fisher's Exact Tests Comparing TA Support between Inorganic Instructional Laboratories Implementing CUREs ($n = 25$) and Those Not Implementing CUREs ($n = 117$)[a]

Support	Frequency of Courses Implementing CURE	Frequency of Courses Not Implementing CURE	p-value	Odds Ratio
TA	9	56	.377	1.63
No TA	16	61		
Graduate TA	2	32	.041*	4.31
No graduate TA	23	85		
Undergraduate TA	6	19	.388	1.62
No undergraduate TA	19	98		
Other	2	16	.740	1.82
No other	23	101		

[a] Initial significance was set at $\alpha = .05$, and the Bonferroni adjusted significance level was set at .01 (.05/4). *corresponds to $p < .05$.

It is further possible that graduate TAs impede CURE implementation. This instructor population constitutes the majority of chemistry laboratory instructors at graduate degree granting institutions.[19] CUREs are inquiry-based and incorporate faculty instructors' research interests; therefore, effective implementation of CUREs at these institutions requires pedagogical and content knowledge not necessarily held by graduate TAs.[19] For instance, research demonstrates that graduate TAs often lack instructional skills needed to facilitate inquiry.[19] In some instances, graduate TAs may lack the necessary content knowledge necessary to teaching introductory-level courses.[45] This potential barrier may in part account for the lack of association between CURE implementation and departments granting graduate-level chemistry degrees. Helping faculty members train graduate TAs to instruct CURE laboratories using existing programs may thus serve as one way to promote CURE adoption within departments granting graduate-level terminal degrees.[46] Conversely, graduate TA support may be inversely associated with CURE implementation because of other factors (e.g., limited time for course development) that impede use of this pedagogy within departments granting graduate-level degrees. Additional work is thus needed to understand this finding.

■ IMPLICATIONS FOR CURRICULUM DESIGNERS AND COMMUNITIES OF PRACTICE

Results point toward several productive ways curriculum designers and communities of practice can support CURE adoption within the inorganic chemistry curriculum. Most notably, inorganic chemistry educators report limited familiarity with the CURE pedagogy while also indicating an overall willingness to implement CUREs in future iterations of their courses. Increasing knowledge of the pedagogy, including the chemistry-specific goals of colleagues implementing their own CUREs, is one promising first step.

Results further indicate that inorganic chemistry faculty members likely need intensive support in developing their own instructional materials. Guideline-style materials and professional-development opportunities may provide such support. Existing communities of practice (e.g., the Interactive Online Network of Inorganic Chemists) may also consider forming subcommunities of practice aimed at developing and implementing CUREs. These resources may then highlight the range of curricular contexts in which CUREs can be implemented, as well as provide guidance on training graduate TAs for inquiry-based instruction within departments granting graduate-level terminal degrees.

■ IMPLICATIONS FOR EDUCATORS

Findings suggest that faculty members who implement CUREs in their inorganic chemistry instructional laboratory place greater emphasis on goals relating to research experience and associated skills (e.g., collaborating, communicating scientifically, executing laboratory techniques relevant to professional chemists, etc.). Faculty members who share these desired learning outcomes may wish to consider implementing their own CURE, as these goals align with the broader objectives of the pedagogy.[12] Instructors seeking to implement a CURE should also consider the feasibility of group work in their instructional context, as it may be necessary for accomplishing related goals. They should further consider the potential limitations of graduate TA support when using CUREs and the possibility of TA training prior to implementation.[46]

■ IMPLICATIONS FOR RESEARCHERS

Given the proportion of respondents indicating an unlikelihood of future CURE use, additional research is needed that focuses on the major barriers that instructors perceive to CURE implementation, strategies other practitioners use to circumvent these challenges, and additional underlying dynamics resulting in either resistance to or disinterest in the pedagogy. Such research can inform the efforts of curriculum designers as they work to increase the community's knowledge of CUREs.

Additional research on the relationships between instructional context and CURE implementation is also needed. Research that investigates the role of group-only student work in CUREs, including strategies for using group-only student work in restrictive contexts, will be necessary for increasing the use of the pedagogy in such contexts. Insight is also needed into the underlying dynamics resulting in relatively limited CURE use within chemistry departments granting graduate-level terminal degrees. This observation could be due to the potentially restrictive nature of graduate TA support,[46] limited time for course development in departments prioritizing research,[47] average course size, and/or the availability of instrumentation for instructional purposes, among other variables. Understanding these dynamics will be necessary to effectively support this instructor population in implementing CUREs.

Lastly, psychometric evaluation of the Faculty Goals for Undergraduate Chemistry Laboratory instrument points toward needed areas of instrument refinement.[24] For instance, three factors demonstrated collinearity and therefore may be measuring a single, broader construct. A study with a larger sample size is needed to explore these correlations and potentially revise the instrument's factor structure. Such revision would provide a more valid measure of faculty members' goals for the undergraduate chemistry laboratory in future investigations.

■ CONCLUSION

Results from a national survey of inorganic chemistry faculty members ($n = 142$) provide an overview of CURE implementation in the undergraduate inorganic chemistry laboratory curriculum. Findings suggest that use of CUREs is relatively limited, although a majority of faculty members indicate some likelihood of future use. Findings also suggest that instructors who implement CUREs place greater emphasis on a distinct set of instructional goals when compared to instructors who do not implement CUREs. CURE implementation in the inorganic curriculum is further associated with multiple instructional and departmental characteristics, including group-only student work, independent course development by faculty instructors, limited graduate TA support, departments with an ACS-certified degree program, and departments granting a bachelor's-level terminal degree. This investigation points toward a need for additional efforts focused on increasing CURE adoption among this instructor population. It also provides a foundation for developing guideline-style instructional materials and professional development opportunities aimed at supporting CURE implementation.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00267.

> Complete *Faculty Goals for Undergraduate Chemistry Laboratory* instrument (cf. Bruck and Towns, 2013); additional psychometric evaluation results of the *Faculty Goals for Undergraduate Chemistry Laboratory* instrument; and complete survey instrument (PDF)

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M.C.C., J.M.P., and J.R.R. conceived the project. J.M.P. and J.R.R. collected the data. M.C.C. conducted the statistical analyses. M.C.C. and J.R.R. authored the paper. M.C.C., J.M.P., and J.R.R. reviewed and edited the paper.

Notes

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